BJBS

September 2024

Education and Training in Biomedical Science

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Education and Training in Biomedical Science

ISSN 2474-0896
ISBN 978-2-8325-5438-8
DOI 10.3389/978-2-8325-5438-8

The British Journal of Biomedical Science is excited to present –'Education and Training in Biomedical Science' - a Special Issue showcasing the best practices in pedagogical approaches which have significantly impacted teaching, workplace training and assessment ensuring graduates have the knowledge and skills required for employment within the biomedical science sector.

The Special Issue showcases the global diversity of innovative educator and practitioner-led research and practice, performed across the entire breadth of the biomedical science sector and present advances in theory, methodology and application of embedding workforce skills and knowledge requirements into current education and development programs.

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SPECIAL ISSUE EDITORIAL
published: 02 September 2024
doi: 10.3389/bjbs.2024.13598

Editorial: Education and Training in Biomedical Science

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Keywords: biomedical science, continual professional development, education, employability, laboratory medicine, Training, pedagogy

Editorial on the Special Issue

Education and Training in Biomedical Science

INTRODUCTION

Biomedical science is an expanding discipline encompassing healthcare delivery, technological advances, and scientific research. Whether a biomedical science graduate is entering a regulated healthcare profession or uses their education as a platform for further study, leading to varied careers both within and outside of healthcare, it is important that biomedical science education providers deliver high quality educational and training programmes, which provide opportunities to develop essential skills required for tomorrow's workforce.

Higher qualifications in biomedical science offer a gateway to a diverse range of career pathways and ongoing professional development. Whether employment is sought in a clinical laboratory environment in a healthcare related discipline (medical microbiology, clinical chemistry, haematology, transfusion, cell pathology, immunology and genetics), research and development, teaching, communication and bioinformatics or careers encompassing environmental, pharmaceutical, nutrition and forensic sectors, the skills and knowledge required are a key concern in curriculum development.

This Special Issue "*Education and Training in Biomedical Science*" showcases best practices in pedagogical approaches which have recently impacted upon teaching, workplace training and assessment to ensure graduates have the knowledge and skills required for employment within the biomedical science sector. This editorial provides context and a snapshot glance of these approaches.

COURSE DELIVERY

The last 4 years have seen a transformation in the way biomedical science education is delivered and the acquired knowledge assessed. The COVID-19 pandemic brought unprecedented and unplanned changes in educational delivery during 2020–2021. Rapid moves to online delivery, utilisation of digital pedagogies and adopting virtual assessments became a necessity in order for students to complete higher education programs (Pearse and Scott). Online and blended-learning approaches have incrementally increased in popularity [1–3]. McKenna's paper discusses the provision of "dry-lab" final year honours projects, as a viable alternative to traditional "wet-lab" projects. The main themes of the study encompassed expectations, skills and employability, quality of experience and

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Received: *30 July 2024*
Accepted: *15 August 2024*
Published: *02 September 2024*

Citation:
Scott S, Millar BC and McClean S (2024) Editorial: Education and Training in Biomedical Science. Br J Biomed Sci 81:13598. doi: 10.3389/bjbs.2024.13598

choice. The findings support the rationale for dry projects as a suitable and equitable alternative for wet-lab project provision.

Online learning offers flexibility in study and a more environmentally sustainable education option. The ongoing development of digital technologies, support a wide variety of undergraduate and post graduate level programmes. Despite the popularity of such programmes, online learning provides minimal opportunities for face-to-face interaction, subsequently impacting on student programme satisfaction, engagement and peer communication. Millar et al. explore the pedogeological approach of how group assessments can help build online learning communities in Biomedical Science Distance Learning Programmes. Student reflections provided the basis for the evaluation. Enjoyment, collegiality, the development of digital skills and the gaining of knowledge scored the highest in the student reflections.

CURRICULUM DEVELOPMENTS

Recent changes in HCPC standards of Proficiency (SoPs) [4] and the Biomedical Science QAA benchmark statement [5] have further initiated changes in Biomedical Science curriculums. Science communication, quality assurance, equality, diversity and inclusion, point-of-care-testing (POCT) and sustainability are now required as part of curriculum enhancements. In a second paper by Millar et al., curriculum inclusion of scientific communication and digital capabilities is presented. In this paper, details on the production of a co-designed online scientific communication and digital capabilities resource is provided, whereby students gain creative, digital, analytical and scientific communication skills including lay writing and visual abstracts, enabling students to communicate with individuals with different levels of understanding using different formats aligning with the HCPC SoPs and QAA benchmark [4, 5]. The findings of this research supported development of transferable skills applicable to student future career choices.

The recent HCPC SoPs changes and the HCPC Standards of Education and training in emphasise the need for interprofessional learning opportunities and service user involvement in applied biomedical science undergraduate courses [4, 6]. Students are expected to demonstrate the ability to build and sustain professional relationships and participate in training that supports high standards of practice, professional conduct and positive interpersonal relationships. Two papers by Bashir et al., look at service user involvement (Bashir et al.) and interprofessional learning, respectively (Bashir et al.). Bashir et al. first presents a workshop where patients discuss how pathology services have contributed to their medical care, while service providers discuss their roles and their interactions with the pathology services. Outcomes from the workshop include the reinforcement of "a patient behind each sample" and the incorporated student reflection highlighted potential improvements to pathology services. Bashir et al.'s second paper looked at using a cytomegalovirus (CMV) case study with Audiology and Biomedical Science Students. Over 82.4% of respondents either "agreed" or "strongly agreed" that understanding of the roles of other healthcare professions is needed for successful career development.

A key component of clinical modules taught on IBMS accredited and HCPC approved Biomedical Science undergraduate programmes, is the fundamental requirement for students to be able to apply theory to practice, significantly in the form of clinical case interpretation and the diagnosis of patients from presented results [7]. Posner et al., present a problem-based learning approach to case study interpretation. The aim was to improve engagement, skill acquisition and the student experience by utilising active student-centred methods, to improve student self-learning. Results from the study demonstrated improved student engagement and an improved student experience. Similarly, Bashir et al. measured the impact of incorporating case study presentations into applied biomedical science placement workshops for Trainee Biomedical Scientists. In this paper, the study aimed to evaluate the effectiveness of a redesigned workshop where students generated and presented medical case studies to peers, academics, and training leads. Findings from the study not only showcased a unique collaborative partnership between higher education institutions and pathology laboratories but evidenced enhanced student confidence in 1) the knowledge of clinical conditions, 2) presentation skills, and 3) ability to think critically.

COMPETENCIES AND EMPLOYABILITY

Higher education providers providing IBMS accredited and HCPC approved programmes, strive to produce high quality graduates attractive to employers. These graduates in biomedical science need both discipline specific knowledge and skills, plus transferable skills essential for HCPC regulation. The paper by Dudley and Matheson explore opinions from stakeholders on the Biomedical Scientist role. Questions were asked on how to recognise that Biomedical Scientists are meeting the HCPC standards and other professional guidelines to support the achievement of patient outcomes. Putting the patient at the centre scored highly as an essential aspect of the Biomedical Scientist role. Interestingly, a divergence of opinion was noted predominantly in the academic and student groups, thus identifying the possible existence of a gap between theory and practice. This research initiates the question that if such a gap exists, what strategies can be put into place to bridge this gap? Furthermore, how do higher education institutions ensure students graduate with the required skills and knowledge?

A recent article by Hussain and Hicks [8], assessed the employability skills of Biomedical Science graduates. The article highlighted perceived gaps in skills and knowledge by employers, which could negatively impact on the future workforce pipeline and subsequent service delivery. A subsequent study by Hussain et al. in this Special Issue explores the use of a practical session utilising an "Authentic Pathology Specimen Reception" within the biomedical science programme. The implementation this resource for developing biomedical science student competencies and employability demonstrates how simulation-based learning can be used as a

tool to enhance the development of core biomedical science knowledge and strengthen employability of the graduate.

The paper by Garden describes how a collaboration with the Advanced Therapies Skills Training Network utilised current best practice to significantly impact upon teaching and workplace training in Scotland. The case provided insight on how to ensure biomedical sciences students graduate with the knowledge and skills required for employment within the Life Science sector.

Robertson et al. also describes an approach to enhancing graduate skills. This paper discusses the successful implementation of an assessment literacy strategy derived from a vocational veterinary teaching context and implemented as a foundational Biomedical Science learning activity. This concept highlights how teaching strategies can be affective across different disciplines and career pathways.

PEDAGOGICAL APPROACHES AND STUDENT ATTAINMENT

Scenario-based learning and gamification have many advantages over traditional didactic lecture-style teaching methods [7]. May et al. explore the use of a scenario-based learning tool called Resimion, which had been adapted for Biomedical Science education. Resimion is a platform that blends applied learning pedagogy with gamification pedagogy. Learners work through problem- or scenario-based activities alone or collaboratory. Results of this study demonstrated good student engagement and positive feedback, with comparable results for neurodiverse and neurotypical groups.

Active learning pedagogy involves students in learning activities which promote doing, rather than listening [9]. Active learning is a tool which increases interactivity and stimulates engagement. Lees-Murdock et al. assess the efficacy of active learning in supporting student performance. They report how full engagement with an active learning approach, significantly correlates with increased student performance.

Student attainment and satisfaction was also explored in the study by Veuger et al. This study supporting students during their Biomedical Science UG Project Research project through a staff-student partnership. Students felt strongly that their experience, satisfaction and success was influenced by the student-supervisor relationship. This study and that by Millar et al. highlights the importance of staff student partnerships which ultimately promote student outcomes in relation to increased engagement, motivation, ownership and meta-cognitive learning.

The final paper in this Special Issue explores application of the theoretical principles of Malcolm Knowles' theory of andragogy. Knapke et al. evaluated data collected from participants involved in science training workshops as part of a biomedical research setting. The paper collected data on the participants' readiness to learn and problem-based learning orientation. Interestingly, the participants in this study were faculty, staff, and graduate students from the University of Cincinnati (UC). It would be interesting to see if their approach can be applied to Biomedical Science education and training in the United Kingdom and further afield.

FUTURE ASPIRATIONS RELATING TO BIOMEDICAL SCIENCE EDUCATION AND TRAINING

Although many current and evolving pedagogical concepts were explored in this Special Issue, future consideration is needed for the evolving nature of the digital age. In a generation where AI technologies are increasingly becoming available, educators and trainers need innovative ways to consider the pros and tackle the challenges associated with the development of robust, authentic and valid assessment. Furthermore, educators and trainers need to consider the preparedness of future biomedical scientists for an ever-changing pathology service, whether this involves automation, AI platforms or sustainable working. In the next Special Issue, it will be interesting to see how these aspects have been integrated into curriculums.

CONCLUSION

This Special Issue presents a range of advances in theory, methodology and application of embedding workforce skills and knowledge requirements into current biomedical science education and development programmes. We hereby invite you to explore these articles in this Special Issue and consider applying these principles within to your own educational and training programmes.

AUTHOR CONTRIBUTIONS

SS was the lead author. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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ORIGINAL RESEARCH
published: 12 June 2024
doi: 10.3389/bjbs.2024.12629

Identification of a Theory-Practice Gap in the Education of Biomedical Scientists

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Introduction: The Biomedical Scientist (BMS) role is established in healthcare, working in laboratory environments to provide diagnostic testing and to monitor treatment effects on a patients' health. The profession is subject to several professional standards which highlight the importance of working in the best interests of the patient and service user. However, Biomedical Scientists have little or no patient contact. This study aimed to determine how Biomedical Scientists evidence that they meet the professional standards and support the achievement of patient outcomes.

Materials and Methods: This study utilised a Delphi method to explore the opinions of professional stakeholders to determine whether there was consensus for how this professional group contributes to patient outcomes and offers evidence that they are working in the best interests of the patient. The qualitative 1st round of the study consisted of focus groups and interviews with staff and students on the BSc Biomedical Science awards, Professional, Statutory and Regulatory body (PSRB) representatives and Biomedical Scientists from the National Health Service (NHS). The first-round responses were analysed using thematic analysis which then generated attitude statements which participants scored using a 5-point Likert scale in the 2nd round. Consensus or divergence of opinion was determined based upon a 70% consensus level within each participant group and overall.

Results: Following analysis of the 2nd round data, there was divergence of opinion across all stakeholders, with consensus rates being highest in the Biomedical Scientist group (72.7% of statements reached 70% consensus), followed by the student group (54.5% of statements reached 70% consensus) and lowest in the academic group (40.9% of statements reached 70% consensus).

Discussion: This demonstrates a theory-practice gap in both the academic and student groups, suggesting that graduates are insufficiently prepared for their post-graduate role. This gap was particularly evident when discussing topics such as how Biomedical Scientists contribute to patient care, professional registration and working as part of

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Received: *28 December 2023*
Accepted: *13 May 2024*
Published: *12 June 2024*

Citation:
Dudley K and Matheson D (2024) Identification of a Theory-Practice Gap in the Education of Biomedical Scientists. Br J Biomed Sci 81:12629. doi: 10.3389/bjbs.2024.12629

the multi-disciplinary team (MDT). The identification of a theory-practice gap in the education of Biomedical Scientists is a novel finding, indicating that students may graduate with insufficient understanding of the Biomedical Scientist role.

Keywords: biomedical scientist, professional practice, biomedical science graduates, patient outcomes, education and training

INTRODUCTION

Biomedical Scientists form a significant part of the healthcare scientific workforce within the UK healthcare system. There are 21,427 Biomedical Scientists registered in the UK, representing 7.6% of the 283,750 Health and Care Professions Council (HCPC) registered professionals within the UK [1]. Despite this, the role that Biomedical Scientists play in achievement of patient outcomes and how a Biomedical Scientist can evidence the impact of their role on those outcomes is not always explicit to students completing undergraduate Biomedical Science programmes. In many of the key biomedical science disciplines, Biomedical Scientists routinely experience minimal or no patient contact. However, the work carried out by Biomedical Scientists is an important part of patient care pathways and clinical decision making.

The HCPC award the protected title of "Biomedical Scientist" to those who meet the necessary requirements to practice. Biomedical Scientists must successfully complete an Institute of Biomedical Science (IBMS) accredited degree (or equivalent qualification), a period of training in an approved laboratory, completion of the IBMS registration training portfolio and award of the Certificate of Competence [2, 3]. There are several different routes to achieve HCPC registration as a Biomedical Scientist (**Figure 1**), but availability of trainee Biomedical Scientist positions limits the number of graduates from IBMS accredited programmes who can join the register. Accredited Biomedical Science degrees must cover all key pathology disciplines and the academic requirements to become HCPC registered. Increasingly, HCPC registration for Biomedical Scientists involves the completion of a year-long placement or an integrated degree apprenticeship. This demonstrates that

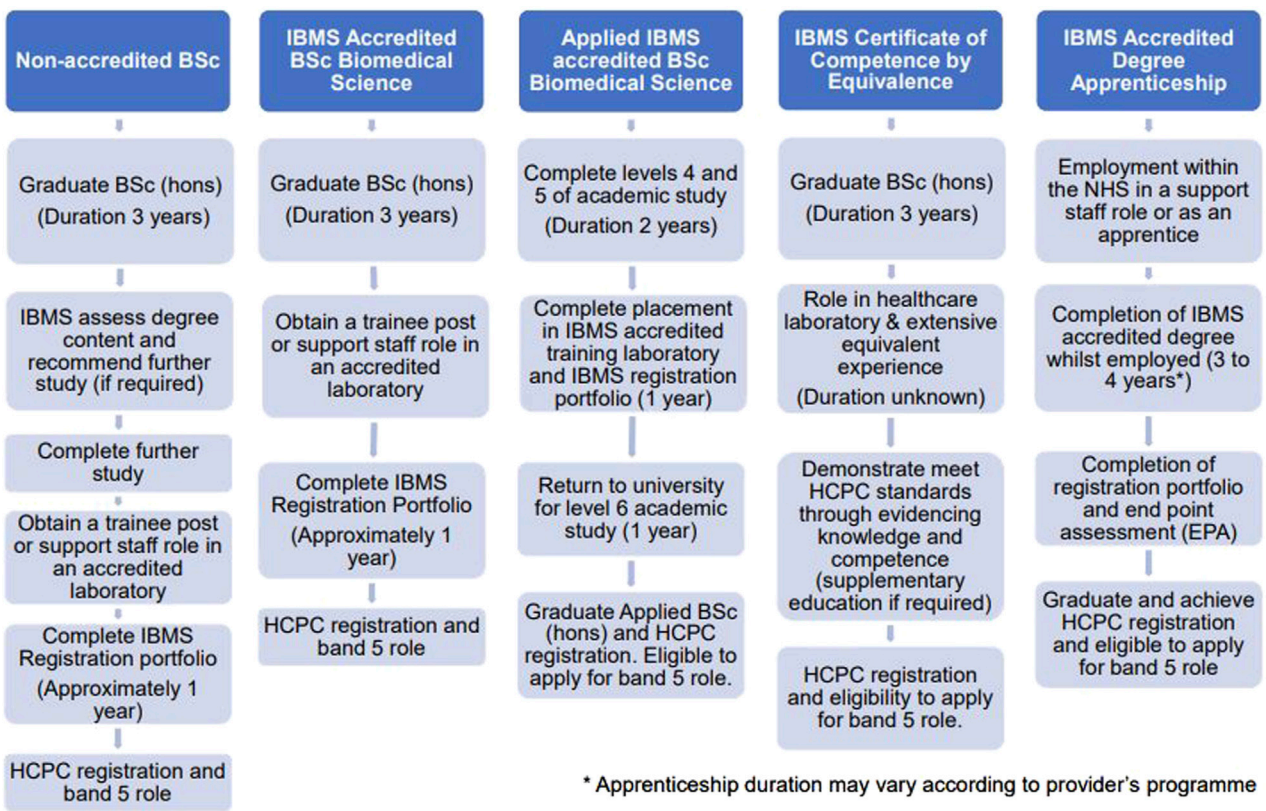

FIGURE 1 | An overview of the different routes for achieving HCPC registration as a Biomedical Scientist [2–4].

TABLE 1 | An overview of a selection of the key patient centred standards and guidelines in the literature associated with the Biomedical Scientist role [5, 6, 10]. These standards may be challenging for students to comprehend without clinical laboratory experience. Copyright permissions have been obtained from the HCPC and IBMS to reproduce these standards and professional guidelines.

HCPC standards of proficiency for biomedical scientists [5]	
Standard number	**Standard**
2.2	"Promote and protect the service user's interests at all times"
2.5	"Respect and uphold the rights, dignity, values and autonomy of service users, including their role in the assessment, diagnostic, treatment and/or therapeutic process"
2.6	"Recognise that relationships with service users, carers and others should be based on mutual respect and trust, maintaining high standards of care in all circumstances"
7.4	"Work with service users and/or their carers to facilitate the service user's preferred role in decision-making, and provide service users and carers with information they may need where appropriate"
8.1	"Work in partnership with service users, carers, colleagues and others"
8.12	"Understand the need to engage service users and carers in planning and evaluating diagnostics and assessment outcomes to meet their needs and goals"
8.13	"Demonstrate awareness of the impact of pathology services on the service user care pathway"
11.5	"Evaluate care plans or intervention plans using recognised and appropriate outcome measures, in conjunction with the service user where possible, and revise the plans as necessary"
14.1	"Understand the need to maintain the safety of themselves and others, including service users, carers and colleagues"
15.3	"Empower and enable individuals (including service users and colleagues) to play a part in managing their own health"
HCPC standards of conduct, performance and ethics [6]	
Standard number	**Standard**
1.1	"You must treat service users and carers as individuals, respecting their privacy and dignity"
1.2	"You must work in partnership with service users and carers, involving them, where appropriate, in decisions about their care, treatment or other services to be provided"
2.2	"You must listen to service users and carers and take account of their needs and wishes"
6.1	"You must take all reasonable steps to reduce the risk of harm to service users, carers and colleagues as far as possible"
IBMS good professional practice in biomedical science [10]	
Guideline number	**Relevant guideline**
Code of Conduct 1.2	"Maintain the highest standards of professional practice and act in the best interests of patients, the service and other professionals"
Code of Conduct 3.2	"Take action without delay if patient safety or service delivery is at risk according to local and national "whistleblowing" guidelines"
Code of Conduct 3.3	"Treat all patients, service users and colleagues respectfully and equally without any discrimination or prejudice that could hurt or embarrass"
1. Professional practice	"As a biomedical science professional, you have a duty of care (directly or indirectly) to the patient and must always ensure their safety and wellbeing"
11. Communication	"You understand the need to provide service users or people acting on their behalf with the information necessary to enable them to make informed decisions"
12. Partnerships and cooperation	"You will work in partnership and cooperation with service users, carers, colleagues and others for the benefit of the patient and service"

education providers play a pivotal role in fostering student understanding of the Biomedical Scientist role and preparing students for their post-graduate roles.

Understanding the Wider Context of the Biomedical Scientist Role

Biomedical Scientists must comply with the HCPC standards of proficiency (SoPs) associated with their profession [5] and also with the standards of conduct, performance and ethics [6]. The standards of conduct, performance and ethics are currently under review with a new version being implemented in September 2024 [7]. The HCPC regulate 15 health professions, including dieticians, physiotherapists and occupational therapists [8]. The standards recognise that the range of different professions regulated by the HCPC may have differences in their scope of practice. As a result, some professions are acknowledged to work with patients, others with clients and some with service users. The standards of proficiency for Biomedical Scientists use the phrase *"service user"* when describing the groups that use or are affected by the Biomedical Scientist role [5]. For Biomedical Scientists, service users can be regarded as patients and also as clinical staff utilising the laboratory service.

For students and trainee Biomedical Scientists, it can be challenging to comprehend the importance of the individual patient as the ultimate service user due to a lack of patient contact included as part of their role. This can also provide a challenge for academic staff who are attempting to communicate this key concept to students on a Biomedical Science degree programme, many of whom will lack clinical exposure due to the

competitive nature of NHS placement availability. This lack of clinical exposure can provide difficulties when relating theoretical ideas delivered in a taught session to real-world scenarios, which is often described as a theory-practice gap.This is exacerbated because academics delivering Biomedical Science programmes represent a diverse range of backgrounds, including both practitioners with firsthand NHS experience and researchers who may have little knowledge of the clinical laboratory environment. This differs from other fields of healthcare, for example, nursing, where most academics have firsthand experience of the role [9]. Furthermore, only some of the graduates of Biomedical Science awards aspire to work as a Biomedical Scientist, which provides a challenge for course design and ensuring appropriate course content that will interest the range of students which study Biomedical Science.

Applying the professional standards of the HCPC can be challenging for Biomedical Scientists. For example, HCPC standard of proficiency 2.5 states that Biomedical Scientists will "respect and uphold the rights, dignity, values and autonomy of service users, including their role in the assessment, diagnostic, treatment and/or therapeutic process" [5]. For Biomedical Scientists and academic teams preparing Biomedical Science students for practice, it can be challenging to recognise the service users' values due to a lack of opportunities for patient interaction. It is possible that students on Biomedical Science degree courses lack practice opportunities which would allow them to contextualise how their work impacts the patient and service user. Further examples of the key HCPC standards which students may find difficult to contextualise are provided in **Table 1**.

The IBMS guidelines for good professional practice and conduct in Biomedical Science are clear about the significance of the patient for Biomedical Science professionals, stating that "you will work in partnership and cooperation with service users, carers, colleagues and others for the benefit of the patient and service" [10]. Whilst this guideline is of key importance for Biomedical Scientists and students aspiring to this as a future career, the way in which Biomedical Scientists relate to this guideline and how students can develop an understanding of it through their education and professional experience requires further exploration.

The Role of Pathology Laboratories in Patient Outcomes

There is no commonly accepted universal definition of patient outcomes, but these usually represent a change in health of a group or an individual due to an intervention [11]. In most cases, these outcomes are centred around a particular disease and assessment involves determining symptoms and clinical presentation [12]. However, this disease-centred model fails to focus upon key measures from the patients' perspective, such as health status and quality of life. The focus upon disease-centred metrics could provide a further challenge for Biomedical Scientists to recognise the importance of the patient as service user, as described in the HCPC standards [5, 6] and the IBMS guidelines [10]. For Biomedical Scientists and students aspiring to this career, the role that Biomedical Scientists have in supporting achievement of patient outcomes has not been defined in professional literature.

It is well established that pathology services have a significant impact upon healthcare and patient care pathways. The work carried out by pathology services is involved during the lives of most patients, with a role from pre-natal screening and throughout the patient's lifetime. As a result, pathology services cost the NHS between £2.5 and £3 billion per annum and represents 1.5%–3% of overall NHS expenditure [13]. Those practicing within Biomedical Science are familiar with the statistic suggesting that more than 70% of NHS diagnoses depend upon pathology test results [14–16]. This suggests that Biomedical Scientists are involved in diagnostic testing of a significant number of specimens and through this, impact upon a significant number of patient care pathways.

Incorrect or inaccurate laboratory test results or inappropriate result reporting is known to negatively impact patient care, resulting in unwarranted diagnostic testing, inappropriate treatment, patient anxiety and even death [17]. However, the role that Biomedical Scientists play within this process has not been explored, since much of the literature focuses upon pathology services as a whole. The role that Biomedical Scientists play within patient outcomes is challenging to measure due to the complex and integrated nature of healthcare. To provide a benefit to patient care, laboratory testing should be carried out at the right time, on the right patient and actioned in an appropriate time frame [17–20]. Through the impact of pathology services on patient care, the Biomedical Scientist role is key for supporting other healthcare professionals to fulfil their roles effectively. However, to what degree the Biomedical Scientist role impacts upon outcomes for the individual patient has not been explored.

Putting the Patient at the Heart of the Biomedical Scientist Role

In the UK, several key NHS values are defined within the NHS constitution. The NHS constitution states "the patient will be at the heart of everything the NHS does" [21]. This includes involving patients, family members and carers in health and treatment decisions. Despite these concepts being a central part of NHS policy, the nature of the Biomedical Scientist role and the lack of direct patient contact means that evidencing these characteristics can be challenging. To date, the literature has not defined what it means to put the patient at the heart of the Biomedical Scientist role. For many healthcare professions, this is aligned to person-centred care (PCC). However, providing a definition of PCC that is applicable to the Biomedical Scientist role has proved challenging. Definitions of PCC are mainly focused upon clinicians, rather than recognising the role played by other healthcare professionals, but suggests that clinicians must be honest and respectful, demonstrate empathy and be compassionate [22]. Based on this definition, there is no reason why other

healthcare professionals cannot be seen to evidence PCC in their practice.

For laboratories to practise PCC, it is necessary for them to investigate all stages of the total testing process (including sample collection, test requesting, reporting and actioning results) that may negatively impact patient outcomes [17]. The assumption is often made that through reporting laboratory results and the subsequent impact of these on patient care pathways, that optimising laboratory processes and achieving accurate results in a timely fashion are key to positively influence patient care. However, without appropriate and timely clinical action following laboratory testing, there is little clinical benefit to carrying out these tests [23].

According to McCormack and McCance [24], PCC is developed via the establishment of a therapeutic relationship between care providers, patients and carers. For Biomedical Scientists, developing these therapeutic relationships with patients and their carers is challenging due to a lack of interaction with the patient. However, providing high-quality care which is patient focused is considered an essential aspect of the Biomedical Scientist role by most in the profession. Despite this, key terms which are often used when describing the Biomedical Scientist role, such as "putting the patient at the centre" or "working in the best interests of the patient" have not been fully explained within the literature. Although the HCPC standards define the requirements of Biomedical Scientists with respect to service users and carers, students completing a Biomedical Science degree without clinical laboratory experience may find these standards difficult to interpret.

Aims and Objectives

This study aimed to identify how stakeholders of the Biomedical Scientist role recognise that Biomedical Scientists are meeting the HCPC standards and other professional guidelines to support the achievement of patient outcomes.

As a result, this study aimed to address the following research questions through the recruitment of stakeholders of the Biomedical Scientist role:

1. Is there consensus amongst stakeholders upon how the role of the Biomedical Scientist influences patient outcomes?
2. Do stakeholders have a common understanding of how Biomedical Scientists might demonstrate that they are working to achieve patient outcomes?
3. How do stakeholders consider the importance of achieving patient outcomes within the Biomedical Scientist role?
4. How do stakeholders recognise a Biomedical Scientist who is working to support the achievement of patient outcomes?

The stakeholders were Biomedical Scientists working within the NHS, academic staff teaching on the BSc Biomedical Science degree programmes, representatives from the professional and statutory bodies and final year students on the BSc Biomedical Science awards.

MATERIALS AND METHODS

The Delphi Methodology

This study aimed to identify how stakeholders of the profession recognised the Biomedical Scientist role in achieving patient outcomes. These concepts had not previously been defined in the literature. To do this, a modified Delphi methodology was used. Delphi is a consensus methodology whereby experts are invited to participate with a view to determining the consensus level on a topic. This is underpinned by the concept that the opinion of a group is seen as more beneficial than that of a single individual [25]. The Delphi methodology is useful to generate ideas and understand complex topics and is particularly useful in fields which lack previous data, which suggested it was valuable in this case [26].

The study considered whether there was stakeholder consensus in key aspects of the Biomedical Scientist role and was carried out across two rounds. The qualitative first round involved semi-structured interviews and focus groups where participants were presented with a vignette and questions relating to role of the Biomedical Scientist within that case (**Supplementary Data Sheet S1**). The first-round data was analysed using thematic analysis which was used to produce a series of statements for the second round of the study. The second round was quantitative where participants scored their agreement with statements generated following the thematic analysis using a Likert scale (**Supplementary Data Sheet S2**). It was important to present statements in the 2nd round which utilised the participants' phrasing with minimal editing to minimise researcher bias [27]. In a traditional Delphi study, there usually follows 2–4 subsequent rounds, but this modified Delphi methodology employed only a single subsequent round because the study was concerned with determining whether consensus existed and did not aim to necessarily achieve consensus. An overview of the study design can be found in **Figure 2**.

Ethical Approval

This study was conducted during height of the COVID-19 pandemic and, as a result, involved the use of virtual data collection methods to comply with the requirements of the ethics committees that reviewed the study. Ethical approval was obtained from the Faculty of Education, Health and Wellbeing (FEHW) ethics committee, along with the Life Sciences ethics committee where the participating staff and students were recruited. Ethical approval was obtained from the NHS Health Research Authority (HRA) (IRAS ID: 273632, REC reference 20/LO/0675). HRA approval for the study was made subject to the 2nd round questionnaire being sent to the committee once it was developed. The Research and Development (R&D) department at the participating NHS Trust also confirmed capacity for the study.

Round One

In the first round of the study, academics (n = 5) and final year students (n = 7) involved with the BSc Biomedical Science

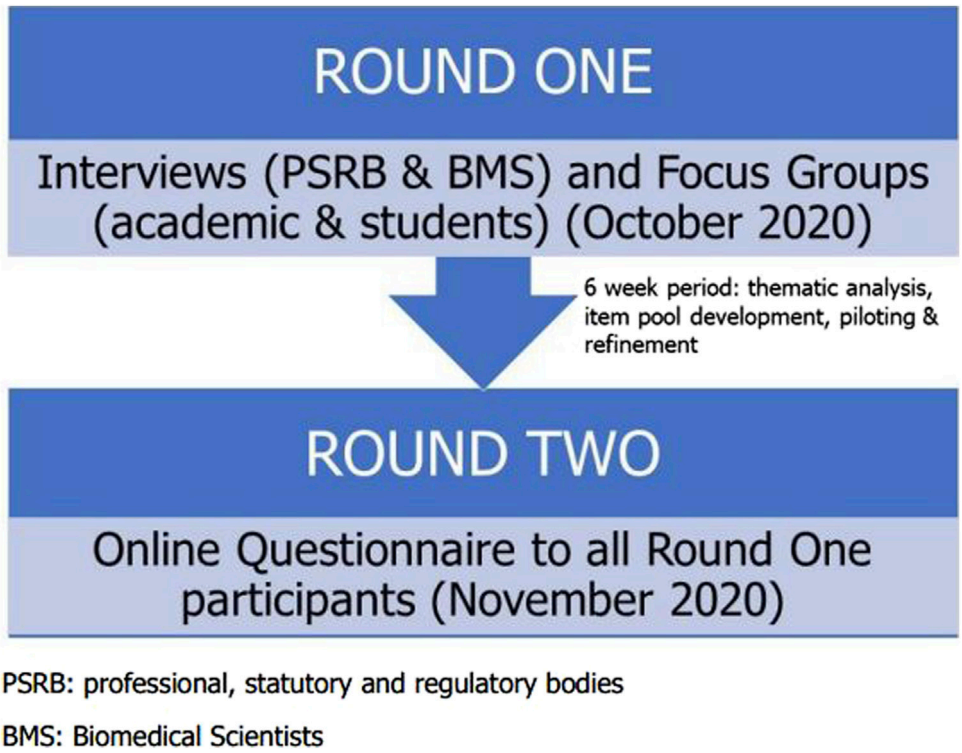

FIGURE 2 | A schematic representation of the design of this Delphi study.

programmes and Biomedical Scientists (n = 5) at a local NHS Trust were invited to attend a series of virtual focus groups. Focus groups were considered a suitable data collection method for round one, as these are beneficial for generating rich, high-quality data [28]. Policy influencing representatives from professional, statutory and regulatory body (PSRB) organisations, such as the HCPC, IBMS and Department of Health were invited to attend one-to-one online or telephone interviews. PSRB organisations are external bodies which accredit and approve degree courses associated with professional qualifications. PSRB representatives (n = 2) were invited to attend interviews rather than a focus group to provide a more appropriate data collection method for this smaller stakeholder group.

Stakeholders were presented with a carefully designed case study which was accessible regardless of discipline and professional background and required prompt action from a Biomedical Scientist. The questions presented in the focus groups and interviews were developed and refined following an interview with a non-HCPC registered academic colleague. One of the strengths of Delphi methodology is that it allows for verification of findings through the use of both qualitative and quantitative data, where the quantitative data can be used to support the conclusions drawn from the qualitative data.

Audio recordings of the focus groups and interviews were made and stored in an anonymised format. These were transcribed shortly after the interview or focus group had taken place to ensure accuracy of the transcripts [29]. The transcription utilised a verbatim transcription approach to accurately record the discussions which had taken place. Participant responses were recorded without correcting sentence structure to capture the voice of the participants. The final stage of transcription involved addition of punctuation, which was checked for accuracy by replaying the recordings.

Thematic Analysis

Analysis of the 1st round data was carried out using content analysis techniques, utilising the Braun and Clarke [29] thematic analysis methodology, which is a flexible and accessible methodology. The initial step in thematic analysis involved becoming familiar with the transcripts through re-reading to identify the most obvious themes. This involved developing an understanding of the data through reading the words critically and analytically. Manual complete coding was carried out to ensure that all relevant data was considered. Coding involved identifying aspects of the data that related to the initial research question and the codes generated provided a label for a feature of the data that may have been of interest [29]. The codes were designed to be concise and capture the essence of the data. Codes were based upon the discussion points generated by the participants but were often defined in different terminology due to the need to be informative without the use of the data set.

As the codes were identified from the transcripts, patterns within the data began to emerge. Themes were identified when commonalities and areas of overlap became clear within the codes. Themes were defined as patterns seen across the data which had a clear central organising concept and also captured

the principle of the participant's experiences [29, 30]. This process required constant revision as new themes and relationships between themes were identified. Once the themes were identified, these themes were the basis for the attitude statements used in the 2nd round of the study.

Round Two

In round two, participants were given a number of statements that they scored using a 5-point Likert scale. These statements were developed following the thematic analysis carried out at the end of the 1st round. Following the 1st round, an item pool was generated which consisted of numerous statements, according to the protocols outlined by Oppenheim [31] and Hicks [32]. These statements were developed using quotes provided in round one. In total, 94 attitude statements were development, including 47 positive and negative paired statements. To minimise satisficing, the attitude statements consisted of pairs of positive and negative statements. Satisficing involves research participants selecting responses they perceive as acceptable, agreeing with positive statements, or responding to every statement in a similar way [33, 34]. Statements were written to address a single opinion and to be clear and explicit to avoid confusion.

The 94 attitude statements that were initially developed were reduced using an item pool reduction. Traditionally, Delphi studies often experience high levels of attrition between questionnaire rounds; therefore, it was necessary to include an appropriate number of statements which would not be considered excessive or repetitive [25, 35]. The original 94 draft attitude statements were shared with 15 academics in the Department of Biomedical Science and Physiology who had not participated in the 1st round of the study. The decision to pilot this questionnaire with a group of academics is a recognised limitation of the study. The implications of this are discussed further in the discussion. Through this piloting exercise, statements with low power to discriminate between high and low scoring groups were removed [32]. This resulted in 22 pairs of statements which were included in the 2nd round questionnaire (**Supplementary Data Sheet S2**). There was an additional one ranking question which was focused around identifying key priorities within the Biomedical Scientist role.

Participants were asked to score the attitude statements using a 5-point Likert scale, consisting of strongly agree, agree, neither agree nor disagree, disagree and strongly disagree. If a participant felt that they could not express an opinion on a topic for whatever reason, they were asked to omit their response. Before distribution, randomisation of the statements was performed to ensure it was not clear that positive and negative statements were present. This was designed to reduce satisficing [32].

Consensus

The aim of the second round was to determine whether consensus amongst stakeholders of the Biomedical Scientist role existed when considering the role of the Biomedical Scientist in patient outcomes. In a Delphi study, consensus is defined as a participant agreeing with a particular statement, which demonstrates both a group opinion and a level of participant agreement [25, 36]. Consensus levels differ in the literature, but usually range from 51% up to 80% [27, 37]. This study adopted a consensus level of 70%, despite the wide-ranging consensus levels reported in the literature. This meant that consensus was reached only if 70% or more of participants agreed or strongly agreed and disagreed or strongly disagreed with a particular statement. This 70% consensus level has been widely employed within the literature [25, 38].

Recruitment Strategy

Two focus groups were carried out at a large West Midlands university. The first focus group involved final year students (n = 7), five on the BSc Biomedical Science and two on the BSc Applied Biomedical Science programmes. The second focus group involved academic staff (n = 5) delivering the Biomedical Science programmes. Final year students were invited to participate regardless of whether they had obtained experience in a clinical laboratory and some participants lacked clinical laboratory experience whilst others had returned from a placement year and would be able to apply for HCPC registration upon graduation. Biomedical Scientists employed at a local NHS Trust (n = 5) were also invited to attend a focus group through a gatekeeper, but the logistics of arranging a focus group for this group proved challenging and participants expressed a preference for a one-to-one interview. Representatives of 3 different PSRB organisations were invited to participate in one-to-one interviews held electronically, with both participants in this group representing the IBMS. Participants received a recruitment letter, a copy of the participant information sheet which provided an overview of the study and a link to the online consent form via email.

Sample Size

The Delphi methodology has no universally accepted minimum number of participants [25]. However, the focus groups initially planned to include 6–8 participants. Possibly because of the COVID-19 pandemic, the number of participants recruited for the study was low but deemed acceptable if focus groups rather than questionnaires were used in the 1st round. Focus groups with too many attendees can become difficult to manage and it can be challenging for individuals to make their point known [28]. Two virtual focus groups were carried out in the 1st round via Microsoft Teams. One of these focus groups recruited 7 students from the BSc Biomedical Science programmes whilst the other recruited 5 academic staff from the same award. One-to-one interviews were carried out with 2 PSRB representatives (both representing the same organisation) and 5 HCPC registered Biomedical Scientists, resulting in a total of 19 participants recruited in the first round. An overview of the participant's experience of the Biomedical Scientist role is presented in **Table 2**.

Although recruitment of 19 participants for the first round of the study was lower than anticipated, utilising qualitative data collection methods in the 1st round allowed for a deep approach to data acquisition [36]. One advantage of the Delphi methodology is that smaller participant numbers are acceptable, with panel sizes of between 10 and 15 participants recognised as acceptable [39]. As the research was conducted during the COVID-19 pandemic, this may have contributed to the lower-than-expected number of participants.

TABLE 2 | The chosen method of data collection used in round one of the study by participant. As far as possible, participant codes, any relevant experience and their chosen discipline are presented unless it was considered necessary to withhold this to maintain anonymity.

Participant group	Data collection method	Participant codes	Experience of the BMS role	Discipline
Biomedical Scientists (n = 5)	One-to-one interviews	BS1	1 year in NHS	Haematology
		BS2	<1 year in NHS	Haematology
		BS3	>25 years in NHS	Immunology
		BS4	>25 years in NHS	Biochemistry
		BS5	5–10 years in NHS	Haematology
Academics (*n* = 5)	Focus group	AC1	HCPC registered	Not disclosed to preserve anonymity
		AC2	No experience as a BMS	
		AC3	No experience as a BMS	
		AC4	HCPC registered	
		AC5	Completed NHS placement	
Students (*n* = 7)	Focus group	S1	Not completed placement	N/A
		S2	Not completed placement	N/A
		S3	Not completed placement	N/A
		S4	Not completed placement	N/A
		S5	NHS placement student	Biochemistry
		S6	NHS employment (non-BMS)	Immunology
		S7	NHS placement student	Histology
PSRB (*n* = 2)	One-to-one interviews	PB1	Experience as a BMS	Not disclosed to preserve anonymity
		PB2	Experience as a BMS	
Total Participants		19		

TABLE 3 | Response rates and the number of participants recruited for each round of the study.

Participant group	Participants in round one	Participants in round two
HCPC Registered Biomedical Scientists	5	4 (80% response rate)
Academics on BSc Biomedical Science programme	5	5 (100% response rate)
Students on BSc Biomedical Science	7	7 (100% response rate)
PSRB Representatives	2	0 (0% response rate)
Total number of participants	**19**	**16**
Overall Response rate	**35/38 = 92.1% Response rate**	

Response Rates

Due to the use of a gatekeeper at the participating NHS Trust who sent out invitations to prospective participants, the response rate for the 1st round of the study is unknown. Participants who had consented to participate in the 1st round received a link to the 2nd round JISC Online Surveys questionnaire via email. Respondents did not provide any identifiable information in the 2nd round, but instead selected their participant group meaning that it was not possible to identify individual participants. A final reminder email was sent a week before the deadline to participate. This resulted in 16 responses received in round 2 and response rates for each group are shown in **Table 3**. Unfortunately, both PSRB representatives were lost in the 2nd round of the study. The 2nd round response rate of 92.1% was considered acceptable for Delphi methodology, where it is commonly accepted that response rates exceeding 70% are required to maintain rigour [25].

RESULTS

Round 1

In the 1st round, participation involved contribution in focus groups or semi-structured interviews. Following this qualitative round, a thematic analysis was carried out and a thematic map was devised (**Figure 3**). This thematic map identified the link between several of the themes and sub-themes. Illustrative quotes, previously presented in the doctoral thesis [40] from which the present article is drawn, are provided which support the thematic analysis and are representative of the voice of the participants.

Round One Findings to Support the Presence of a Theory-Practice Gap

Putting the Patient First

For many participants, putting the patient at the centre was considered an essential aspect of the Biomedical Scientist role, despite this term not being defined in the literature. The Biomedical Scientist role was seen as essential for patient care and fulfilling this role in patient care was considered an essential motivation for aspiring Biomedical Scientists.

Participants highlighted the importance of the patient for Biomedical Scientists and why it was necessary to support achievement of outcomes for their patients. One of the participants in the Biomedical Scientist group stated how every specimen represents a patient:

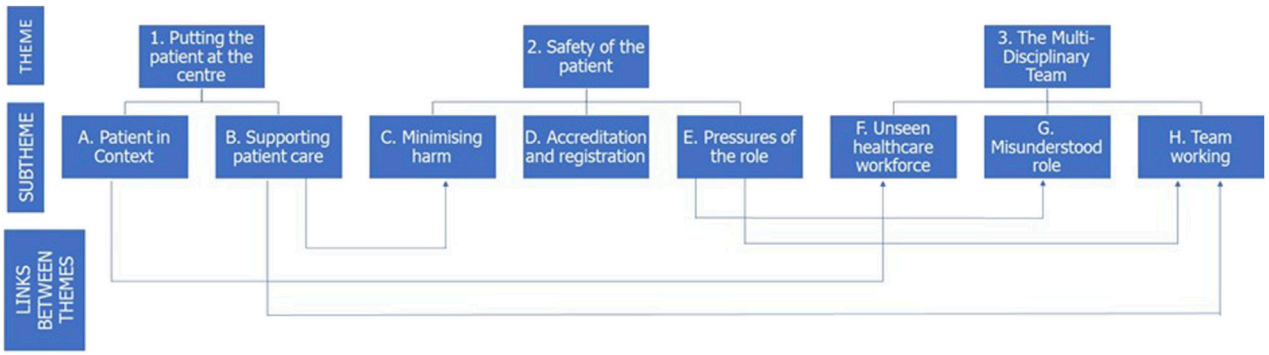

FIGURE 3 | Diagrammatic representation of the three themes and subthemes identified following thematic analysis of the 1st round data. Where overlap between the themes exist, this is indicated by arrows.

> *"If you don't see the patient at the end of it you almost think 'well I'll take my time over that, I won't worry about doing it particularly quickly', whereas, you know, you could have a patient sat in the emergency department or the theatre waiting for a particular result and they're not getting it."*—Biomedical Scientist BS4.

This was also reflected by one of the participants in the student group:

> *"When you're looking at just the lab results, as a Biomedical Scientist so you need to have that in mind, that there is a patient on the other side of that test result and it . . . ultimately, what you decide, well . . . will affect their lives."*—Student S4.

Participants frequently used expressions such as "putting the patient first," but how this can be defined for Biomedical Scientists has not been previously discussed. One participant in the student group who had completed an NHS laboratory placement stated that focusing upon the importance of the patient motivated them to join the profession:

> *"You're becoming a Biomedical Scientist because you want to help people, particularly in a hospital setting because you're going into pathology to run patient tests. You've kind of got to have a reason for doing that."*—Student S5, NHS placement student.

This was further reflected by a Biomedical Scientist participant who spoke passionately about their role in patient care:

> *"So that's why I took the role as a Biomedical Scientist, because in my role, I'm still helping the patient and I'm still helping to find out what's wrong with the patient."*—Biomedical Scientist BS5.

Following the interview questions, one PSRB representative discussed how Biomedical Scientists can demonstrate that they are working to achieve patient outcomes:

> *"OK. I found those quite difficult. I feel quite ashamed of myself because you'd think, after all these years of me talking to people (pause) but it's just one of those things you take for granted."*—PSRB representative PB1.

The fact that this key concept associated with the Biomedical Scientist role was considered as "taken for granted" was an important finding for this study.

Another PSRB representative remarked that there were challenges associated with appreciating the patient's perspective as part of the Biomedical Scientist's role due to minimal patient contact.

> *"There's not many Biomedical Scientists now who do phlebotomy, so they've got a lack of understanding of what patients are going through. When I trained, we went round, especially as trainees, to bleed the patients and you get a huge understanding of what patients are actually going through that I don't think modern Biomedical Scientists get."*- PSRB representative PB2.

Amongst the academic stakeholders, there were some conflicting opinions expressed by participants which did not align with those of other stakeholder groups. When discussing whether it was necessary to focus upon the patient's best interests, the pressurised nature of the laboratory environment was noted by one HCPC-registered participant and how this could detract from the necessary focus upon patient outcomes:

> *"When you get that many specimens, it's difficult to devote . . . the same amount of attention to each one, but yeah, you're striving to have the patient's interests at heart and their outcomes . . . I think the size of modern labs almost, they've turned into sausage factories if you will . . . Patients are almost viewed as a number."*—Academic AC4, HCPC-Registered academic.

This was further reflected by another academic participant, who stated the following when discussing whether patient

outcomes were considered a crucial aspect of the Biomedical Scientist role:

> *"I still think a Biomedical Scientist would do the tests accurately, even if they didn't think about the patient, you'd hope, because that's the scientist part of it."*—Academic AC2.

Across the student and practising Biomedical Scientist groups, stakeholders felt the importance of the patient was an essential motivator for the role, but some of the academic stakeholders felt the high-pressured nature of the role detracted from this.

Professional Registration and Accreditation

Participants also discussed why professional registration, accreditation of laboratories by relevant organisations and adherence to guidelines provided by the IBMS [10] and the importance of the HCPC standards [5–7] for ensuring high quality care:

> *"I wouldn't want myself or a family member to come into a hospital that doesn't have these regulatory bodies or these legal aspects to them because then I wouldn't feel safe."*—Biomedical Scientist BS5.

This was further reflected by comments from one of the PSRB representatives when asked how to recognise a Biomedical Scientist who is failing to focus upon patient outcomes:

> *"It can seriously affect the patient and also contravenes the regulatory, the regulations by which we are registered which can lead to disciplinary action and, people being taken off the register so there are professional consequences as well as consequences for the patient."*—PSRB Representative PB1.

Pressures of the Role

Comments related to the pressures of the role existed only in the academic group and not in the student or Biomedical Scientist groups. Some of the academic participants discussed the pressures associated with turn-around times and the volume of samples received in the laboratory, recognising that these could prevent Biomedical Scientists focusing upon the individual patient.

> *"Yeah, I feel that in the lab that I came from, that if you imagined those two poles apart, quantity and quality, I feel it's moving slightly from the quality towards the quantity . . . As a result, the quality of the work is not as good as it should be because they are focusing upon quantity."*—HCPC Registered Academic AC4.

This was reflected by another academic participant who stated:

> *"You've always got people breathing down your neck, haven't you? Where is the result for this? The consultant's coming, and I need this out today."*—HCPC Registered Academic AC1.

This comment demonstrated a perception of "them and us" between Biomedical Scientists and clinical staff, rather than demonstrating the importance of all individual roles within healthcare. It is interesting that the pressures felt by academic stakeholders were not reflected in the Biomedical Scientist group.

The Multi-Disciplinary Team (MDT)

Participants also expressed that Biomedical Scientists often felt underappreciated within the wider healthcare system, and that both patients and other clinical staff failed to understand the role.

> *"I think because we're hidden, like we're in the labs and we don't get any sort of patient face-to-face care or receive patients face-to-face, so I think a lot of people forget that we are there, and we do help in the decision making."*—Biomedical Science BS5.

As part of this, participants also discussed the importance of team-working and recognised that healthcare professionals must work together to support patient care.

> *"If this was a member of my family that was being tested, would I be happy just leaving it like 'I'm doing my job OK'? If we all work together as a team then, like everyone that's involved in the patient pathway, then it will, I think, achieve a better outcome for the patient."*—Student S2.

The "behind the scenes" nature of the Biomedical Scientist role was also discussed by participants.

> *"People don't always appreciate that there's a laboratory behind that and the extent of the work, and, even when it does come into the lab, it's not always a case of just putting a sample on an analyser and pressing a button and 5 minutes later you get the results."*—Biomedical Scientist BS4.

The hidden nature of the role was perceived to provide a challenge when determining whether other healthcare professionals and patients understood the complexities of the role. Within the wider MDT, the failure to understand the intricacies of the role can have implications for how the role is perceived externally and can result in frustrations due to not understanding why certain policies and procedures are in place.

Round 2

Statements scored by the participants are presented as paired positive and negative statements to aid data interpretation (**Tables 4–7**), but statements were randomised when shared with the participants to prevent bias. Consensus level is presented according to participant group and overall. The consensus statements used in round 2 of the study are

TABLE 4 | Consensus levels for each of the paired statements for putting the patient first across all participant groups. Fields highlighted in green demonstrate achievement of an agree consensus, fields highlighted in red demonstrate achievement of a disagree consensus and fields highlighted in grey demonstrate that the 70% consensus level was not achieved.

Positive statements	Students (*n* = 7)	Biomedical scientists (*n* = 4)	Academics (*n* = 5)	Overall (*n* = 16)	Negative statements	Students (*n* = 7)	Biomedical scientists (*n* = 4)	Academics (*n* = 5)	Overall (*n* = 16)
Putting the patient at the centre									
2. Biomedical Scientists work in the best interests of the patient at all times	6/7 (85.7%) Agree 1/7 (14.2%) Neutral -	4/4 (100%) Agree - -	4/5 (80%) Agree - 1/5 (20%) Disagree	14/16 (87.5%) Agree 1/16 (6.25%) Neutral 1/16 (6.25%) Disagree	11. The desire to work in the best interests of the patient at all times is not shared by all Biomedical Scientists	1/7 (14.2%) Agree 3/7 (42.9%) Neutral 3/7 (42.9%) Disagree	2/4 (50%) Agree - 2/4 (50%) Disagree	3/5 (60%) Agree 1/5 (20%) Neutral 1/5 (20%) Disagree	6/16 (37.5%) Agree 4/16 (25%) Neutral 6/16 (37.5%) Disagree
25. Despite the lack of proximity to the patient, Biomedical Scientists put the patient at the centre of what they do	6/7 (85.7%) Agree - 1/7 (14.2%) Disagree	4/4 (100%) Agree - -	2/5 (40%) Agree 1/5 (20%) Neutral 2/5 (40%) Disagree	12/16 (75%) Agree 1/16 (6.25%) Neutral 3/16 (18.75%) Disagree	3. It is easier for staff providing direct patient care to prioritise patient outcomes due to their proximity to the patient	5/7 (71.4%) Agree 1/7 (14.2%) Neutral 1/7 (14.2%) Disagree	2/4 (50%) Agree - (2/4) 50% Disagree	4/5 (80%) Agree - 1/5 (20%) Disagree	11/16 (68.75%) Agree 1/16 (6.25%) Neutral 4/16 (25%) Disagree
35. A Biomedical Scientist should recognise the importance of each individual sample by considering the needs of the patient behind each sample	6/7 (85.7%) Agree - 1/7 (14.2%) Disagree	4/4 (100%) Agree - -	5/5 (100%) Agree - -	15/16 (93.75%) Agree - 1/16 (6.25%) Disagree	43. It's possible for a Biomedical Scientist to do their job well without considering the needs of the patient	2/7 (28.6%) Agree 2/7 (28.6%) Neutral 3/7 (42.9%) Disagree	- - 4/4 (100%) Disagree	2/5 (40%) Agree 1/5 (20%) Neutral 2/5 (40%) Disagree	4/16 (25%) Agree 3/16 (18.75%) Neutral 9/16 (56.25%) Disagree
42. By focusing upon the outcome of the individual patient, the Biomedical Scientist achieves greater job satisfaction	6/7 (85.7%) Agree 1/7 (14.3%) Neutral -	4/4 (100%) Agree - -	5/5 (100%) Agree - -	15/16 (93.75%) Agree 1/16 (6.25%) Neutral -	26. Job satisfaction is not determined by the perceived importance of patients within the Biomedical Scientist role	3/7 (42.9%) Agree 2/7 (28.6%) Neutral 2/7 (28.6%) Disagree	- - 4/4 (100%) Disagree	1/5 (20%) Agree 1/5 (20%) Neutral 3/5 (60%) Disagree	4/16 (25%) Agree 3/16 (18.75%) Neutral 9/16 (56.25%) Disagree
36. Biomedical Scientists are able to draw upon their own personal experiences as a patient or carer which allows them to empathise with the patient	6/7 (85.7%) Agree 1/7 (14.3%) Neutral -	4/4 (100%) Agree - -	2/5 (40%) Agree 2/5 (40%) Neutral 1/5 (20%) Disagree	12/16 (75%) Agree 3/16 (18.75%) Neutral 1/16 (6.25%) Disagree	4. Biomedical Scientists do not require empathy for patients to do their job effectively	2/7 (28.6%) Agree 1/7 (14.3%) Neutral 4/7 (57.1%) Disagree	- - 4/4 (100%) Disagree	1/5 (20%) Agree - 4/5 (80%) Disagree	2/16 (12.5%) Agree 2/16 (12.5%) Neutral 12/16 (75%) Disagree
Key	Consensus (>70%) reached agree or strongly agree				Consensus (>70%) reached Disagree or strongly disagree	Failed to reach consensus			

tabulated and colour-coded to aid interpretation. Red shading represents achievement of consensus disagreement, whilst green shading represents consensus agreement and grey shading represents a failure to achieve consensus. Any statements where participants failed to provide a response are also recorded. These omitted responses may result from a participant accidentally failing to provide an answer to the statement, or from a deliberate choice as the participant deemed they were unable to express an opinion on a particular topic.

Round Two Findings to Support the Presence of a Theory-Practice Gap

Of the 44 consensus statements that were presented to the stakeholders in the 2nd round, only 45.5% of statements achieved consensus. The consensus level was highest in the Biomedical Scientist group, where 72.7% of statements achieved the 70% consensus level. However, in the student group, only 54.5% of statements achieved the 70% consensus level. . In the academic group, consensus level was lowest with only 40.9% of statements reaching the 70% consensus level. This demonstrated a divergence of opinion across the stakeholders. However, it is important to note that both PSRB representatives were lost in round 2 of the study.

Putting the Patient First

There were several statements which demonstrated the emergence of a theory-practice gap in both the academic and student groups when responses were compared with the Biomedical Scientist group. Those statements which relate to putting the patient first are presented in **Table 4**. One important finding was that for statement 11, "The desire to work in the best interests of the patient at all times is not shared by all Biomedical Scientists" did not reach consensus in any of the stakeholder groups. However, the positive version of the statement that "Biomedical Scientists work in the best interests of the patient at all times" reached consensus overall and in all stakeholder groups. As outlined in the limitations section, the phrasing of these two statements may have impacted upon the consensus rate as the statements were not a perfect pair.

Most participants agreed with statement 3, "Despite a lack of proximity to the patient, Biomedical Scientists put the patient at the centre of what they do." However, this statement failed to reach consensus amongst the academic stakeholders with two participants disagreeing with this statement. This suggests that some stakeholders felt that patients were not considered to be a central part of the Biomedical Scientist role. This was further supported by statement 43, "It is possible for a Biomedical Scientist to do their job well without considering the needs of the patient" which exhibited divergence of opinion. This demonstrates that some individuals felt that a Biomedical Scientist could do their role well without focusing upon the importance of the patient, which is a key finding.

Statement 36, "Biomedical Scientists are able to draw upon their own personal experiences as a patient or carer which allows them to empathise with the patient," failed to achieve consensus in the academic group, and one participant disagreed with this statement. The alternative version of the statement, (number 4), "Biomedical Scientists do not require empathy for patients to do their job effectively" failed to reach consensus in the student group. This supports the presence of a theory-practice gap in both the student and academic groups.

Professional Registration and Accreditation

The theory-practice gap was further evidenced when discussing professional responsibilities and the importance of laboratory accreditation and professional registration for Biomedical Scientists. **Table 5** presents the key statements that indicate a theory-practice gap in both the academic and student groups related to professional registration and accreditation.

Statement 45, "it is not within the Biomedical Scientist's remit to question clinical decisions that put the patient at risk," failed to achieve consensus in the student group, with 2 participants agreeing with this statement. This was further demonstrated in the student group in response to statement 13, "Biomedical Scientists must question inappropriate clinical decisions." which did not achieve consensus amongst the student stakeholders, with one student participant disagreeing with this statement. These responses demonstrate a poor understanding of the Biomedical Scientist role in ensuring patient safety and advocating for the patient in the student group.

Statement 37, "Statutory registration with the Health and Care Professions Council (HCPC) ensures that Biomedical Scientists feel empowered to make autonomous decisions," achieved consensus agreement amongst the Biomedical Scientist stakeholders only. Interestingly, amongst the academic participants, 2 stakeholders disagreed with this statement. The negative form of this statement (number 15), "Biomedical Scientists are not required to make autonomous decisions" reached a disagree consensus in the Biomedical Scientist group only. In response to this statement, 2 students and 1 academic agreed with the statement. This further supports the presence of a theory-practice gap in both the academic and student groups.

Pressures of the Role

This theme was identified in the academic group only. Statement 17, "the pressures of the Biomedical Scientist role do not detract from the importance of the individual patient," achieved consensus agreement in the student group only. One academic participant omitted their response to this statement. This is shown in **Table 6**. The opposing statement (number 29), "other pressures of the Biomedical Scientist role detract from the importance of the individual patient" did not reach consensus in any of the stakeholder groups but 60% of academic participants agreed with this statement.

The Multi-Disciplinary Team

There was further evidence of the theory-practice gap with regards to the Biomedical Scientist role within the MDT. Statement 25, "Despite the lack of patient contact, Biomedical Scientists can focus upon achieving outcomes for each individual

TABLE 5 | Consensus levels for each of the paired statements for professional registration and accreditation across all participant groups. Fields highlighted in green demonstrate achievement of an agree consensus, fields highlighted in red demonstrate achievement of a disagree consensus and fields highlighted in grey demonstrate that the 70% consensus level was not achieved.

Positive statements	Students (*n* = 7)	Biomedical scientists (*n* = 4)	Academics (*n* = 5)	Overall (*n* = 16)	Negative statements	Students (*n* = 7)	Biomedical scientists (*n* = 4)	Academics (*n* = 5)	Overall (*n* = 16)
Safety of the patient, subtheme c: minimising harm									
27. The Biomedical Scientist plays an essential role in patient safety	5/7 (71.4%) Agree 2/7 (28.6%) Neutral -	4/4 (100%) Agree - -	5/5 (100%) Agree - -	14/16 (87.5%) Agree 2/16 (12.5%) Neutral -	45. It is not within the Biomedical Scientist's remit to question clinical decisions that put the patient at risk	2/7 (28.6%) Agree 2/7 (28.6%) Neutral 3/7 (42.9%) Disagree	- - 4/4 (100%) Disagree	- - 5/5 (100%) Disagree	2/16 (12.5%) Agree 2/16 (12.5%) Neutral 12/16 (75%) Disagree
13. Biomedical Scientists must question inappropriate clinical decisions	4/7 (57.1%) Agree 2/7 (28.6%) Neutral 1/7 (14.3%) Disagree	4/4 (100%) Agree - -	5/5 (100%) Agree - -	13/16 (81.25%) Agree 2/16 (12.5%) Neutral 1/16 (6.25%) Disagree	5. Patient safety is the responsibility of others in the clinical team and it is not appropriate for a Biomedical Scientist to question their decision making	1/7 (14.3%) Agree 1/7 (14.3%) Neutral 5/7 (71.4%) Disagree	- - 4/4 (100%) Disagree	- - 5/5 (100%) Disagree	1/16 (6.25%) Agree 1/16 (6.25%) Neutral 14/16 (87.5%) Disagree
28. Statutory HCPC registration for Biomedical Scientists provides confidence for patients and others in the clinical team about the quality of the Biomedical Scientist's practice	5/7 (71.4%) Agree 2/7 (28.6%) Neutral -	4/4 (100%) Agree - -	4/5 (80%) Agree - 1/5 (20%) Disagree	13/16 (81.25%) Agree 2/16 (12.5%) Neutral 1/16 (6.25%) Disagree	14. Statutory registration for Biomedical Scientists has no meaning to patients and others in the clinical team as they lack an understanding of the role	5/7 (71.4%) Agree 1/7 (14.3%) Neutral 1/7 (14.3%) Disagree	2/4 (50%) Agree - 2/4 (50%) Disagree	3/5 (60%) Agree 1/5 (20%) Neutral 1/5 (20%) Disagree	10/16 (62.5%) Agree 2/16 (12.5%) Neutral 4/16 (25%) Disagree
37. Statutory registration with the Health and Care Professions Council (HCPC) ensures that Biomedical Scientists feel empowered to make autonomous decisions	2/7 (28.6%) Agree 5/7 (71.4%) Neutral -	3/4 (75%) Agree - 1/4 (25%) Disagree	2/5 (40%) Agree 1/5 (20%) Neutral 2/5 (20%) Disagree	7/16 (43.75%) Agree 6/16 (37.5%) Neutral 3/16 (18.75%) Disagree	15. Biomedical Scientists are not required to make autonomous decisions	2/7 (28.6%) Agree 1/7 (14.3%) Neutral 4/7 (57.1%) Disagree	- - 4/4 (100%) Disagree	1/5 (20%) Agree 1/5 (20%) Neutral 3/5 (60%) Disagree	3/16 (18.75%) Agree 2/16 (12.5%) Neutral 11/16 (68.75%) Disagree
Key	Consensus (>70%) reached agree or strongly agree				Consensus (>70%) reached Disagree or strongly disagree	Failed to reach consensus			

patient," failed to reach consensus amongst the academic stakeholders and one participant in this group disagreed with the statement. The responses associated with the MDT are shown in **Table 7**. Statement 20, "the nature of the Biomedical Scientist role makes it difficult for them to feel part of the healthcare team," reached consensus agreement in the Biomedical Scientist group only. This suggests that a real-world understanding of the Biomedical Scientist role may be lacking in both the academic and student groups.

There was divergence of opinion for how well the Biomedical Scientist role is understood by other professionals within healthcare. This was demonstrated by statement 21, "the role of the Biomedical Scientist in healthcare is well understood by other healthcare professionals" and statement 31, "the role of the Biomedical Scientist in healthcare is poorly understood by other healthcare professionals." Statement 21 reached a disagree consensus amongst the student participants only. Statement 31 failed to achieve consensus in the academic group. This demonstrates that there was a divergence of opinion amongst the stakeholders with regards to the Biomedical Scientist role in the MDT.

This theory-practice gap was further reflected in statement 34, "the technical and analytical nature of the Biomedical Scientist role does not detract from the importance of the individual patient" which did not achieve consensus in the student group, with one student disagreeing with the statement. The negative version of the statement (number 10), "the technical and analytical nature of the Biomedical Scientist role makes it difficult to recognise the importance of the individual patient," achieved consensus disagreement in the Biomedical Scientist group only. Amongst the student and academic stakeholders, two participants agreed with the statement, which conflicted with the findings from the Biomedical Scientist group.

Statement 41, "softer skills such as patient empathy are important aspects of the training and education of Biomedical Scientists," failed to reach consensus amongst the academic stakeholders, and one participant disagreed with this statement. However, this response may have been made in error because the negative statement (number 24), "Biomedical Scientists do not require soft skills such as empathy as their priority should be analysing samples in a timely fashion" achieved consensus disagreement within all groups.

Summary

Throughout both rounds of this study, a divergence of opinion was evident amongst the stakeholders, with more statements reaching consensus amongst the Biomedical Scientist group than in the student and academic groups. For some statements, there were individuals in the academic and student groups which expressed conflicting opinions to those of the Biomedical Scientist group. There was also evidence in both the student and academic groups that the Biomedical Scientist role and what was expected of this professional group was unclear in some cases. This demonstrates the existence of a theory-practice gap in both the academic and student groups, which has not previously been described.

TABLE 6 | Consensus levels for each of the paired statements for pressures of the role across all participant groups. Fields highlighted in green demonstrate achievement of an agree consensus, fields highlighted in red demonstrate achievement of a disagree consensus and fields highlighted in grey demonstrate that the 70% consensus level was not achieved.

Positive statements	Students (n = 7)	Biomedical scientists (n = 4)	Academics (n = 5)	Overall (n = 16)	Negative statements	Students (n = 7)	Biomedical scientists (n = 4)	Academics (n = 5)	Overall (n = 16)
Pressures of the role									
17. The pressures of the Biomedical Scientist role do not detract from the importance of the individual patient	6/7 (85.7%) Agree 1/7 (14.3%) Neutral - -	2/4 (50%) Agree 2/4 (50%) Neutral - -	1/5 (20%) Agree 1/5 (20%) Neutral 2/5 (40%) Disagree 1/5 (20%) Omitted	9/16 (56.25%) Agree 4/16 (25%) Neutral 2/16 (12.5%) Disagree 1/16 (6.25%) Omitted	29. Other pressures of the Biomedical Scientist role detract from the importance of the individual patient	1/7 (14.3%) Agree 3/7 (42.9%) Neutral 3/7 (42.9%) Disagree -	- 2/4 (50%) Neutral 2/4 (50%) Disagree -	3/5 (60%) Agree 1/5 (20%) Neutral 1/5 (20%) Disagree -	4/16 25% Agree 6/16 (37.5%) Neutral 6/16 (37.5%) Disagree -
Key	Consensus (>70%) reached agree or strongly agree				Consensus (>70%) reached disagree or strongly disagree	Failed to reach consensus			

TABLE 7 | Consensus levels for each of the paired statements for the MDT across all participant groups. Fields highlighted in green demonstrate achievement of an agree consensus, fields highlighted in red demonstrate achievement of a disagree consensus and fields highlighted in grey demonstrate that the 70% consensus level was not achieved.

Positive statements	Students (*n* = 7)	Biomedical scientists (*n* = 4)	Academics (*n* = 5)	Overall (*n* = 16)	Negative statements	Students (*n* = 7)	Biomedical scientists (*n* = 4)	Academics (*n* = 5)	Overall (*n* = 16)
The multi-disciplinary team									
25. Despite the lack of patient contact, Biomedical Scientists can focus upon achieving outcomes for each individual patient	7/7 (100%) Agree - -	4/4 (100%) Agree - -	3/5 (60%) Agree 1/5 (20%) Neutral 1/5 (20%) Disagree	14/16 (87.5%) Agree 1/16 (6.25) Neutral 1/16 (6.25%) Disagree	38. Lack of patient contact makes it difficult for a Biomedical Scientist to recognise their role within an individual patient's outcomes	2/7 (28.9%) Agree 2/7 (28.9%) Neutral 3/7 (42.9%) Disagree	2/4 (50%) Agree - 2/4 (50%) Disagree	3/5 (60%) Agree - 2/5 (40%) Disagree	7/16 (43.75%) Agree 2/16 (12.5%) Neutral 7/16 (43.75%) Disagree
47. Biomedical Scientists are well integrated within the healthcare team, despite a lack of patient contact	1/7 (14.3%) Agree 2/7 (28.6%) Neutral 4/7 (57.1%) Disagree -	1/4 (25%) Agree 1/4 (25%) Neutral 2/4 (50%) Disagree -	- 1/5 (20%) Neutral 4/5 (80%) Disagree -	2/16 (12.5%) Agree 4/16 (25%) Neutral 10/16 (62.5%) Disagree -	20. The nature of the Biomedical Scientist role makes it difficult for them to feel part of the healthcare team	2/7 (28.6%) Agree 2/7 (28.6%) Neutral 2/7 (28.6%) Disagree 1/7 (14.3%) Omitted	4/4 (100%) Agree - - -	3/5 (60%) Agree 1/5 (20%) Neutral 1/5 (20%) Disagree -	9/16 (56.25%) Agree 3/16 (18.75%) Neutral 3/16 (18.75%) Disagree 1/16 (6.25%) Omitted
21. The role of the Biomedical Scientist in healthcare is well understood by other healthcare professionals	1/7 (14.3%) Agree 1/7 (14.3%) Neutral 5/7 (71.4%) Disagree	1/4 (25%) Agree 1/4 (25%) Neutral 2/4 (50%) Disagree	2/5 (40%) Agree - 3/5 (60%) Disagree	4/16 (25%) Agree 2/16 (12.5%) Neutral 10/16 (62.5%) Disagree	31. The role of the Biomedical Scientist in healthcare is poorly understood by other healthcare professionals	7/7 (100%) Agree - -	3/4 (75%) Agree 1/4 (25%) Neutral -	3/5 (60%) Agree - 2/5 (40%) Disagree	13/16 (81.25%) Agree 1/16 (6.25%) Neutral 2/16 (12.5%) Disagree
8. Biomedical Scientists are regarded as being an essential part of the multi-disciplinary team by the wider healthcare team	4/7 (57.1%) Agree 1/7 (14.3%) Neutral 2/7 (28.6%) Disagree	1/4 (25%) Agree 1/4 (25%) Neutral 2/4 (50%) Disagree	2/5 (40%) Agree - 3/5 (60%) Disagree	7/16 (43.75%) Agree 2/16 (12.5%) Neutral 7/16 (43.75%) Disagree	32. Biomedical Scientists are not considered part of the multi-disciplinary team by the wider healthcare team	3/7 (42.9%) Agree 3/7 (42.9%) Neutral 1/7 (14.3%) Disagree	2/4 (50%) Agree - 2/4 (50%) Disagree	3/5 (60%) Agree - 2/5 (40%) Disagree	8/16 (50%) Agree 3/16 (18.75%) Neutral 5/16 (31.25%) Disagree
33. Biomedical Scientists must recognise when referral to a consultant or member of the medical team is required to ensure the best outcome for a patient	5/7 (71.4%) Agree 2/7 (28.9%) Neutral - -	4/4 (100%) Agree - - -	5/5 (100%) Agree - - -	14/16 (87.5%) Agree 2/16 (12.5%) Neutral - -	40. Biomedical Scientists are not responsible for referring a patient case for a consultant to review	1/7 (14.3%) Agree 2/7 (28.6%) Neutral 3/7 (42.9%) Disagree 1/7 (14.3%) Omitted	- - 4/4 (100%) Disagree -	1/5 (20%) Agree 1/5 (20%) Neutral 3/5 (60%) Disagree -	2/16 (12.5%) Agree 3/16 (18.75%) Neutral 10/16 (62.5%) Disagree 1/16 (6.25%) Omitted

(Continued on following page)

TABLE 7 | (*Continued*) Consensus levels for each of the paired statements for the MDT across all participant groups. Fields highlighted in green demonstrate achievement of an agree consensus, fields highlighted in red demonstrate achievement of a disagree consensus and fields highlighted in grey demonstrate that the 70% consensus level was not achieved.

Positive statements	Students (*n* = 7)	Biomedical scientists (*n* = 4)	Academics (*n* = 5)	Overall (*n* = 16)	Negative statements	Students (*n* = 7)	Biomedical scientists (*n* = 4)	Academics (*n* = 5)	Overall (*n* = 16)
34. The technical and analytical nature of the Biomedical Scientist role does not detract from the importance of the individual patient	4/7 (57.1%) Agree 2/7 (28.9%) Neutral 1/7 (14.3%) Disagree	4/4 (100%) Agree - -	4/5 (80%) Agree - 1/5 (20%) Disagree	12/16 (75%) Agree 2/16 (12.5%) Neutral 2/16 (12.5%) Disagree	10. The technical and analytical nature of the Biomedical Scientist role makes it difficult to recognise the importance of the individual patient	2/7 (28.9%) Agree 1/7 (14.3%) Neutral 4/7 (57.1%) Disagree	- - 4/4 (100%) Disagree	2/5 (40%) Agree 1/5 (20%) Neutral 2/5 (40%) Disagree	4/16 (25%) Agree 2/16 (12.5%) Neutral 10/16 (62.5%) Disagree
41. Softer skills such as patient empathy are important aspects of the training and education of Biomedical Scientists	5/7 (71.4%) Agree 1/7 (14.3%) Neutral 1/7 (14.3%) Disagree	4/4 (100%) Agree - -	3/5 (60%) Agree 1/5 (20%) Neutral 1/5 (20%) Disagree	12/16 (75%) Agree 2/16 (12.5%) Neutral 2/16 (12.5%) Disagree	24. Biomedical Scientists do not require soft skills such as empathy, as their priority should be analysing specimens in a timely fashion	- 1/7 (14.3%) Neutral 6/7 (85.7%) Disagree	- - 4/4 (100%) Disagree	- 1/5 (20%) Neutral 4/5 (80%) Disagree	- 2/16 (12.5%) Neutral 14/16 (87.5%) Disagree
Key	Consensus (>70%) reached agree or strongly agree				Consensus (>70%) reached disagree or strongly disagree	Failed to reach consensus			

DISCUSSION

Round 1 and 2 of this Delphi study demonstrated several key findings which are relevant to practice and enabled the initial research aims to be addressed. How the research has addressed these aims will now be outlined.

1. Is there consensus amongst stakeholders upon how the role of the Biomedical Scientist influences patient outcomes?

Stakeholders considered how the role of the Biomedical Scientist contributed towards achievement of patient outcomes and how these were considered important within the role. It was evident that many of the statements regarding the importance of the Biomedical Scientist role in achievement of patient outcomes demonstrated consensus amongst the stakeholders. However, greater divergence of opinion existed for whether Biomedical Scientists always work in the best interests of the patient, which is contrary to both professional and statutory guidelines [5, 6, 10].

2. Do stakeholders have a common understanding of how Biomedical Scientists might demonstrate that they are working to achieve patient outcomes?

Stakeholders felt that a Biomedical Scientist who was focused upon achieving patient outcomes demonstrated this through the high standard of their work, a professional attitude and adherence to professional guidelines and the HCPC standards [5]. These regulatory standards and professional guidelines were considered essential to standardise care and prevent harm.

3. How do stakeholders consider the importance of achieving patient outcomes within the Biomedical Scientist role?

Stakeholders recognised that achieving patient outcomes was evidenced through processing of samples to achieve a diagnosis and to initiate treatment pathways, which then supports other healthcare professionals to enable them to carry out their role. The stakeholders demonstrated consensus of opinion regarding the importance of the Biomedical Scientist role for contributing to patient outcomes through input into the MDT and this was considered an important consideration for entering the profession.

4. How do stakeholders recognise a Biomedical Scientist who is working to support the achievement of patient outcomes?

Participants identified this as a Biomedical Scientist that processes specimens accurately, ensuring that results are reported in a timely manner and, if necessary, are communicated within a clinically appropriate timeframe. Through these actions, Biomedical Scientists were seen as supporting the actions of other healthcare professionals through their role within the MDT. It was also considered essential for Biomedical Scientists to recognise when clinical referrals are necessary.

The Theory-Practice Gap in the Education of Biomedical Scientists

This study has identified a theory-practice gap related to the education of Biomedical Scientists. The concept of a theory-practice gap has been extensively described in nursing and results from the difficulties in application of theoretical ideas delivered in an academic setting and the challenges of applying these to real-world professional practice [41]. Within the field of nursing, this gap has been found to be most significant for newly qualified professionals. This is because of the significant physical separation between a student's academic studies and clinical practice, which is challenging when trying to relate theory to practice [41–43]. This is of greater significance in Biomedical Science, where only a small cohort of the students on the course will complete a healthcare laboratory placement.

This theory-practice gap has been described in several healthcare professions, including paramedic science [44], medicine [45], pharmacy [46] and extensively in nursing [41, 43, 47, 48]. However, this study has demonstrated for the first time that this gap exists within the Biomedical Scientist workforce. Now that this gap has been identified, it is necessary to develop strategies to overcome this gap and changes to the curriculum are likely to be required as a result.

This theory-practice gap amongst the stakeholders was identified due to divergence of opinion in both the academic and student groups when responses were compared to the Biomedical Scientist group. In addition, it became clear that more statements reached consensus in the Biomedical Scientist group than in the student and academic groups, with consensus level being lowest in the academic group. This demonstrates a difference between perceived understanding of the role in the academic and student groups. In the student responses, there was evidence of a larger degree of divergence of opinion, along with an increased number of responses recorded as "neither agree nor disagree" in round 2. This suggests that some of the student participants did not feel able to comment upon some aspects of the Biomedical Scientist role.

Graduates of a Biomedical Science programme aspire to a diverse range of careers, including teaching, research or further education. As not all graduates aspire to work as Biomedical Scientists this provides a challenge when designing the curriculum. Although placements at the end of the 2nd year of their award are open to all students, inevitably only a small number of placements in NHS laboratories are available on an annual basis. This prevents students from being exposed to key skills and gaining an in-depth knowledge of the Biomedical Scientist role.

Whilst the presence of this theory-practice gap amongst the student participants was perhaps not surprising as many student participants had not been exposed to working within a clinical laboratory, there was also evidence of the presence of a theory-practice gap amongst the academic group. Divergence in the responses in the academic group when compared to the Biomedical Scientist group demonstrated a lack of understanding of key aspects of the role. To obtain HCPC approval for a degree programme, it is necessary for a HCPC-registered Biomedical Scientist to take overall responsibility for oversight of the award. This is outlined in HCPC Standards of Education and Training (SET) 3.3 as follows: "The education provider must ensure that the person holding overall professional responsibility for the programme is appropriately qualified and experienced and, unless other arrangements are appropriate, on the relevant part of the Register" [49].

Unlike in other programmes allied to healthcare, not all academic staff teaching on the BSc Biomedical Science programmes have professional experience of working in NHS laboratories and being on the necessary professional register is not a requirement of all staff. Academics who lack personal experiences as a Biomedical Scientist may indirectly influence student responses through selection of curriculum content and delivery of taught materials. Practitioner involvement in professionally approved and accredited courses is essential for providing students with a realistic understanding of the role through instilling the skills required for professional practice into their students [50].

Participants demonstrated a divergence of opinion for several key statements, including when discussing whether all Biomedical Scientists worked in the best interests of the patient at all times. However, it is important to note that the phrasing of this statement to include "all Biomedical Scientists" rather than "Biomedical Scientists in general" may have contributed to this failure to reach consensus. This divergence was further evidenced when discussing whether it is possible for a Biomedical Scientist to do their job well without considering the needs of the patient, which also failed to reach consensus in the student and academic groups. This fails to comply with professional guidelines [10] and HCPC standards [5, 6], which require Biomedical Scientists to focus upon the best interests of patients and service users within their role. This suggests that a real-world understanding of the Biomedical Scientist role may be lacking in both the academic and student groups.

In Round one, one PSRB representative remarked that the understanding of key concepts related to the significance of achieving patient outcomes for Biomedical Scientists was "taken for granted." It is important that guidelines and regulatory standards provided for healthcare professionals are clear, explicit and cannot be misinterpreted to guarantee patient safety [51, 52]. This statement by that PSRB representative demonstrates the rationale for this study and suggests the need for development of professional guidelines and standards which outline the skills and qualities expected of students and registered Biomedical Scientists. Unfortunately, in Round two, neither PSRB representative responded to the questionnaire, which is a recognised limitation.

Further evidence of the theory-practice gap was reflected when asked to score agreement regarding whether Biomedical Scientists are not required to make autonomous decisions. This reached consensus disagreement in the Biomedical Scientist group only. The statement showed divergence of opinion overall and in the student and academic groups. In response to this statement, two students and one academic demonstrated agreement, despite the disagree consensus in the Biomedical Scientist group. This further

supports the theory-practice gap in the academic and student groups and suggests a poor understanding of the role of the Biomedical Scientist amongst these groups.

When considering whether Biomedical Scientists can focus upon achieving patient outcomes despite a lack of patient contact, an agree consensus was reached overall as well as in the student and Biomedical Scientist groups. However, this statement did not achieve consensus in the academic group, where one participant disagreed with the statement. This further supports the theory-practice gap and also contravenes the professional and statutory guidelines appropriate to the profession [5, 6, 10].

Pressures of the Role

Considering whether the pressures of the Biomedical Scientist role detract from the importance of the patient, there was failure to achieve consensus in all the stakeholder groups. Although this did not achieve consensus, 60% of academic participants agreed with this statement. In Round one, several quotes demonstrated that the academic participants perceived the Biomedical Scientist role to be challenging with a "them and us" perception when discussing clinical staff. In the academic group, both workload pressures and time pressures were perceived to reduce the significance of achieving patient outcomes. In nursing, workload pressures are also recognised as detracting from high quality care and are known to impact patient safety [53, 54]. Amongst the academic stakeholders, the recognition of the pressures of the Biomedical Scientist role may have resulted in the decision to enter academia with a view to improving work-life balance. This has been recognised as motivation for nursing staff who pursue academic careers [55] but has not been described in relation to the Biomedical Scientist role.

Social Desirability Bias

In Round two, there was an emerging pattern that positive versions of the statements achieved consensus more readily than negative versions. The data demonstrates that 13/22 (59.1%) of positive statements reached consensus whilst only 7/22 (31.8%) of negative statements reached consensus. This is a known limitation of researching using questionnaires as participants can agree with a statement whether it expresses their true opinion or not [33]. Participants are also at risk of social desirability bias, whereby they select responses that they believe are socially acceptable, even if this doesn't represent their true opinion to prevent perceived judgement from the researcher [56, 57]. The use of paired attitude statements was designed to minimise the risk of social desirability bias by providing verification of the participant responses.

Limitations of the Study

Whilst the study successfully addressed the research aims and questions, there are several limitations which will now be discussed. Recruitment of study participants yielded low participant numbers, particularly in the Biomedical Scientist group. Although Delphi studies do not have a specified minimum number of participants, it is generally accepted that at least 10–15 participants should be included in the panel [25, 39]. Unfortunately, due to low numbers of participants, it is necessary to recognise the limitations of drawing conclusions with such a small sample size [58]. This may have resulted from the challenges of conducting the research during a pandemic when laboratories were subject to staff absences and increased workloads [59]. Upon reflection, it would have been advantageous to seek an amendment from the ethics committees to approach several NHS Trusts for participants and to consider an additional stage of recruitment.

When analysing the Round 2 data, it was clear that for some of the attitude statements, the positive and negative versions were not perfect mirror images of each other. As a result, this may have caused some of the inconsistencies seen within the stakeholder responses. The fact that more positive statements achieved consensus than negative statements may have resulted from this ambiguity with the statement wording. This may have also been a factor in the satisficing observed in round 2 [33].

It was considered important to recruit PSRB individuals to participate in the study. Representatives of three PSRB organisations received an invitation to participate, but only a single organisation responded favourably. It was unfortunate that both PSRB representatives from the 1st Round were lost in the 2nd Round. It is necessary to include PSRB involvement in courses associated with specific professions to ensure that course content is appropriate and academic staff have the required knowledge to facilitate achievement of learning outcomes [60]. Recruitment of PSRB representatives to the study was essential to influence professional practice. As a result, the loss of both PSRB representatives in the Round 2 was an unfortunate limitation of the study.

Although the study explored the perceptions of several different stakeholders of the Biomedical Scientist role, it would have been beneficial to include patients and carers as a final stakeholder group. Unfortunately, time pressures prevented this key group from inclusion, and this is something that should be addressed in future research. A further limitation of the study was that the attitude statements were piloted with a group of 15 academic staff. In hindsight, this piloting exercise should have been carried out with a variety of stakeholder groups. As Delphi methodology is associated with a degree of attrition [25, 35], it was considered necessary to distribute the 2nd round questionnaire without undue delay. This meant that there was insufficient time to pilot the questionnaire with a range of stakeholders.

Stakeholders in the academic and student groups were recruited from a single academic organisation and Biomedical Scientist participants were recruited from a single NHS Trust. This represents a narrow scope for the study. Furthermore, the online survey which was distributed to the participants in the 2nd Round could have been shared with a wider audience of key stakeholders. This will be carried out as a 3rd Round of the Delphi study in the future to determine whether the findings of the study are more widely applicable. It would be worthwhile verifying the findings of this study across a range of NHS Trusts and a range of academic institutions by completing a further round of data collection to verify the understanding of a larger audience.

Recommendations From the Study

- Changes to the professional guidelines and regulatory standards are required to include the addition of important concepts identified in the study. This includes the patient-focused elements of the Biomedical Scientist role, as well as empathy, the requirement to work in the best interests of the patient and how these requirements can be evidenced. The use of the term "service user" in the HCPC standards of proficiency [5, 6] may be unclear for students. Consequently, the term "service user" should be clearly defined within the context of patient care and the importance of putting the patient first.
- Course content for the BSc Biomedical Science programme should also discuss the role of the Biomedical Scientist in healthcare to adequately prepare students for practice and should be incorporated within a professional practice module for those students pursuing a career in a clinical diagnostic laboratory.
- The role of the Biomedical Scientist within the MDT was poorly understood, and participants perceived that the role was undervalued within healthcare. To gain recognition for the role within the MDT, it is necessary to promote and publicise the role externally and for students on Biomedical Science awards. This content should be delivered through collaboration involving both higher education and healthcare organisations.
- Biomedical Scientists need to be more integrated into the wider healthcare system to increase awareness of their professional knowledge and skills. To develop understanding of the Biomedical Scientist role as part of the MDT, MDT meetings should be attended by experienced Biomedical Scientists to gain external recognition of the complexities of the role. Although clinical staff attending MDT meetings can focus upon clinical aspects of a complex case, Biomedical Scientists can advise upon technical matters such as whether an existing sample is available for further testing or how long this would take. This opportunity will provide greater opportunity for Biomedical Scientists to focus upon patient outcomes within their role.
- Now that a theory-practice gap in the education of Biomedical Scientists has been identified, it is necessary to develop strategies to reduce the gap and these must be evaluated to ensure that graduates are better prepared for their role.
- In recognition of the wide range of potential careers of Biomedical Science graduates, it would be beneficial to distinguish between those students aspiring to a career in a diagnostic laboratory and those with other career aspirations. This would allow the cohort who wish to pursue careers in a diagnostic laboratory to receive more tailored and relevant degree content. However, this would be challenging to deliver as students are not always clear on their career aspirations early on in their degree.
- Academics delivering the BSc Biomedical Science programme without experience as Biomedical Scientists should be given the opportunity to explore this "real-world" setting to develop a better understanding of the intricacies of the Biomedical Scientist role. The patient-focused aspects of the course should be delivered by experienced practitioner lecturers who possess professional experience in this area. The content of the degree programme should also include an overview of the role of the Biomedical Scientist within the MDT. Students on Biomedical Science programmes should be better integrated with other students on professional health related courses to foster this understanding of the post-graduate role.

SUMMARY TABLE

What Is Known About This Subject?

- Anecdotal evidence exists of the importance of patient outcomes for Biomedical Scientists, but this has not been documented.
- The role pathology services play within patient care pathways is well recognised.
- Students on BSc Biomedical Science programmes do not always have the opportunity to complete an integrated placement.

What This Work Adds

- Provides evidence of a theory-practice gap relating to multi-disciplinary patient care and the role of Biomedical Scientists.
- Following identification of a gap, strategies for education and training are required to address this.
- The Biomedical Scientist role within the MDT is undervalued and poorly understood outside of the laboratory.

Concluding Statement

This work represents an advance in biomedical science because the study has identified a theory-practice gap for the first time within Biomedical Scientist education.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving humans were approved by the University of Wolverhampton School of Life Sciences Ethics Committee, University of Wolverhampton School of Health Ethics Committee, NHS Ethics HRA Approval IRAS Ref 273632. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

KD designed the study, collected and analysed the data. KD prepared the manuscript. DM offered guidance throughout the research. All authors contributed to the article and approved the submitted version.

FUNDING

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ACKNOWLEDGMENTS

The data included within this study forms part of a doctoral thesis submission for the corresponding author [40]. Thank you to the students, Biomedical Scientists, academics and professional and statutory body representatives who gave up their time to support this study. Thank you also to Professor Rebecca Jester, Dr Faith Muir and Dr Katherine Birch for their guidance, input and support during the design and completion of this study.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2024.12629/full#supplementary-material

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ORIGINAL RESEARCH
published: 29 May 2024
doi: 10.3389/bjbs.2024.12215

Supporting the Biomedical Science UG Project Research Journey Through Staff-Student Partnerships

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Introduction: Developing research skills enhances graduate attributes and student employability. The UG research project is coined the pedagogy of the 21st century but the diversity of supervisory styles is a source of student perceived inequality of experience. The goal of this study was to provide structure and support to undergraduate (UG) biomedical science research students and supervisors by co-creating research informed resources that are accessible, engaging and student centred. We asked 1) How do UG students experience research supervision? 2) What approaches do supervisors use to support UG project students? 3) How do students as partners benefit from being involved in pedagogical research?

Materials and Methods: In Stage One, 3 UG student research partners co-developed questionnaires and followed these up with semi-structured interviews. Fifty two UG project students took part in an interactive poll and 14 supervisors answered a questionnaire. Seven students and 4 supervisors were interviewed. These were analysed by thematic analysis. In Stage Two, the questions were asked of UG project students (n = 79) via an interactive poll and the resource developed in Stage One was trialled with students (n = 68) and supervisors (n = 37).

Results: The global theme identified was that students feel strongly that the student-supervisor relationship influences their experience, satisfaction and success. In all polls, >90% of students but <60% of supervisors agree that a good student/supervisor partnership has an effect on the success of the final project. A smaller percentage of students felt strongly that they were able to develop a successful partnership with their supervisor. We co-created a visual model and a list of discussion points of how the student-supervisor partnership can be developed, aimed at making supervision more effective whilst being non-prescriptive.

Discussion: The resource can be easily adapted. Students believe it helped them to develop a staff-student partnership and supervisors commented that it helps to clarify roles and manage student expectations. This scalable project will support the practice of future UG biomedical science project research students and supervisors. Working with students as partners enabled the development of richer ideas whilst supporting their employability.

Keywords: biomedical science, students as partners, research project, employability, graduate attributes

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Received: *10 October 2023*
Accepted: *09 May 2024*
Published: *29 May 2024*

Citation:
Veuger S, Cookson L, Creighton H, Gallaher S, Racey S, Ridley M and Robson I (2024) Supporting the Biomedical Science UG Project Research Journey Through Staff-Student Partnerships. Br J Biomed Sci 81:12215. doi: 10.3389/bjbs.2024.12215

INTRODUCTION

Working in partnership with students as partners (SaP) holds immense value in ensuring that we uncover concerns and develop proactive responses that impact those who are directly affected [1]. In doing so, we are able to shift the focus from staff to students to develop authentic student centred resources, fostering student engagement and driving increased student responsibility for their learning. Partnership can take many forms as discussed by Healey et al and works best when it forms part of the culture and ethos of a department or institution [15]. Partnership with students is therefore effective when a sense of community can be built amongst staff and students. This project sought to work with students to develop resources that drive the development of a culture and community of individual staff-student research partners. In doing so, the study seeks to support the biomedical science undergraduate (UG) project research journey, increasing both the graduate attributes and employability of biomedical science students.

Employability can be considered a set of knowledge, skills and behaviours that support university graduates to be successful in their chosen career path [2]. Employers are seeking graduates with high level transferrable skills alongside personal attributes. Programmes accredited by the Institute for Biomedical Sciences (IBMS) seek to ensure that students receive wide ranging research-informed scientific education and develop skills and experience that employers value. In addition to running and developing new tests, biomedical scientists undertake research and therefore benchmark statements for biomedical sciences include the ability to execute independent research-centred data generation, analyse, interpret and critically evaluate data [3]. As many as 34% of biomedical science graduates choose to enter research as a career [4]. Important skills for researchers are broad ranging and include analytical, communication, problem solving, data analysis, critical thinking and team working. These skills enable the development of solutions to complex problems and therefore research skills are highly valued by employers as they are essential to a wide range of industries.

Graduate attributes and the final destination of Higher Education (HE) leavers both impact university ranking. There are sector-wide concerns over students' career readiness and difficulties transitioning from university into a working environment [5]. Employability is therefore a key Teaching Excellence Framework (TEF) metric and embedding opportunities to support the development of skills into the UG curriculum can positively enhance graduate employability. Pedagogic approaches to developing students as independent researchers that optimise the development of research skills are therefore beneficial to the development of student employability.

The UG research project is the most sustained research heavy piece of work that students undertake during their degree programme. Coined the pedagogy of the twenty-first century [6,7], numerous studies have reported research as a pedagogic practice [8–10]. Serbic and Bourne identify the final year research project as a tool for maximising the employability prospects of students [10]. During their final year UG research project, students are expected to review the literature, collect and analyse data and write up independently. The shift from tutor-directed to self-directed learning is often cited as a mechanism to drive independent learning in final year UG research project students [11]. Students are able to make explicit links between taught material and knowledge with professional applications. The UG research project is therefore an ideal mechanism to develop students as researchers [12] whilst encouraging a deep approach to learning and fostering employability skills.

Anecdotally, supervisors distinguish supervision from other forms of teaching, viewing the UG research project as a unique opportunity for the student to venture into a new territory where authority and relationships are reconfigured [13]. The UG research project is an important learning experience at the end of the biomedical science (BMS) programme. Uniquely, this is delivered by multiple members of staff which leads to diverse approaches to the supervision of projects. This range of supervisory styles is perceived by students as an inequality in experience. The focus that is taken by the supervisor during the research project can vary and also change throughout the project and may not rely on only one approach. Pedagogic research-teaching approaches defined by Healey et al [15] include "research-led" (learning about current research in a discipline), "research-oriented" (developing research skills and techniques), "research-tutored" (engaging in research discussions) and "research-based" approaches (undertaking research and inquiry) [15].

The BSc. (Hons) biomedical sciences programme at Northumbria University recruits in the region of 200 students per year. A major consideration for proactive students is the employability aspects of their curriculum vitae (CV) following a degree programme. Student feedback also highlights a belief that there is a benefit from opportunities to engage in learning and assessment activities that help them develop and enhance their employability. The programme at Northumbria is accredited by the IBMS. As well as an expectation that students will undertake independent research, the IBMS benchmark statements highlight that there should be "a commitment to equity and inclusive practices for diverse student cohorts through considered course design" [3].

Firmly aimed at enhancing the student learning experience, graduate attributes and employability, the aims of this action research project were to 1) improve supervision quality to allow all students studying biomedical science to achieve their potential and realise their ambitions, irrespective of their background or motivations for studying biomedical Science. 2) work in partnership with students to co-create a robust solution that "values and harnesses differences and encourages openness and participation where everyone feels respected, supported and valued" [3].

Our goal was not to change the subject specific aspects of the UG research project but to develop mechanisms that support the pedagogical teaching approach. The IBMS benchmark also states that "students should expect to be embraced as partners within their own courses . . . .. student voice should play a significant role in course development, delivery, review and the overall student experience within biomedical science" [3].

The objectives of this action research project were 1) to work with students as partners (SaP) to understand the perceptions and expectations of students and supervisors of the UG research project 2) to understand the developing identity of UG research project students as researchers 3) with inclusivity and partnership in mind, to co-create research informed resources that are accessible, engaging and student-centred 4) to reflexively assess the benefits of participating in pedagogical research for the UG student co-researchers 5) to trial and evaluate a "making supervision work" resource with biomedical science supervisors and their students.

METHODOLOGY

This study is qualitative, participatory, small-scale pedagogical research. It is an interpretive project with a focus on understanding the subjective experience and process of UG biomedical science research. This action research project is sustainable and ongoing since 2016 with 4 phases undertaken in two key stages (**Figure 1**). Stage One involved initial data collection and resource development [14], and Stage Two involved further data collection and trial of the resource. The study was and continues to be informed by the concept of working in partnership with students [15] as change agents. In this study, UG students are involved in the scholarship of teaching and learning [16]. In working with UG students as equal partners, the project was participatory and aspects of the project design were co-designed with students. In Stage One, 3 UG student co-researchers were involved in all aspects; study design, methods, resource development and dissemination of the outputs. In Stage Two, 2 biomedical science UG project students collected further data on the experience of students using the questionnaire designed in Stage One (**Supplementary S1**). They also developed a supervisor student feedback sheet and collected narrative responses from students and supervisors on the resource developed in Stage One (**Supplementary S4**).

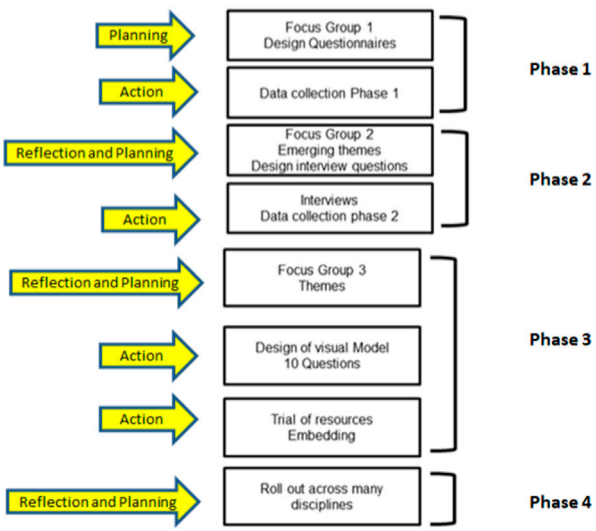

FIGURE 1 | Phases of this action research project. Stage One of the study followed three key phases incorporating UG student co-researcher training, question design, data collection and theme development [14]. Stage Two of the study has finalised phase 3 by trialling the resource in the programme of biomedical science and started phase 4 of rolling out the study into other disciplines.

In Stage One, 3 selected methods (questionnaires, semi-structured interviews and focus groups) were used [17]. Stage Two of the study utilised questionnaires only. Biomedical science UG students were co-researchers, collecting data for their own UG research project. We used the POWER framework described by Verwood and Smith (2020) to ensure all students felt empowered to fully contribute [18].

Stage One of the study followed three key phases incorporating UG student co-researcher training, question design, data collection and theme development [14].

Stage Two of the study has finalised phase 3 by trialling the resource in the programme of biomedical science and started phase 4 of rolling out the study into other disciplines.

Participants

Participants were identified through a combination of purposive and convenience sampling. In Stage One, all UG students n = 111 (44 Males, 67 Females) including the UG student co-researchers (n = 3) were enrolled on the final year 40 credit UG research project of the biomedical science programme at Northumbria University and were invited to participate in this study through questionnaire and interview (**Supplementary S1, S3**). All supervisory staff (n = 67) were invited to complete a questionnaire and then invited for a follow up interview (**Supplementary S2, S4**). In Stage Two, all UG students n = 158 (73 Males, 85 Females) were enrolled on the final year 40 credit UG biomedical science research project and were invited to participate in an interactive poll (**Supplementary S1**). All supervisory staff n = 67 and students n = 158 were invited to trial the resource and provide their qualitative perceptions via feedback questionnaire (**Supplementary S4**).

Recruitment was via a central email. There was no solicitation of volunteers. It was made clear that participation is voluntary and a full participant information sheet (PIS) was provided. The process of consent included opportunity for questions about the research to be raised.

Focus Groups

Focus groups were run both as an initial training exercise for the student co-researchers involved with the research and as a mechanism to work together to design questions and draw out themes from the data. For both Stage One and Two, focus groups ensured we worked as a collective research team in equal partnership for all aspects of the study. In Stage One, the detail of the methods and how they were implemented were co-designed with the 3 UG student co-researchers. In Stage Two, the focus groups enabled, the co-creation of the questionnaire to evaluate the resource (**Supplementary S4**).

Questionnaires

UG biomedical science students n = 52 (Stage One 46% response rate) and n = 79 (Stage Two 50% response rate) anonymously

completed a questionnaire containing 16 questions (**Supplementary S1**) as an interactive poll. Using a five point Likert scale, the student questionnaire provided students with the opportunity to reflect on and respond quantitatively about their perceptions and expectations of the UG research project alongside their researcher identity.

Supervisors n = 14 (20% response rate) were given a similar questionnaire in Stage One (**Supplementary S2**) via email which also incorporated opportunity for free text responses to qualitatively consider their supervision style, views on the benefit of research as well as exploring aspects of the student-supervisor partnership.

In Stage Two, supervisors n = 37 (55% response rate) and their UG biomedical science research project students n = 68 (43% response rate) trialled the resource and filled a questionnaire (**Supplementary S4**).

Interviews

The data from the questionnaires in Stage One enabled us to begin early theme development and to explore these themes via semi-structured interviews to encourage dialogue. Broad themes of confidence, independence and the importance of the supervisor-student partnership were identified in the questionnaire data. Interview questions were written with the 3 UG student co-researchers to explore these aspects further (**Supplementary S3**).

In Stage One, four supervisor (3 Males, 1 Female) and seven student (2 Males, 5 Females) interviews took place. All interviewees had previously filled in the questionnaire. The interviews were carried out by the 3 UG student co-researchers who emphasised a) that the process is appreciative, so they are to think about "what worked" and what would be "even better if," and, b) the purpose of the reflective activity is to appreciate their experience and insights.

Data Analysis

The data from both questionnaires and interviews were analysed and discussed in focus groups with the whole research team. Thematic analysis looked at the perceptions and experiences of supervision for both students and supervisors [14].

We used a mixed methods approach with elements of qualitative and quantitative methods [19]. Quantitative data focussed on median Likert scores whilst analysis of qualitative narratives from interviews and free text in questionnaire responses were used to evaluate the perceptions and expectations of both students and supervisors of the UG research project. Analysis of open-ended responses to interviews took a grounded approach. In addition to data in the form of transcripts of audio-recorded interviews, the project generated reflective and reflexive data. Transcripts were subject to basic coding analysis to generate themes for further reflection and group (academic staff and student co-researcher) discussion. This two-step analysis therefore built on initial themes. The interviews were analysed individually, informed by a phenomenological approach to qualitative data [14].

RESULTS

All polls and interviews show that supervisors and students consider the UG research project to be a valuable experience. However, they also showed that the diversity of supervisory styles is a source of student perceived inequality of experience for UG biomedical science research project students.

Selected questions from the Stage One questionnaires were compared for their median scores to see if there are areas where scores and comments align or show disparity (**Figure 2**). A complex picture emerged about the students' expectations for

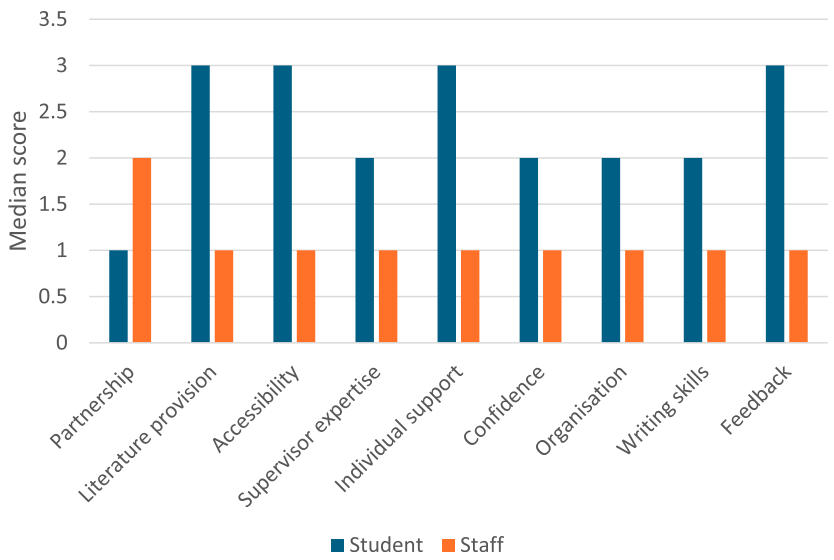

FIGURE 2 | Alignment of student and supervisor views in the Stage One poll. Perceptions and expectations of aspects of supervision for students (n = 52) and supervisors (n = 14) as ranked using the median scores of a Likert scale. 1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, 5 = strongly disagree. Data derived using questionnaire responses in Stage One. Questions 1–9 relate to each of the nine themes shown for students and supervisors (see **Supplementary S1, S2**).

their UG research project and the student-supervisor partnership in comparison to what the supervisors agreed to be important. Although student views were not fully consistent with supervisors (for literature provision, accessibility, individual support and feedback), there are some interesting areas of overlap with respect to partnership, staff expertise, student confidence, organisation and writing skills.

The global theme identified from the student data was that students feel strongly that the student-supervisor relationship influences their experience, satisfaction and success. Across all questionnaires in both Stage One and 2, >90% of students (versus <60% of staff) strongly agreed/agree that the student-supervisor partnership influences the success of their UG research project (Q1 **Supplementary S1, S2**, Stage Two student data shown in **Figure 3A**). Whilst none of the supervisors said they strongly disagreed with this statement 29% were neutral (n = 4, Q1 **Supplementary S2**). Strikingly, only 40% of students strongly agreed that they felt they had achieved a partnership with their supervisor in the Stage One questionnaires (n = 21, Q11 **Supplementary S1**, **Figure 3B**). Moreover, 15% of students strongly disagreed which indicates varied practice amongst supervisors (n = 7, **Figure 3B**). Interestingly, the median Likert score of three for students being able to build a strong partnership mirrored that of the staff belief about its importance (neutral, Q11 **Supplementary S1** and Q13 **Supplementary S2**). In Stage Two, the student interactive poll (**Figure 3C**) showed similar patterns to the poll in Stage One shown in **Figure 2**. Interestingly students were more favourable in rating individualised support with the median improving from 3 (neutral) to 2 (agree) (**Figure 3C**) and the percentage of students who strongly agreed that they had achieved a partnership rose to 53% (n = 42, **Figure 3D**) which may be positively influenced by the Stage Two small scale trial of the resource developed in Stage One. However, not all respondents to the Stage Two poll had trialled the resource (68 trialled the resource and 79/158 students answered the poll) and therefore a true quantitative measure using these scores for the impact of the resource is not able to be drawn.

The researcher identities of students had developed as a result of the UG research project experience (>70% strongly agreed/agreed across both questionnaires; Stage One, n = 40 and Stage Two, n = 61. Q6 **Supplementary S1**) and the majority of supervisors (>80%, n = 12) strongly agreed/agreed that students had grown in confidence, becoming more organised and independent (Q6, **Supplementary S2**). Similarly, >65% of students strongly agreed/agreed that they had become more organised and independent (n = 35, Q7, **Supplementary S1**). Greater than 50% of students disagreed or strongly disagreed that they were confidant before the project (n = 27, Q13, **Supplementary S1**) whilst >80% agreed the experience of undertaking research had increased their confidence (n = 46, Q14, **Supplementary S1**). However, perceptions around the

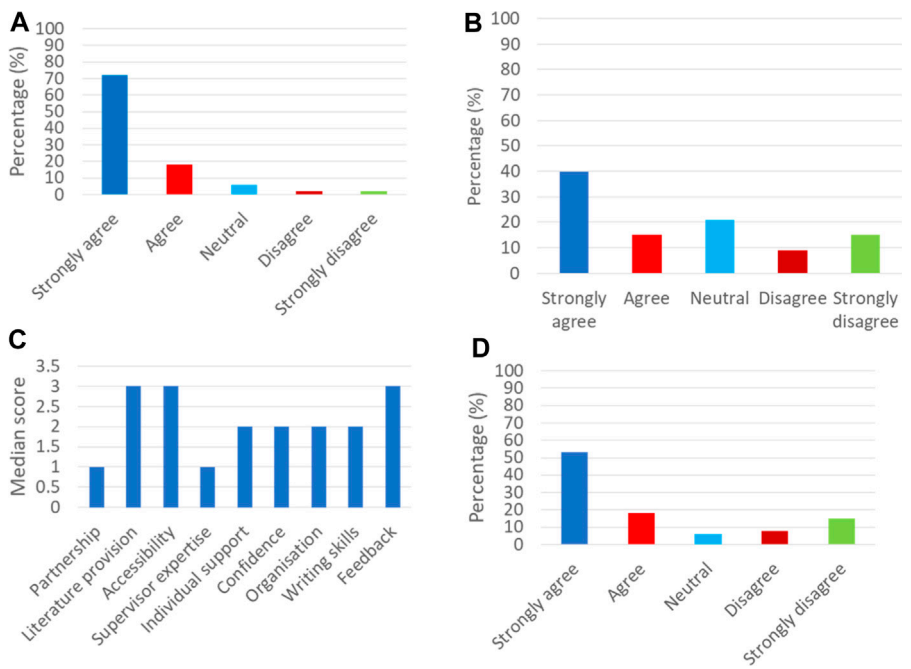

FIGURE 3 | Student perceptions of their project success. **(A)** Stage One poll (n = 52): Q1 90% students believe that the student-supervisor partnership strongly influences the success of their project. **(B)** Stage One poll (n = 52): Q11, only 40% of students strongly agreed that they were able to build a strong partnership with their supervisor. **(C)** Student poll Stage Two (n = 79). Perceptions and expectations of aspects of supervision for students as ranked using the median scores of a Likert scale. 1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, 5 = strongly disagree. Data derived using interactive poll responses in Stage Two. Questions 1–9 relate to each of the nine themes shown for students (see **Supplementary S1**). **(D)** Stage Two poll (n = 79): Q 11, 53% of students strongly agree they were able to build a strong partnership with their supervisor.

student-supervisor partnership were mixed, with supervisors not necessarily attributing the increase in student confidence and acquisition of skills to the development of a partnership, preferring to state that the process of the research was responsible for this increase (n = 4, Q13, **Supplementary S2**). More than 50% of supervisors were neutral or disagreed that they should be directive (n = 12, Q14, **Supplementary S2**) whilst 90% state that working independently is important (n = 13, Q11, **Supplementary S2**).

These findings were explored further in Stage One interviews with questions focussed on understanding what worked and what could have been done differently. Student and supervisor voice showed some similar ideas around the importance and perception of a partnership. Students commented that feeling they were working in a partnership helps build trust and the confidence to ask questions which in turn helped to make them feel more supported, driving their motivation.

> "Need to be able to have a good relationship to be able to ask questions and advice." (UG project student)

Moreover, others reported that a partnership with their supervisor promoted feelings of belonging and acceptance through approachability and respect that in turn drives independence.

> "I felt there was mutual respect and that my supervisor had confidence in me to allow me to work independently." (UG project student)

Staff views varied with some believing the partnership to not be relevant or adding the caveat that this is about raising awareness to the student that independence is expected.

> "The partnership is important as long as it's the student that owns the project." (supervisor)

Others take a more student-centred approach, believing their approach should be about what works for the individual student

> "It depends on the needs of each student—everyone is different." (supervisor)

Fostering independence is an important element of the UG research project and staff are keen to ensure that students are independent. Students commented during interviews that the reason they lacked confidence was because this was a new endeavour and that this led them to question their capability to conduct independent research. Issues for students included anxiety, isolation and lacking a clear structure.

> "Taking responsibility for my own learning creates uncertainty." (UG project student).
>
> "We were given instructions and left to work independently without constant supervision. At times this was scary." (UG project student)

Students commented that through partnership with their supervisor, these concerns could be allayed. Staff and students agree that the supervisor role changes as students move through project with staff discussing the need to strike a balance and scaffold their support:

> "It is important they try to think of solutions themselves. It is an autonomous module." (supervisor)
>
> "Some direction at the start of project is needed but after that the majority of direction should be self-direction." (supervisor)

The majority of the students interviewed said that the primary role of the supervisor is to give support. Whilst >80% of both students (n = 42) and supervisors (n = 14) strongly agreed/agreed in the Stage One poll that the member of staff were sufficiently skilled to guide the research (Q4 **Supplementary S1, S2**). Most comments from students were related to aspects of flexibility, approachability and support (**Figure 2**), highlighting the variety of approaches offered by different supervisors. The same trends were seen in the follow up student poll in Stage Two (**Figure 3C**). The ease with which students felt they could meet with their supervisor varied, with 25% of students across both Stage One and 2 polls strongly disagreeing that they were able to do this when required whilst staff believed they made efforts to be accessible to their students (**Figure 2** median Likert scores 3 neutral versus 1 strongly agree. Q3 **Supplementary S1, S2**). In addition, students reflected that a good student-supervisor relationship should ensure that individual preferences and needs are considered and supported accordingly. Greater than 50% (n = 9) of supervisors strongly agreed in the Stage One poll that they provide individualised support, whilst none disagreed (Q5 **Supplementary S2**). However, >40% of students (n = 23) in the Stage One poll were neutral or disagreed that their supervisor appreciated their individual needs (Q5 **Supplementary S1**) although this improved slightly in the Stage Two poll with 52% agreeing (n = 41). The attempt by supervisors at balancing provision of support to drive the move towards autonomy may result in students feeling less supported. The differences may also reflect the emphasis placed on the type of support.

Three organising themes were identified in the Stage One interviews; education support, practical support and emotional support. Narratives highlight that a difference in the type of support offered may account for the different perceptions of students and staff. Supervisors placed more emphasis on supporting practical and educational skills whilst many students spoke at length about emotional support.

> "My personal struggles impact my ability to do well at university. My supervisor was not interested in this which made the project hard." (UG project student)

Supervisors focussed ons skills development (including communication and time management skills) while students believe strongly that to ensure that a good working

relationship is developed, staff need to engage in emotional support. This will improve researcher confidence and help with stress.

> "I advised on their practical ability to help them gain the best mark possible." (supervisor)
>
> "I emailed protocols each week so that everything was planned ahead of time." (supervisor)

Interestingly, whilst supervisors focussed on skills, they were less inclined to support writing skills:

> "No, these are not research skills and should've been learned and developed at previous levels/modules and APPLIED in the project. Students need guidance on format and not writing skills." (supervisor)

In terms of practical support, students expressed frustration at the lack of communication and flexibility of their supervisor and differences between resources provided by supervisors. The provision of literature was one area where there was mixed practice which is perceived by students as a disparity that was driving their dissatisfaction.

> "My friend was provided with 5 key papers but my supervisor said that was not their role." (UG project student)
>
> "Providing a key paper only but must not give the students their literature search." (supervisor)
>
> "This is critical so they have an understanding of previous literature that underpins work." (supervisor)

Students felt that educational support is required to provide direction and motivation for the topic area. Although there is agreement that feedback is an important mechanism to drive learning and reflection in students, >30% of students across both the Stage One (n = 19) and Stage Two (n = 24) questionnaires disagreed that feedback was helpful or constructive (Median score 3, neutral. **Figures 2**, **3C**, Q9 **Supplementary S1**). In contrast, > 50% of staff strongly agree (n = 8) that they provide quality feedback (Median score 1, strongly agree. **Figure 2**, Q9 **Supplementary S2**).

> "Marking of drafts was integral on the feedback process along with discussion each week. On the occasion when students had not submitted drafts the report mark was affected." (supervisor)
>
> "Verbal feedback is an important part of the supervision meetings." (supervisor)

Perhaps students do not fully recognise the value of verbal discussions as feedback:

> "It is unfortunate that our conversations are poorly recalled by students during write up." (supervisor)

Students commented positively on the skills that they developed as a result of carrying out a piece of research and importantly >65% (n = 35) of students strongly agreed/agreed (>30% remained neutral or disagreed, n = 17) that they were more likely to choose research as a destination demonstrating a developing identity as a researcher (Stage One poll, Q15, **Supplementary S1**). Greater than 60% (n = 32) of students said they had improved their critical thinking and writing skills (Stage One poll, Q8, **Supplementary S1**).

> "I learned to critically evaluate sources and I have a much better understanding of how to arrive at a good piece of work" (UG project student)

However, some staff are focussed on the research outputs rather than the learning of the students:

> "The students should already have these skills." (supervisor)

Interestingly some staff commented that a good student-supervisor relationship as having an impact on the developing researcher identities of UG project research students whilst others felt it was the research process itself.

> "The working relationship is important so there are open and frank discussions between student and supervisor. This allows them to develop as researchers." (supervisor)

Resource Development—Parity Without Prescription

The first few meetings that a supervisor has with each student are therefore critical and can help to set the tone for the whole research experience. Supervisors were clear that they did not want resources that direct them to supervise in a prescriptive manner with 50% n = 7 voting neutral or disagreeing (Q10 **Supplementary S2**). Nevertheless, the perceived disparity in experience that students talk about means that there needs to be a mechanism whereby students feel they are receiving a parity of experience. The results have shown that this can be achieved by ensuring the following conditions are met:

- There should be an open discussion between each staff -student pair at the beginning of the project. This should contextualise the project and a discussion to agree how they will build a positive working partnership.
- Expectations of both student and supervisor should be clarified.
- Setting of realistic targets for each person throughout the project.
- Regular communication and flexibility with respect to resources (e.g., literature provision).
- Opportunities to ask questions should be provided.
- Ability for students to negotiate the style of supervision they receive.

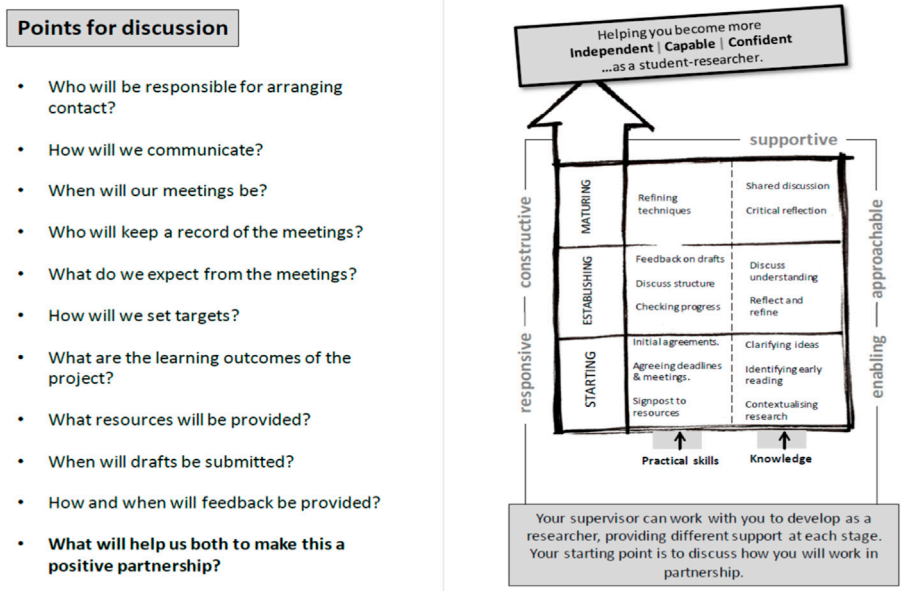

FIGURE 4 | Making supervision work resource developed in Stage One and trialled in Stage Two. 10 questions to discuss between each supervisor and student at an initial 1:1 meeting. Visual model highlighting types of support and the changing nature of supervision. Resource was co-developed as a research team with 3 UG students. Design by author Iain Robson [14].

With the 3 UG student co-researchers, we co-created a "making supervision work" resource in Stage One (**Figure 4**) to help support students and supervisors manage their expectations and ensure that the opportunities in the above wish list are provided.

Evaluation

The resource shown in **Figure 4** was evaluated in collaboration with 2 UG project researchers in Stage Two of the study. Feedback from supervisors and students was positive, highlighting that using the 10 questions alongside the visual model at the first meeting was mutually beneficial for all concerned and served to increase student confidence. An important finding was that 86% ($n = 59$) of students who trialled the resource commented that the points for discussion supported the development of the student supervisor partnership (Qs 6 and 7, **Supplementary S4**). Encouragingly, all supervisors with the exception of one said they would use the resource in future rounds of supervision (verbal feedback on collection of feedback sheets and follow up).

> "I believe I did so much better thanks to the ability to talk through the supervisory approach because I felt much less anxious." (UG project student Q7 **Supplementary S4**)
>
> "Being able to feel free to ask lots of questions has made me feel a lot less worried." (UG project student Q7 **Supplementary S4**)

Supervisors were able to take a student-centred approach:

> "Very valuable in clarifying roles and managing student expectations." (Supervisor Q5 **Supplementary S4**)

For other supervisors, it enabled them to support students to develop independence and ownership of the research while recognising that they need to build in some flexibility.

> "The exercise clarified the responsibilities of the students - that this was a piece of independent research work, and the role of the supervisor is to guide them through the journey rather than telling them what to do." (Supervisor Q2, **Supplementary S4**)

Supervisors commented that agreement on two particular questions ("Who will be responsible for arranging contact" and "Who will keep a record of meetings") will drive motivation and support the shift towards independence (Q3, **Supplementary S4**)

Benefits of Working in Partnership With Students as Partners

In the Stage One focus group 3, the 3 UG student project co-researchers were asked to reflexively consider the benefits of their involvement in this study.

Student co-researchers unanimously feel that they are more employable having developed/refined a range of desirable skills that they would not have developed through the course alone; including leadership skills, professionalism, communication skills and decision making skills.

> "Being able to work with staff and students as peers to carry out the project was greatly beneficial and increased confidence in my ability to research and communicate." (Stage One UG student project co-researcher)
>
> "I personally got a huge boost in confidence. It has given me an insight into working with other people on a professional manner which is a great thing to take away." (Stage One UG student project co-researcher)

Working in partnership gave students a sense of identity and improved their confidence.

> "Working with staff as an equal partner gave me confidence to think like a researcher." (Stage One UG student project co-researcher)

In Stage Two of the project, one of the UG project students who was also a co-researcher commented that they were able to rethink theoretical concepts and practical issues in ways they had not considered before.

> "As a biomedical science student, qualitative research is very new to me . . ..I have learned more research skills than I thought I ever would." (Stage Two, UG student project co-researcher)

DISCUSSION

Graduates in biomedical Sciences will develop the qualities of "professionalism, critical independent thought, and decision-making in complex and unpredictable circumstances" [3]. Jenkins and Healey argue "all UG students in all HE institutions should experience learning through and about research and inquiry" [20]. The UG research project is considered a journey towards independent thought achieved through a shift in focus from tutor-directed to self-directed learning. It needs to offer the best possible experience to students to ensure they are able to develop the skills set required to engage and progress into employment. Here, we describe our approach to working with students as partners (SaP) to develop resources that support the student-supervisor partnership to ensure we offer our biomedical science students an UG research project experience that is inclusive and harnesses differences. One that encourages "openness and participation so that everyone feels respected, supported and valued" [3] and moves away from considering the project as a purely research endeavour. As previously described [14], Healey, Flint and Harrington's conceptual framework helped us to locate our research as "co-researching and co-inquiring," somewhere in the overlap between "subject based research" and "scholarship of learning and teaching" [15]. This study investigated the inclusion of students in subject-based inquiry, as well as the scholarship of teaching and learning where students engage in pedagogical research. Therefore, students were not only involved in carrying out research towards their final UG research project, but engaged alongside staff in pedagogical research into the student research experience. All students involved as co-researchers throughout both stages of the project felt they had developed important skills that enhance their employability. Working in partnership with staff has gained recognition in HE, recently being described as a "powerful approach to enhancing the quality of education and fostering more engaging and inclusive learning environments" [21]. We found that actively including students as co-researchers and developers in this study drove positive learning experiences and a sense of developing professionalism for the students whilst staff benefitted from discussion with those that the research was directly impacting. In doing so, student researchers not only brought newer ideas that had not been previously considered but were also able to garner richer more honest feedback from their peers that in turn supported the development and evaluation of an inclusive and equitable resource.

This study built on previous work [14], further demonstrating that there are differing expectations between students and staff and this drives dissatisfaction amongst students particularly as the supervision approaches vary. Each supervision is unique and is affected by a number of factors including the student -supervisor relationship. This study has highlighted that the approaches and views of supervisors can vary greatly. Moreover, negotiation, motivation, ability to ask questions, skills development, communication and the changing nature of supervision over time were all concerns of both supervisors and students.

Many of the supervisors interviewed said that supervision is one of their most enjoyable but challenging aspects of their role, citing the development of students into independent researchers as a significant achievement. Particular benefits of the UG research project include the promotion of critical thinking, increased confidence and the intention to pursue post-graduate research [22]. For UG biomedical science students there is also the benefit of developing key laboratory skills as well as their analytical skills. In this study, UG biomedical science research project students reported that they also learned many general skills not necessarily all science based to include literature searching and referencing skills. Supervision approaches can vary considerably which may impact the student experience. Research projects undertaken by students on our biomedical science programme are diverse involving mainly wet lab projects but also dry projects including bioinformatics and systematic reviews. All projects require 120 h of research and analysis and although this data is not available for this study, it would be interesting to investigate whether the type of project influences student satisfaction and success. Both students and supervisors recognised the value of the individual supervisor for their knowledge and expertise. Students and supervisors also agreed that students grow in confidence and were able to develop skills including writing and organisation. Although supervisors were focused on ensuring students developed excellent practical skills through a range of approaches, supervisors were less willing to provide emotional support, perhaps because they feel they lack

the expertise or they do not consider this to be part of their role. Providing a mechanism (**Figure 4**) where supervisors and students can openly discuss this aspect of supervision is therefore very valuable even if it means supervisors choose to refer students for further support elsewhere. Moreover, the resource helps to define the respective roles of the student and supervisor, helping to drive independence and a researcher identity in UG biomedical science students.

As a starting point—the use of the resource (**Figure 4**) enables each student-supervisor pair to have a discussion at the start of the project. The 10 questions serve as prompts to help focus the discussion. The key issue is that students feel they can raise any concerns and ask questions. The answers are personal to each supervisor/student pair but the use of a standard set of questions provides parity, clarity and structure. The visual model highlights the changes in power as the project progresses from the supervisor as tutor through mentor through to peer. It also enables a discussion that explores the types of support that will be provided. This is especially useful where there is a variety in approach amongst supervisors/mismatches in expectations between student and supervisor (e.g., provision of literature). An open discussion allows each person to explain their viewpoints and enable an understanding to be reached for each student supervisee pair rather than a broad set of directives that staff may see as too directive.

Our findings show that the challenge is to strike a balance in the level of support provided in order to support a move towards independence. This can be difficult to do and many supervisors grapple with the need to support their students whilst also leaving them to puzzle concepts for themselves [23]. Del Rio et al explored this more recently and their findings are in line with ours, suggesting that supervision involves a complex interaction between autonomy and support [24]. In our study, a lack of accessibility was frequently cited by students as a factor that drives dissatisfaction along with being left too much on their own. Yet, students also acknowledged that being left to think through problems for themselves drove their independence.

> "At times I felt really alone . . .looking back—I learned a lot during those uncertain times." (student)

Walkington (2015) conceptualised five successive levels of student involvement in their research project which were adapted to incorporate 10 dimensions of effective UG research supervision; focus, motivation, inclusivity, setting collaboration, originality, content, audience, compensation and staff-student relationship [25,26]. Each of these represents a continuum and our research across multiple years of biomedical science students shows that partnership (one end of the continuum) is preferred by students and viewed as highly beneficial, driving confidence, independence and a researcher identity as well as alleviating feelings of anxiety and uncertainty.

In this study, we have brought together multiple pedagogical frameworks - pedagogy of employability, pedagogy of the UG research project and pedagogy of SaP [1, 7, 25, 27]. We worked in equal partnership with UG biomedical science students to uncover the expectations and perceptions of students and supervisors. We used the results to develop the following outputs that seek to support the research journey and drive the development of graduate attributes of biomedical science students:

- Evidence for the importance of the student–supervisor partnership in driving confidence and researcher identity.

The importance of the student—supervisor partnership in developing a "student-researcher" pedagogy is significant as it shifts the role of the staff member as knowledge provider to that of co-inquirer, facilitating students to become experts in their research area.

- A resource to support the supervision process and aid the development of a partnership (**Figure 4**). This includes a visual model of how the student supervisor partnership changes over time and 10 questions to support discussions between each student–supervisor pair.

Feedback demonstrated that the resources can act as a framework to help reduce the disparity and therefore discontent felt by students as a result of perceived differences in approach taken by supervisors.

- Evidence that inclusion of students as equal partners in pedagogic research as co-enquirers and co-creators enables the development of richer more authentic resources to support the curriculum.
- Evidence that student co-researchers benefit by further developing their employability and graduate attributes.

Supervisory styles are often described as a spectrum from laissez-faire to authoritarian, with no one style fitting every situation. Supervisors should adapt their approach to accommodate the student and the stage of the research project. Moreover, this study has highlighted the importance of striking a balance between a "research focus" and a "student development focus." Therefore, the context in which the research is taking place is important in determining the approach to take at a given stage. Our research highlighted the most effective practices of supervisors to be; responding to students' needs and abilities throughout the research process, setting clear expectations, teaching the methods for the discipline, balancing emotional support with expectations and supporting students to take ownership of the research. Our model (**Figure 4**) highlights the changing nature of supervision over the course of the research project and encourages supervisors to reflect on their personal style and to further consider what would work for each supervisee pair. The findings in this study agree with Del Rio et al, who concluded that the role of the supervisor should be clarified beforehand as well as consideration of the skills to be developed and the supervisor's position on the support that will be provided [24].

Study Limitations

There are limitations to the approach taken including power relationships, the motivation of students to get involved, their ability and the research has been limited to one department. The numbers of students and staff who gave their views were unequal

BOX 1 | Advice for Biomedical Science Supervisors Who Wish to Adopt the Resources.

- The supervision process cannot be a prescriptive one.
- Working with students as partners (SaP) provides a robust real world application where the research activity responds directly to the needs of the participants. Consider working with students to refine the resource for your course.
- Use the resource in the first meeting between each supervisor-student pair to facilitate discussion and uncover expectations.
- The student supervisor relationship is very important and this can be developed easily by clarifying expectations for each person throughout the project. Are there other questions that you might discuss?
- Consider having students share the agreed answers to the questions and have both student and supervisor sign this.
- Encourage students to develop their metacognition by building in key points to reflect on their research using the model and refine the supervision approach if necessary.

The resource in **Figure 4** is flexible and can be adapted for use in other programmes.

and staff views were only obtained in a poll in Stage One and not Stage Two. This makes some comparisons and therefore quantitative evaluation of the impact of the resource difficult. However, the aim was to develop resources through the process of action research. Qualitative feedback from both staff and students presented in this manuscript has been very positive and the leaflet and 10 questions therefore serve as a starting point for individual departments who can then decide how to build on these findings.

CONCLUSION

This study sought to support the pedagogy of the UG research project for UG biomedical science students by uncovering the perceptions and expectations of both supervisors and students through a student as partners approach. In this study, we worked in collaboration to support the biomedical science UG research project students and supervisors by co-creating resources that are inclusive and student-centred. Supervisors indicated that approaches to explicitly guide their supervision was not favoured and would be resisted (Q10, **Supplementary S2**). The model and discussion points are simple whilst being non-prescriptive and can be easily adapted to the needs of different programmes (**Box 1**). When embedded into the programme, they represent a mechanism to support the pedagogy of employability. We believe that this scalable project will support the practice of future project students and supervisors through the development of graduates that are distinguished by their intellectual expertise and employability. Moreover, the inclusion of students as co-researchers and co-developers enables the development of resources that are inclusive and equitable as well as supporting the employability of those students.

SUMMARY TABLE

What Is Known About This Subject

- The biomedical science UG research project is an important high stakes assessment.
- QAA subject benchmark: a commitment inclusive practices for diverse student cohorts through considered course design.
- QAA subject benchmark: Student voice should play a significant role in the student experience within Biomedical Science.

What This Paper Adds

- Evidence based recommendations to enable staff to build on their supervision style.
- The co-created model and discussion points are simple yet non-prescriptive and can be easily adapted.
- Benefits of including students as equal partners in pedagogic research for the development of graduate attributes.

CONCLUDING STATEMENT

This work represents an advance in biomedical science because the ability to carry out independent research and develop a researcher identity promotes the development of key skills that are essential for future employment.

DATA AVAILABILITY STATEMENT

The data presented in this article are not all readily available as per our ethics approval. Requests to access the datasets should be directed to s.veuger@northumbria.ac.uk.

ETHICS STATEMENT

The studies involving humans were approved by the Northumbria University Ethics review. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SV conceived, conducted the study, collected and analysed the data, and wrote the manuscript. LC conceived the study, contributed to the development of the study and development of the study themes. HC conducted the study, collected the data, contributed to the development of study themes. SG conducted the study, collected the data, contributed to the development of study themes. SR contributed to the writing of the manuscript. MR conducted the study, collected the data, contributed to the development of study themes. IR conceived the study, designed the resources, contributed to the development of the study and development of the study themes. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2024.12215/full#supplementary-material

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ORIGINAL RESEARCH
published: 24 May 2024
doi: 10.3389/bjbs.2024.12229

Embedding Assessment Literacy Can Enhance Graduate Attribute Development in a Biomedical Sciences Curriculum

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This paper describes the successful implementation of an assessment literacy strategy within a Biomedical Sciences degree. Teaching was aligned with an assessment literacy framework and aimed to prepare undergraduates for a literature comprehension assessment. Students were introduced to the assessment purpose and an adapted Miller's pyramid model illustrated how the assessment contributed to competency development during their degree. Students read primary research papers and answered questions relating to the publications. They were then introduced to the processes of assessment and collaboratively graded answers of different standards. Finally, student and faculty grades were compared, differences considered, and key characteristics of answers discussed. Most students reported that they understood more about assessment standards than prior to the intervention [139/159 (87.4%)] and felt it had helped prepare them for their exam [138/159 (86.8%)]. The majority also reported they had increased confidence in evaluating data [118/159 (74%)], communicating their reasoning [113/159 (71%)] and considering what a reader needs to know [127/159 (79.9%)]. Students were asked to state the most important thing they had learned from the assessment literacy teaching. Notably, no responses referred to domain-specific knowledge. 129 free text responses were mapped to the University of Edinburgh graduate attribute framework. 93 (72%) statements mapped to the graduate attribute category "Research and Enquiry," 66 (51.16%) mapped to "Communication" and 21 (16.27%) mapped to "Personal and Intellectual Autonomy." To explore any longer-term impact of the assessment literacy teaching, a focus group was held with students from the same cohort, 2 years after the original intervention. Themes from this part of the study included that teaching had provided insights into standards and expectations for the assessment and the benefits of domain specific knowledge. A variety of aspects related to graduate attributes were also identified. Here, assessment literacy as a vehicle for graduate attribute development was an unexpected outcome. We propose that by explicitly engaging students with purpose, process, standards, and expectations, assessment

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Received: *13 October 2023*
Accepted: *10 May 2024*
Published: *24 May 2024*

Citation:
Robertson KA, Hughes KJ and Rhind SM (2024) Embedding Assessment Literacy Can Enhance Graduate Attribute Development in a Biomedical Sciences Curriculum. Br J Biomed Sci 81:12229. doi: 10.3389/bjbs.2024.12229

literacy strategies may be used to successfully raise awareness of developmental progression, and enhance skills, aptitudes, and dispositions beneficial to Biomedical Sciences academic achievement *and* life after university.

Keywords: assessment literacy, graduate attributes, biomedical sciences, feedback, peer assessment

INTRODUCTION

Undergraduate Biomedical Sciences (BMS) degree programmes typically provide an interdisciplinary context in which learning about the science underpinning human health and disease is enabled [1]. Importantly, alongside domain-specific learning, it is now widely accepted that higher education should prepare graduates for work and life after their formal studies [2]. In this regard, BMS degrees are no different to any other. Over the past two decades, increasing numbers of fee-paying students, with broad career aspirations, and often significant debt, have created demand for the development of employability during a first degree [2, 3]. BMS programme developers have responded to this in a variety of ways. Examples include the placement of students with employers, the delivery of employability workshops and/or an increased emphasis on integrating opportunities to enhance competency development and graduate attributes within curricula [4–6]. Generic graduate attributes include, for example, competency in reflective practice, communication with diverse audiences, complex problem solving, assessing the performance of self and others, an inclusive and open attitude to engaging with others and intellectual autonomy [7, 8]. A consequence of approaches targeted at integrating domain-specific and generic competencies can be curriculum complexity. This can make it challenging for students to navigate and understand their developmental progression.

Confidence in reading, analysing, interpreting, presenting, and using primary evidence to learn, develop hypotheses, solve problems, and enable decision-making (i.e., "literature comprehension") is integral to all research practice. It is also a health and care professions council (HCPC) requirement for Biomedical Scientists and is key to many graduate careers [9]. Competency in literature comprehension is, therefore, considered a core graduate attribute for all BMS graduates. At the University of Edinburgh (UoE), the BMS Literature Comprehension assessment (LCA) serves as an introduction for a diverse cohort of several hundred 2nd year undergraduates per year to the critical analysis of primary research. At this early stage, it is intended to facilitate the transition of students into their degree (and enhance inclusivity) by (a) clarifying expectations on how practising scientists analyse and use primary research material and (b) delivering a common understanding of standards and expectations prior to summative testing [10].

Since its inception in the early 2000s, the LCA has involved two formative tutorials and an open-book exam. Across the teaching and assessment, students analyse multiple primary research papers in-depth. By responding to short answer questions related to these papers, it is hoped participants can develop their approach to analysing primary evidence and communicating their own interpretations in a concise, logical manner. Before students attempt the summative assessment, they have extensive opportunities to develop their learning—key to both assessment *for* learning and inclusivity [10, 11]. The literature comprehension assessment is not a test of memory, rather it presents an authentic challenge relevant to careers in BMS. In this regard, it serves to develop several attributes considered key by the Institute of Biomedical Science (IBMS). For example, questions require that students explain their rationale and use data to support conclusions. As such, the assessment establishes a foundation for biomedical competencies such as the communication of research findings using appropriate scientific language [1]. End of course feedback from students has described the LCA as *"challenging yet rewarding"* and an opportunity to *"feel like a scientist."* Importantly, integrated within the domain-specific teaching of the LCA are also opportunities for students to develop (a) a general framework for thinking about evidence and (b) how they communicate to different audiences—both crucial to graduate attributes such as a capacity for critical/analytical thinking and ability to communicate in a variety of contexts [1].

Prior to 2019, the LCA was delivered at the UoE as shown in **Figure 1A**. At this time, a course review identified a range of issues related to teaching and assessment that needed to be addressed. These were (a) uncertainty in the student cohort regarding the purpose of the exercise (b) a tutor-focused teaching approach leading to inconsistent engagement of students in tutorials (c) inconsistent student communication of thinking and rationale in exams (d) inconsistent use of data/evidence to support answers in exams and (e) students regularly reporting that they felt, "*the exam was much harder than the tutorial exercises.*" To address these issues, an intervention focused on assessment literacy was identified as a potential solution.

The concept and benefits of assessment literacy have been widely discussed [12–16]. In this regard, a recent review has comprehensively defined a conceptualisation defining domains and dispositions required by students to engage with assessment in an effective manner [16]. In brief, an assessment literate individual has the knowledge, attributes, and skills to "actively engage in assessment, monitor their learning, engage in reflective practice, and develop effective skills, to improve their learning and performance outcomes" (**Figure 2**) [16]. Further, they will understand how assessments contribute to learning and progression, how assessments are undertaken and can use criteria for self or peer assessment. Given this understanding, an assessment literate student will be able to use an appropriate, relevant method for any given assessment task [13]. Crucially, an absence of assessment literacy can impede an individual's capacity to learn and, if

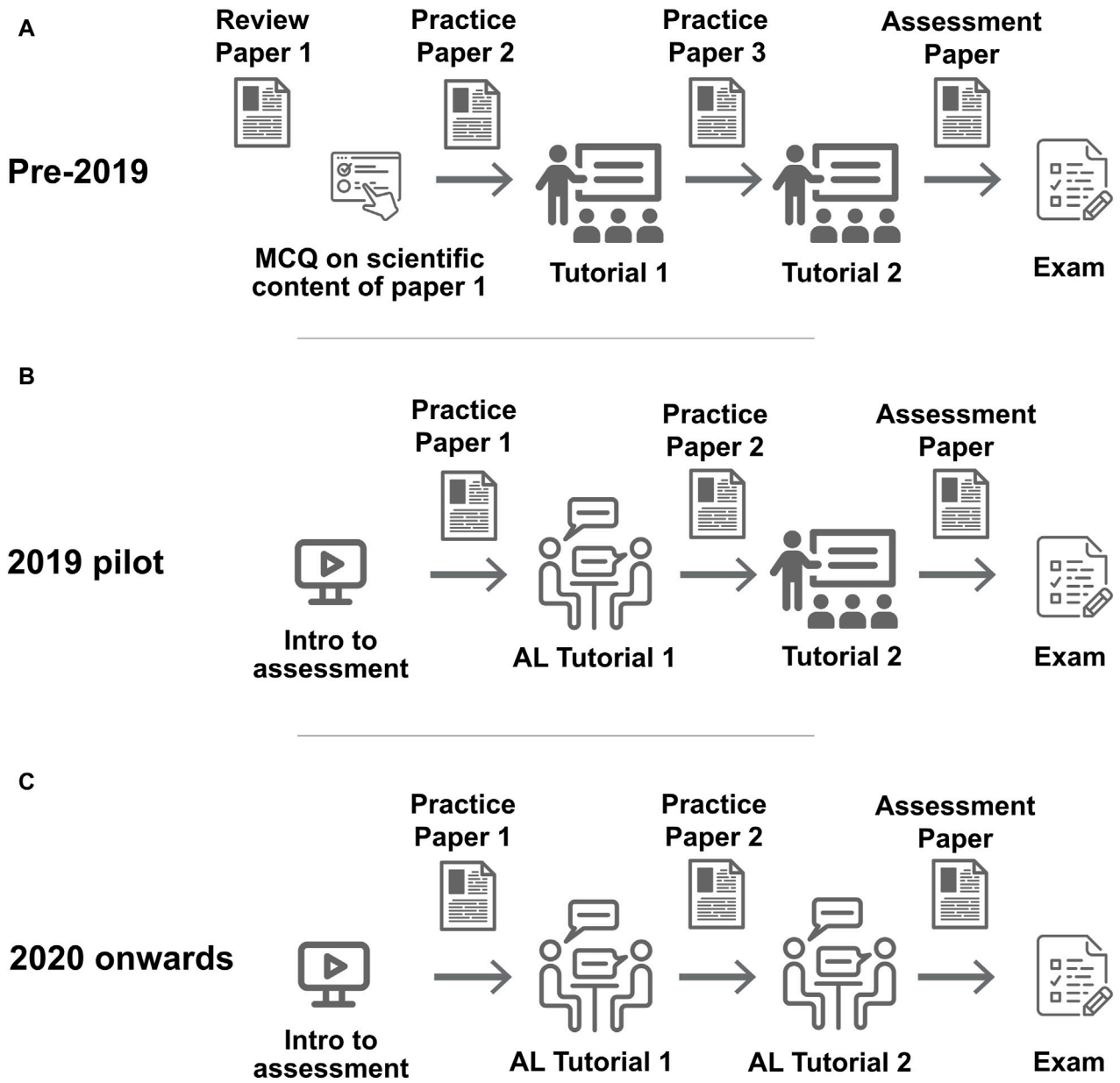

FIGURE 1 | Delivery of literature comprehension teaching before and after the assessment literacy intervention. **(A)** Literature comprehension teaching prior to the assessment literacy intervention. Students engaged with scientific material in Review paper 1 by reading the publication and answering online multiple-choice questions focused on the scientific content of the review. Students then participated in two teacher-led tutorials intended to prepare them for a subsequent assessment paper. Students read a paper then answered questions prior to each session. In the sessions, tutors would lead students through the study and endeavour to generate discussion by, for example, asking students to share their answers. **(B)** Pilot assessment literacy-based literature comprehension intervention. A brief online recorded presentation replaced the first review paper activity and introduces students to the teaching approach and purpose of the assessment. Prior to tutorial 1, students read a primary research paper and answer questions related to the publication. In a revised tutorial 1, students work collaboratively to grade authentic answers with the assessment marking scheme. After grading, group marks are compared with those assigned by faculty. To conclude, tutors and students discuss the question "What makes a good answer?". Tutors then review answers of different standards, facilitate a discussion on key features that are rewarded and discuss the scientific content of the paper. Tutorial 2 is delivered as in previous years. **(C)** The assessment literacy-based teaching described for tutorial 1 above is implemented in both tutorials.

assessment literacy is not promoted, it can limit inclusivity, equity and participation in higher education [15].

In 2015, an assessment literacy intervention was used to enhance veterinary undergraduate teaching at the UoE [13]. In this intervention, the use of Miller's pyramid helped promote a common understanding (in teachers *and* students) of curriculum progression and, importantly, how a given specific assessment functioned within the curriculum. Miller's pyramid has been widely used as a model for assessing levels of clinical competence [17, 18]. In the pyramid, cognitive levels "knowledge" ("Knows")

FIGURE 2 | Characteristics of an assessment literate individual.

and "application of knowledge" ("Knows how") function as a foundation for a subsequent "practical application of knowledge" ("Shows how") which in turn supports "Does"—representing (graduate) practitioner competence. Notably, the 2015 intervention required that students evaluate authentic work of differing quality and discuss attributes that are valued by learners and staff. This resulted in a better understanding of standards, and helped students prepare for a subsequent assessment [13, 18]. Given the success of this assessment literacy intervention, a novel Assessment Literacy Pyramid (ALP) designed to support student assessment of their own and peer performance at all levels of a developmental programme has subsequently been developed [18].

The primary aim of this study was to evaluate assessment literacy as a unifying concept and practical approach to enhance literature comprehension in the context of a BMS curriculum. Specifically, the objective was to explore whether assessment literacy could; clarify for students why an assessment was being used, clarify expectations regarding assessment criteria, answer questions, address past criticisms, improve engagement in, and inclusivity of, teaching sessions, enhance student capacity for self-evaluation and, ultimately, make the assessment less intimidating. As part of this work, we aimed to develop a BMS competency pyramid to enhance communication of curriculum opportunities and progression to our students.

METHODS

Teaching Context

This study was undertaken with students in the 2nd year (Scottish Credit and Qualifications Framework Level 8) of a 4-year non IBMS accredited BMS degree programme. The literature comprehension assessment was a component of a single semester compulsory course focused on the fundamentals of infection and immunity (Learning outcomes presented in **Supplementary Table S1**). Students were required to pass all components (exam, essay, and literature comprehension assessment) of the course to progress to the next academic year. As per standard UoE practice, a range of adjustments were provided to students according to individualised profiles developed by the student and the university Disability and Learning Support Service (DLSS). Adjustments included, for example, extra time for submission of the assessment and the provision of time for students to use proof-reading services. Additionally, for use with screen readers and to enable reformatting, accessible versions of primary research papers (converted to plain HTML, with ALT tag descriptions of data and validated by staff in the DLSS) were available.

Prior to and including 2018, teaching related to the literature comprehension assessment was as shown in **Figure 1A**. In brief, all students read three papers (one per week over a 3-week period) prior to undertaking their assessment. After reading review paper 1, students answered online multiple-choice questions related to the scientific detail of the study. For papers 2 and 3, students read the primary research publications and then answered short-answer questions related to the paper. They then attended tutor-driven teaching sessions in which staff led students through the paper, and students were invited to discuss and report back on their answers. Students were provided with a primary research paper 1 week before their exam. For the 90-min exam, students were permitted to use an annotated copy of the paper to help them answer 12 to 14 short answer questions of a similar style to those they had previously encountered in the formative work.

Assessment Literacy Intervention

To test whether an assessment literacy-based teaching approach could address the issues encountered prior to 2019 (detailed in the introduction), a phased assessment literacy intervention was

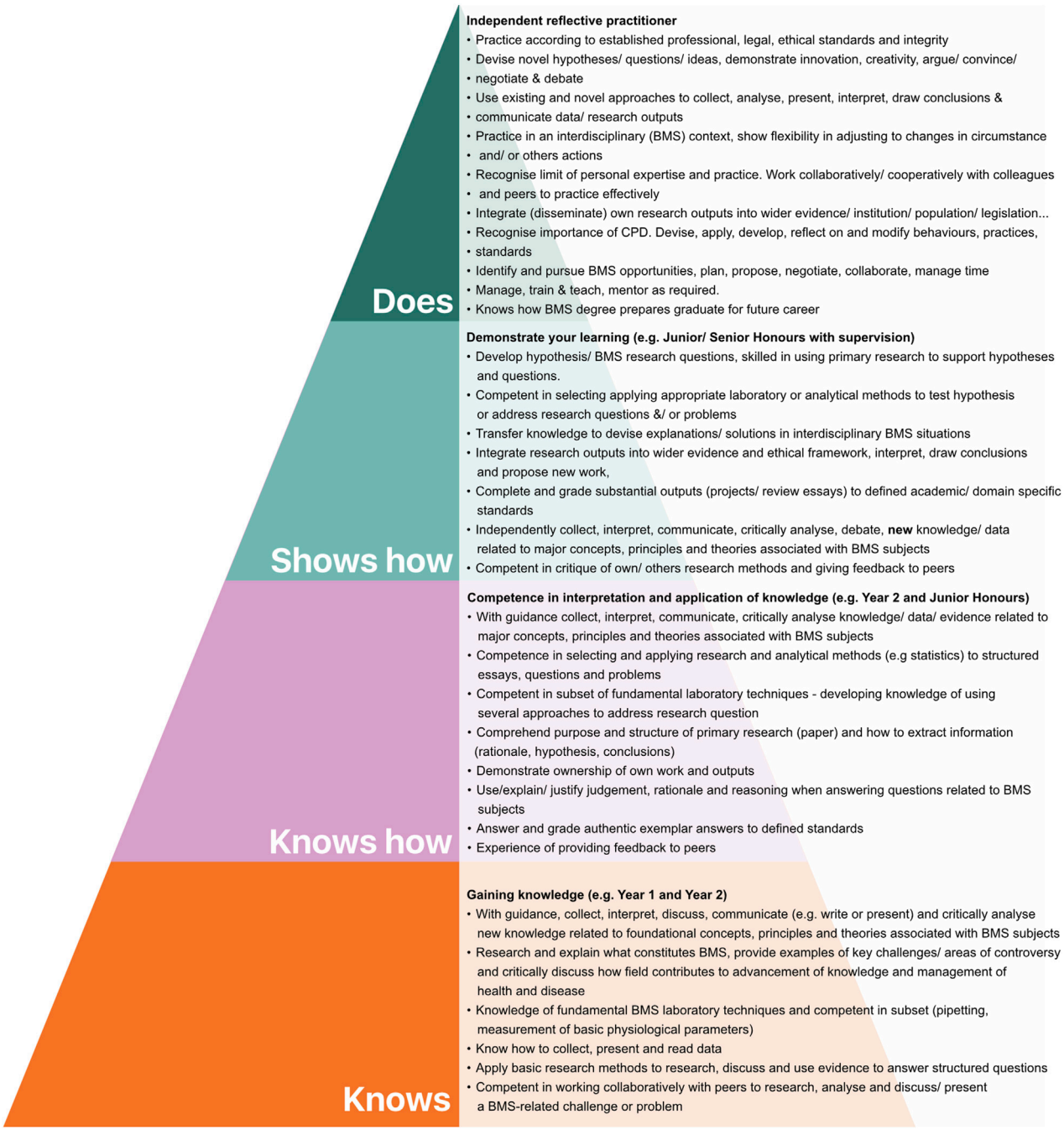

FIGURE 3 | Biomedical Sciences: Undergraduate to Practitioner Competency Pyramid. Using Miller's pyramid as a framework, the UoE degree finder (2022-2023) and the Subject Benchmark Statement for Biomedical Scientists (2019) were used to identify and map competency development from degree entry to reflective practitioner.

designed based on previous work [13]. The development of this intervention is presented in **Figures 1B, C**.

Phase 1 of Intervention (2019)

In phase 1 of the intervention (**Figure 1B**), Review paper 1 and the associated MCQ were replaced with a brief pre-recorded presentation (available in **Supplementary Material**) designed to introduce the purpose of the assessment and address questions often asked about the teaching material. Notably, as part of this intervention, a BMS competency pyramid (based on Miller's pyramid) was developed to help convey and define the function of the assessment in the BMS curriculum. In recent years, Miller's pyramid (and adaptations of the model) have been successfully used as an integral component of

TABLE 1 | Positive impact of assessment literacy intervention on student confidence in literature comprehension assessment. Year 2 Biomedical Sciences students who had completed the literature comprehension assessment tutorials in 2020 were asked to respond to nine statements related to their understanding of assessment and the outcomes of the assessment literacy tutorial teaching. Table shows 159 responses recorded using a Likert scale as follows: Strongly Disagree (SD), Disagree (D), No Strong Feelings (NSF), Agree (A), Strongly Agree (SA), Not Applicable (N/A).

Question	SD	D	NSF	A	SA	N/A	Total
I have a good understanding of how my assessments have been marked up to this point in my degree	1	14	32	78	33	1	159
I don't think it is necessary to understand how our assessments are marked	126	21	5	4	2	1	159
The Literature Comprehension tutorials helped me understand more about different standards in assessment	0	0	18	65	74	2	159
The Literature Comprehension tutorials helped me understand how to prepare for the literature comprehension exam	1	1	17	69	69	2	159
The Literature Comprehension Tutorials helped me feel more confident in communicating my scientific interpretation and reasoning	1	9	34	77	36	2	159
The Literature Comprehension Tutorials have made me consider what a reader needs to know	0	8	22	69	58	2	159
The Literature Comprehension Tutorials have helped me understand how to evaluate and use data to support my interpretation	1	5	33	76	42	2	159
I enjoyed the literature comprehension tutorials	3	7	36	83	28	2	159
I would like similar tutorials in my other courses	2	16	21	63	55	2	159

assessment literacy interventions [13, 18]. In this context, it can show students (a) where they are in their competency development and (b) what function the assessment literacy intervention will play in their development of new competencies. It was hoped the BMS competency pyramid would serve as a useful tool for representing the bridge between academic degree learning and graduate practice. To build a pyramid model with a BMS focus, two main resources were used to identify desirable competencies for each level. Firstly, the UoE degree finder was used to define year-on-year development of BMS knowledge, skills and attributes. Alongside this, desirable competencies drawn from the Subject Benchmark Statement for BMS were also integrated into the pyramid model at all levels [19]. **Supplementary Figure S1** illustrates how early stages of the BMS model evolved from Miller's pyramid to the integration of a preliminary subset of attributes and competencies broadly related to literature comprehension. The current BMS competency pyramid is presented in **Figure 3**.

The first tutor-led teaching session was also adjusted in phase 1 (2019) of our assessment literacy intervention (**Figure 1B**). In the new tutorial, students were introduced to the processes of assessment and the benefits of the assessment to competency development were discussed. Most importantly, students then worked together to grade authentic answers of different standards from previous years. To conclude, student grades were collated and compared with those of faculty and exemplar answers were analysed and discussed to identify characteristics that were rewarded during the marking process. A representative example of a question, analysis of student responses and marking criteria are presented in the **Supplementary Material** (**Supplementary Figure S2**). Following the 2019 pilot intervention, feedback on revised teaching was gathered as part of the standard deanery-wide end of course survey. In this survey, all students were invited to complete an electronic feedback form that included eight tutorial-focused Likert scale questions and a free text question in which respondents were asked to provide comments on the tutorial teaching and associated assessment (**Supplementary Table S2**).

Phase 2 of Intervention (2020)

In 2020, all LCA teaching was migrated to the assessment literacy-based approach (**Figure 1C**). All students were provided with an introductory presentation followed by two tutorials in which they graded authentic answers using a marking scheme, compared marks with those of faculty and discussed desirable features of an answer (as described above). To analyse the effects of our 2020 teaching (completed before disruption due to the COVID pandemic), a short paper-based survey was distributed to 186 students at the conclusion of tutorial 2. This questionnaire was intended to explore student expectations and understanding of assessment and whether students felt prepared for the literature comprehension test. Notably, this survey was also used to analyse student opinions on the importance of graduate attribute development and their awareness of how and when they are developing graduate attributes. Survey questions are presented in **Tables 1**, **2**. Students were presented with 12 statements about assessment or graduate attributes and asked to indicate their level of agreement with these statements on a 5-point Likert scale from strongly disagree to strongly agree. Responses to 2 free text questions were also captured. Free text questions asked students to (a) "give examples of graduate attributes you think you have already developed as part of your studies at the University of Edinburgh?" And (b) "state the most important thing you learned from the literature comprehension tutorials."

Assessment Literacy Intervention: Data Collection, Processing, and Analysis

Student and Faculty Grading Data

Grades awarded by students to each of five questions were recorded in eight tutorials undertaken in 2020. To explore the accuracy of student grading in relation to the faculty grade, student bias was calculated as an average of the difference between each student grade and the recorded faculty grade for each question. The percentage bias as a function of the actual grade for each question was then calculated. This provides a measure of how the mean of the student grades relates to the faculty grade. The root mean square error (RMSE) was also

TABLE 2 | The development of graduate attributes is highly valued by undergraduates. Year 2 Biomedical Sciences students who had completed the literature comprehension assessment tutorials in 2020 were asked to respond to three statements related to graduate attribute development in their degree. Table presents data from 159 responses recorded using a Likert scale as follows: Strongly disagree (SD), Disagree (D), No Strong Feelings (NSF), Agree (A), Strongly Agree (SA), Not Applicable (N/A).

Statement	SD	D	NSF	A	SA	N/A	Total
The development of graduate attributes is an important part of my degree	0	0	12	59	88	0	159
I know when teaching activities are contributing to the development of my graduate attributes	4	9	49	72	25	0	159
I don't think it is important for me to understand how graduate attributes are developed	86	57	8	6	2	0	159

calculated to reflect the variation of student grades around the faculty grade (i.e., it provides a descriptive evaluation of the differences between the faculty grade and the student grades).

Assessment Literacy Questionnaire Data Processing and Analysis

Likert scale data from 159/186 questionnaires returned (85% response rate) in 2020 were compiled and, for each question, the total number of responses for each of the 5 options [strongly disagree (SD), disagree (D), no strong feelings (NSF), agree (A) or strongly agree (SA)] was calculated and tabulated.

Analysis of Free Text Responses to Graduate Attribute Development and Learning

Free text responses to the questions (a) "give examples of graduate attributes you think you have already developed as part of your studies at the University of Edinburgh?" And (b) "state the most important thing you learned from the literature comprehension tutorials" were mapped to UoE graduate attributes [19]. In brief, 115 free text responses to the question "Can you give examples of graduate attributes you think you have already developed as part of your studies at the University of Edinburgh?" were compiled. Each of the responses was then classified according to whether they represented "Mindset" and/or a "Skill Group" as defined in the UoE framework for graduate attributes (summarised in **Supplementary Figure S3**) [19]. Where possible, each response was further classified according to one or more sub skill groups (e.g., Research and Enquiry [Analytical Thinking]). Classifications were not mutually exclusive, and one statement could be assigned several headings. During this process, 18 responses were excluded from further analysis where the meaning of the written response was unclear/ambiguous (**Supplementary Table S3**).

129 free text responses to the question "state the most important thing you learned from the literature comprehension tutorials" were analysed in an identical manner to that described above. During this process, 13 responses were excluded from further analysis where the meaning of the written response was unclear/ambiguous (**Supplementary Table S4**).

Focus Group Analysis of Long-Term Intervention Impact

In 2022, to explore the long-term impact of the 2020 assessment literacy teaching, final year students who had experienced the intervention (n = 186) were sent an open invitation by email to contribute to a focus group. Four students responded to the invitation. Having read a further information form and provided their written consent, the 4 students attended an online focus group lasting roughly 1 h. The focus group was facilitated by a UoE academic with no BMS teaching involvement who sought to gather student feedback on (amongst other aspects) recollections of the LCA purpose, opinions on how it helped their ability to use primary papers, how teaching helped understanding of assessment process and the broader impacts of the teaching. Focus group questions are presented in **Table 3**.

Integration of Graduate Attributes Into Biomedical Competency Pyramid

Having used the BMS competency pyramid (**Figure 3**) as part of the assessment literacy intervention described here, we sought to develop this aspect further and integrate graduate attributes into a pyramid model. For this, the UoE Graduate Attribute Mindsets and Skills framework [19] and Subject Benchmark Statement for BMS were used as a reference. The graduate attribute pyramid generated during this study is presented in **Figure 4**.

Ethical Approval for Study

Ethical approval for both the survey and focus group were obtained from the Social Research Ethics Group (SREG), Deanery of Biomedical Sciences (sub-group of the Research Ethics Committee, School of Health in Social Science, University of Edinburgh).

RESULTS

Students Tend to Award Lower Grades Than Faculty

In eight separate literature comprehension tutorial 2 sessions undertaken in 2020, student grades were recorded for 5 questions (12 answers in total). Histograms derived from this data (**Figure 5**) show variations in the distribution of marks awarded by students for each question. A dotted line indicates the mean mark awarded for the question by two independent faculty markers. Percentage bias for each question is indicated and shows that for 10 out of the 12 answers, students returned lower marks than faculty

TABLE 3 | Questions used in focus groups intended to analyse long term impact of assessment literacy intervention.

Questions regarding literature comprehension tutorials
1. What did you think the main purpose of the literature comprehension tutorials and assessment was?
2. How did the tutorials and assessment help to improve your ability to analyse and discuss a paper?
3. How did the tutorials and assessment help you (or not) to understand the assessment process?
4. Did the tutorials make you feel more confident about the assessment? In what way?
5. Do you think the tutorials came at the right time in your degree? When would be the best time to bring these in?
6. Did the tutorials help you understand where the exercise fitted in to your overall degree development and how?
7. Can you tell us some things you learned from the tutorials that have applied or think you will be able to apply in other settings?
Questions regarding Graduate attributes
1. What kinds of things you're learning about now do you think you will be able to use in your future careers?
2. What, in your mind, are the key graduate attributes a Biomedical Sciences student needs to have gained when they complete their degree?
3. Do you think you've had the opportunity to develop any of these attributes so far in your degree—if yes, please give us some examples
4. At the time, did you realise you were developing a graduate attribute?

members. The maximum percentage bias was −30% highlighting that most students had awarded a lower grade than faculty for this question (Q1A2).

Positive Impact of Assessment Literacy Intervention On Student Confidence in Literature Comprehension Assessment

In 2020, having migrated all teaching of the formative literature comprehension tutorials to an assessment literacy format, our next step was to explore student understanding of their assessment to-date, find out if they were positive about the changes we had implemented and, ultimately, discover if they felt more confident about their upcoming assessment. To achieve this, at the conclusion of the final preparatory tutorials, 186 students across the eight tutorial groups were asked to complete Likert scale questions related to how prepared they felt for their assessment. 159 questionnaires were returned, and the data is presented in **Table 1**. In brief, students broadly agreed that they had a good understanding of how their assessments were marked (111/159 agreed or strongly agreed) and indicated they consider this an important aspect of their learning. Notably, students indicated the assessment literacy intervention had helped them understand more about different assessment standards (139/159 (87.4%) indicated they agreed or strongly agreed). Related to this, most students agreed or strongly agreed that the tutorials had helped them prepare for their exam [138/159 (86.8%)] and made them feel more confident about communicating their own interpretations and reasoning related to primary research papers [113/159 (71.1%)]. Importantly, 127/159 (79.9%) students indicated that they agreed or strongly agreed that the teaching had made them consider what a reader needs to know. Further, 118/159 (74.2%) students agreed or strongly agreed that the tutorials had helped them evaluate and use data to support their answers to questions. The broadly positive response we received via the targeted tutorial questionnaire was supported and reinforced by later free text comments gathered in the standard Deanery end of course survey (2020):

> "I liked the way they were structured. We got to have a practise on our own before the live tutorial. Marking previous answers definitely helped me in understanding how to approach my own answers."
>
> "It was really nice to learn more about the marking schemes, which helped me better understand the learning outcomes for the assignment and in general the quality and kinds of specific details markers look for in good answers. I was also able to apply the skills I learned in the tutorial sessions to similar assignments in other courses"
>
> "I liked the tutorials as it gave an opportunity to consolidate learning. They also gave an idea of what the Literature Comprehension Assessment would be like, which I found beneficial to help remove any anxiety I had about the assessment."

Students Are Aware of Graduate Attributes and Value Their Development

During phase 1 (2019) delivery of our new tutorials, discussions with students as part of our teaching indicated that our assessment literacy approach had not just helped support their engagement with infection-related primary research, it may also have helped facilitate the development of graduate attributes. Amongst other aspects, grading answers of different standards focused students on the logic of their analytical approach, on how they communicated, and encouraged them to reflect on their own work and exercise critical judgement. Given this observation, in 2020 we sought to find out more about student comprehension of graduate attributes and to explore student perceptions of what they had learned from the tutorials. To achieve this, as part of the 2020 end-of-tutorial questionnaire, we integrated several graduate attribute-related questions. To begin, we asked students if they had heard of graduate attributes. Of those who responded (135/159), most (97/135) replied "yes," whilst 38 had not heard of this term. To follow this up, using Likert scale questions we proceeded to ask students if they valued the development of graduate attributes and if they know when they are developing graduate attributes as part of their degree. Responses to these questions showed students consider the development of graduate attributes a very important aspect of their degree [147/159 (92.5%) agreeing or strongly agreeing]. Notably, 97/159 (61%) of students felt they knew when they were developing graduate attributes as part of their normal degree work with less than 1% unsure when graduate attribute development is occurring.

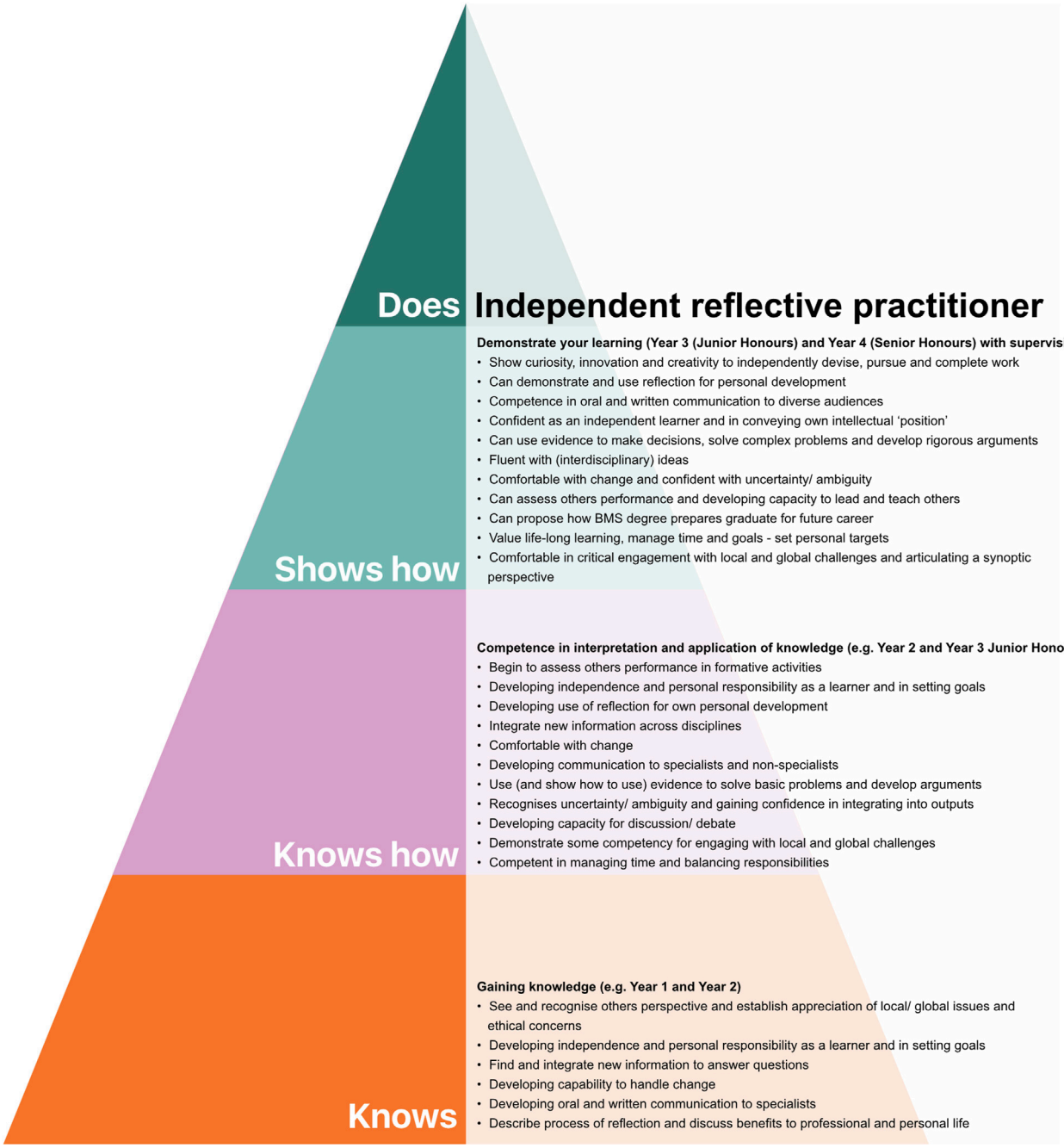

FIGURE 4 | Biomedical Sciences: Undergraduate to Practitioner Graduate Attribute Pyramid. Using Miller's pyramid as a framework**,** the University of Edinburgh Graduate Attribute Framework, and the Subject Benchmark Statement for Biomedical Scientists (2019) were used to identify and map graduate attribute development from degree entry to graduation.

To explore student perceptions of graduate attributes further, we proceeded to ask students if they could provide examples (in free text) of graduate attributes they had developed to-date in their degree. 115 answers were returned in response to this question. Responses were variable and ranged from *"How to write a lab report"* to *"Questioning and analysis of myself and the world around me."* To help us systematically analyse the data, responses were mapped to the UoE graduate attribute framework [19]. Following this mapping, to identify themes, classifications of identical type were grouped and quantitated. The results of this analysis are presented in **Figure 6**. It is important to note that a small number of responses from students referred to specific degree and/or biomedical domain-related skills that would not typically be defined as graduate attributes. To reduce selection

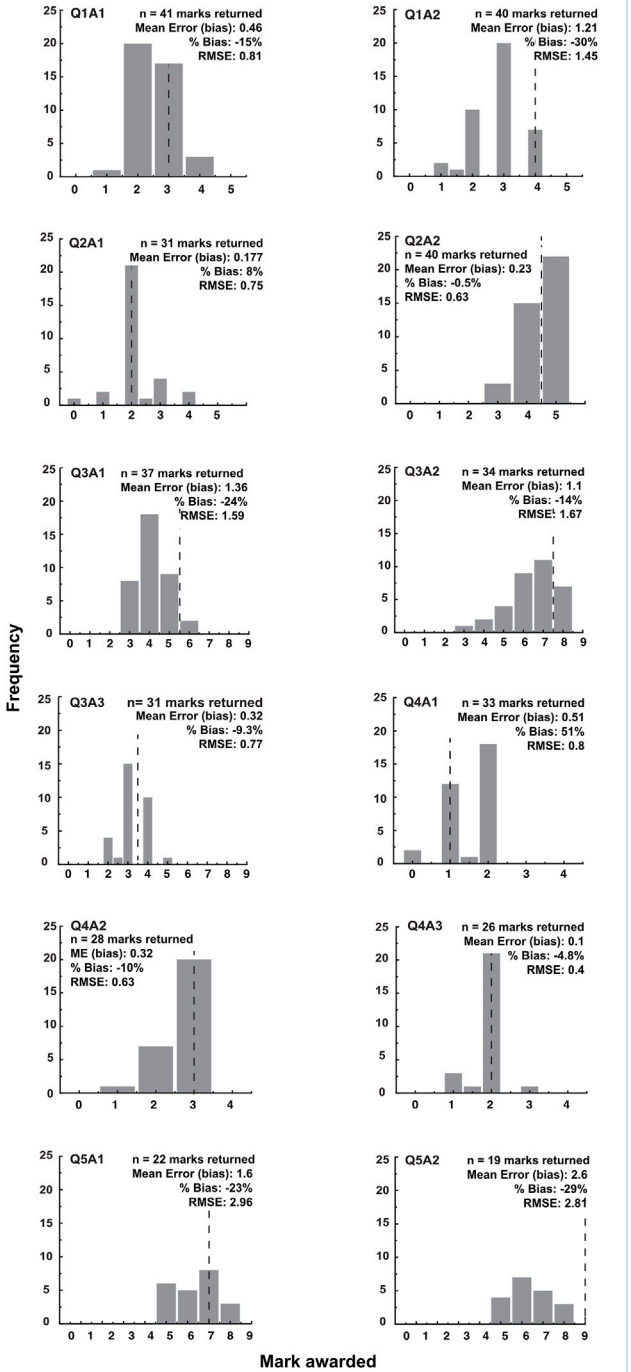

FIGURE 5 | Students tend to award lower marks than faculty. Comparison of student and faculty grades for 5 questions used in formative tutorial 2 of the literature comprehension teaching. Histogram shows frequency of grades returned from 8 tutorials and dotted line represents mean of grades awarded by two independent markers for question. Student (Mean Error) bias was calculated as an average of the difference between each student grade and the recorded faculty grade for each question. Percentage bias as a function of the actual grade for each question was then calculated. The root mean square error (RMSE) was also calculated to reflect the variation of student grades around the faculty grade.

bias, and develop a representative view of the student cohort, the majority of these were retained in our analysis unless meaning was unrelated or ambiguous (e.g., "tutorial skills"). See **Supplementary Table S3** for statements excluded from the analysis.

The most notable theme emerging from the student responses was that they identified "Research and Enquiry" as the main area of graduate attribute development in years 1 and 2 of their study (**Figure 6A**). Under this classification, sub-skills that emerged included "critical thinking," "analytical thinking," "knowledge integration and application" and "problem solving." After "Research and Enquiry," the remaining skill groups (e.g., "Communication," "Personal and Intellectual Autonomy" or "Personal effectiveness") had a similar representation in the data (**Figure 6B**). Importantly, year 2 BMS students referred to very few attributes that could be classified as related to a "Mindset" as defined in the UoE graduate attribute framework (**Figure 6C**) [19]. Where a "Mindset" could be applied to a proposed attribute, the most common classification was "Enquiry and Lifelong Learning". Examples of student statements falling under this classification included "Confidence of how to learn from mistakes," "Being critical of my own work as well as others" and "Ability to take responsibility for my own learning." Notably attributes that could be classified as "Outlook and engagement" (2 statements) ("Understanding the relevance of work and its effect on future research" and "Self-motivation") or "Aspiration and personal development" (1 statement) ("Insight into the qualifications and experience needed to go into a career in academia or research") were sparsely represented in the data.

Given our earlier observation (2019) that students in our assessment literacy tutorials were focussing much of their discussion, questions and learning on the development of broad skills related to graduate attributes, we used our 2020 questionnaire to ask students to state the most important thing they had learned from our teaching. 129 responses to this question were mapped to the UoE graduate attribute framework and themes identified as above (**Figure 7**). As before, to reduce selection bias, and develop a representative view of the student cohort, the majority of these were retained in our analysis unless meaning was unrelated or ambiguous. See **Supplementary Table S4** for statements excluded from the analysis.

Notably, no student responses stated the most important thing they had learned was a specific aspect of the infection-related biology covered in our papers. Almost all responses could be mapped to the graduate attribute framework with a small number excluded from our analysis (e.g., "The kind of questions expected in the exam"). Once again, most student responses (93 (72%) statements classified into this category) could be classified as related to "Research and Enquiry." Examples of statements grouped into this category include "How to take more from a research paper—understand figures and data and analyse them" and "How to pick out important information and which pieces of data are required to draw meaningful conclusions." Alongside "Research and Enquiry," "Communication" was a clear theme evident in the data (66 statements (51%) classified into this

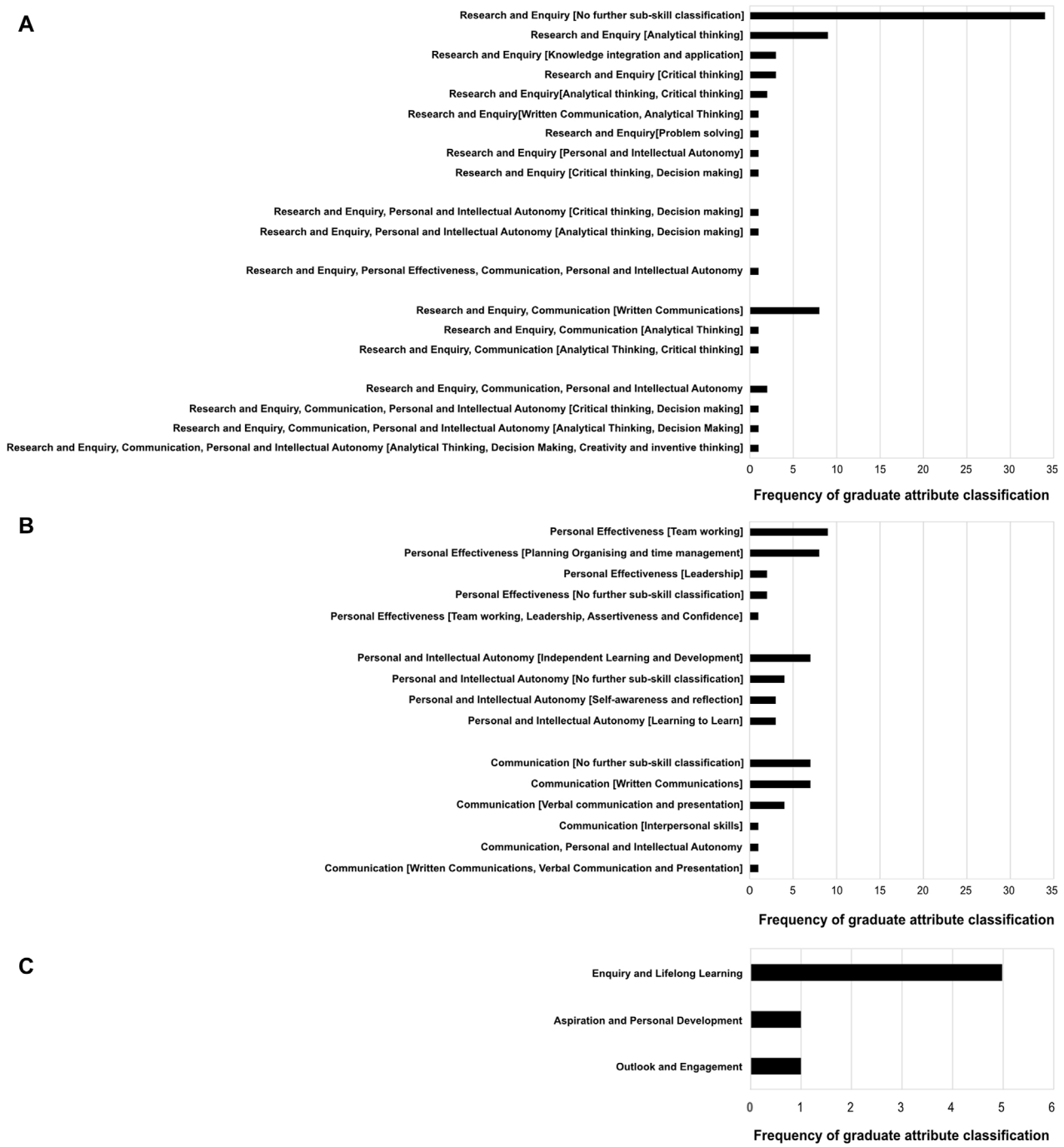

FIGURE 6 | Years 1 and 2 of BMS degree are perceived by students as valuable for the development of graduate attributes related to Research and Enquiry. Year 2 Biomedical Sciences students who had completed the literature comprehension assessment tutorials in 2020 were asked to give examples of graduate attributes already developed as part of their year 1 and 2 studies at the UoE. 115 answers were returned (from 159 questionnaires) as free text. Eighteen were excluded from further analysis as their meaning was unrelated to graduate attributes or considered ambiguous. The remaining statements were then mapped to the UoE Graduate attribute framework according to mindset, skill group and [sub skill group] (indicated in square brackets). Student statements were then grouped according to their mapping classification and group size totals for each classification calculated. Panel **(A)** shows frequencies of statements where classification included "Research and Enquiry." Panel **(B)** shows frequencies of statements classified as "Personal Effectiveness," Personal and Intellectual Autonomy' or "Communication." Panel **(C)** shows frequency of statements classifiable as related to the mindsets "Enquiry and Lifelong Learning," "Aspiration and Personal Development" or "Outlook and Engagement."

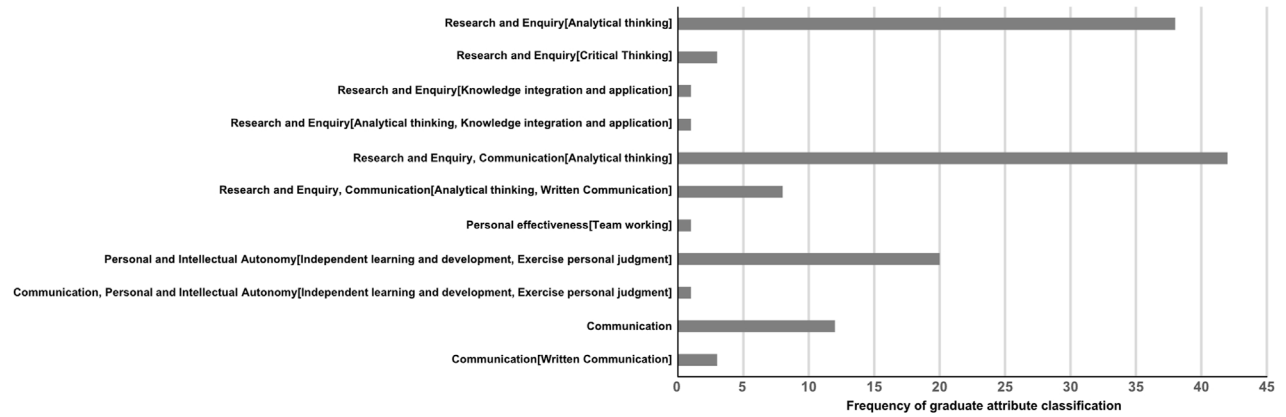

FIGURE 7 | The assessment literacy intervention focused students on the development of graduate attributes rather than domain specific knowledge. Year 2 Biomedical Sciences students who had completed the Literature comprehension assessment tutorials in 2020 were asked to define the most important thing they had learned from the teaching. 142 responses were returned (from 159 questionnaires) as free text. Thirteen responses were excluded from further analysis as the meaning was unclear or considered ambiguous. The remaining statements were then individually mapped to the UoE graduate attributes according to mindset, skill group and, where possible, [sub skill group] (indicated in square brackets). Student statements were then grouped according to their mapping classification and group size totals for each classification calculated.

category). In this regard, statements such as "To answer questions with adequate detail and to refer to data and figures in my answers" and "How to communicate elements of a scientific paper to others" were classified into this category.

Notably, a clear theme emerging from the statements on important learning outcomes related to "Personal and intellectual autonomy" (21 statements (16.27%) were classified into this category). Specifically, a range of statements indicating enhanced confidence in independent learning and exercising judgement. These included "It was really useful to see an actual mark scheme—gives me a better idea of what you look for" and "How to approach a question because we got to see the marking scheme which made it clearer to me to what the markers are looking for."

Long-Term Benefits of Assessment Literacy Literature Comprehension Teaching

The data described above were gathered at the time of (or shortly after) the tutorials and assessment were undertaken. Given the intended function of this teaching is in the development of foundational skills supporting later development ("Knows" and "Knows how") we wanted to explore how final year students felt this work had influenced their later learning. To achieve this, all 4th year students who had undertaken and completed assessment literacy tutorials (before COVID disruption) in 2nd year (n = 186) were invited to contribute to a focus group and four students agreed to participate. When asked what they remembered about the tutorial purpose, student recall of the teaching was variable, however, 3 out of the 4 participants responded with answers that indicated they felt the teaching had been beneficial. For example:

Participant 3:

> [in the past] "I was confident with like understanding what the point of the paper was. Just from, you know, abstract and conclusion mainly, but what I found difficult is understanding like how exactly the method was, what exactly did they use this marker for or what was the point of that enzyme. I remember them asking into like very very details of the methods. Which I found quite difficult, but I think it was beneficial 'cause then we actually were forced to learn, to understand how they made up the experiment or how to connect the dots a bit better."

To develop the discussion, students were then asked if the teaching influenced their understanding of the assessment process. A key theme from answers to this was that students felt the teaching did provide insight into expectations for the assessment. For example:

Participant 1:

> "... the tutorial questions were really quite difficult from what we remember ... and it did probably show you how much detail they were expecting ... yeah, the tutorials definitely showed you how much in depth they were wanting."

When asked to consider whether the literature focused tutorials were undertaken at the correct time in their degree, students responded positively. For example,:

Participant 1:

> "I think going in that much depth it was probably the right time ... I think if someone had said to me in first year, here's some questions on these papers, I would have internally exploded. But at the same time something along those lines, but maybe a bit more basic might have been handy in first year ... I think yes, end of second year is probably about right."

To explore the long-term impact of the teaching, participants were then asked if they thought the tutorials and paper analysis had helped in later years of their degree. Notably, responses to this question were variable and context dependent. One response indicated they felt the teaching had been broadly beneficial, whilst another indicated it was directly relevant to their current work.

Participant 3:

> "I think probably unconsciously. I don't think I would particularly think back to the tutorials and think that definitely helped me in what I'm doing now, but I think it was just one of those skills you pick up along the way and you don't even realize that you've got it until now you can do it fine."

Participant 2:

> "...my project is a systematic review of technologies ... it's definitely very, very literature understanding based ... so for mine it definitely applies"

Finally, having questioned the students on their recollections of the tutorials and their impressions of the benefits, the group were asked "what sorts of things that you've picked up along the way during your degree and that you're doing now in your work [studies] will you be able to apply in whatever you want to do in the future?" Answers were varied but included mention of the benefits of domain specific knowledge as well as a variety of aspects related to graduate attributes (e.g., time-management, communication to varied audiences and a propensity to be more inquisitive).

Participant 3:

> "I would say that the degree has made me more inquisitive, so I'm more likely to wonder about things and then want to go and find out more."

Participant 1:

> "I would say I think it's very general as well, but definitely from our experience, just general like essay writing and like writing skills."

Participant 2:

> [Comfortable with] "A multidisciplinary approach".

DISCUSSION

In the work described here, we have successfully transitioned an assessment literacy strategy from a vocational veterinary teaching context to a foundational BMS learning activity [13, 18]. As an outcome of this, learning became student-focused and engagement in tutorials was enhanced. Importantly, students reported greater confidence in their understanding of how marks were awarded, the features of a good answer and in preparing for their assessment. An unexpected yet welcome outcome of this approach was that our assessment literacy-based teaching functioned as a vehicle for graduate attribute development within a domain-specific activity. The implications of this observation to our BMS teaching will be discussed further here.

The past 20 years has seen a sometimes-controversial shift in the focus of higher education teaching [20]. Over this period, universities have seen their remit widened and it is now accepted they must develop not just discipline-specific graduates but also provide a general foundation for graduate attributes that enhance employability [21, 22]. This presents several challenges. As Green *et al.* point out, graduate attributes have proven difficult to define and are perceived in a variety of ways by academics [21]. As a result, constructive communication between academics, and between academics and students, regarding graduate attribute development has been hard to achieve [21]. Like many higher education institutions, the UoE has published a graduate attribute statement that serves to establish the generic skills and dispositions students can develop during their degree [19]. A key question is how can the development of graduate attributes be integrated into existing curricula and disciplinary contexts? One response to this has been curriculum mapping—most commonly undertaken for degrees integrating some form of professional accreditation or recognition (e.g., HCPC approved degree programme mapping to Standards of Proficiency for Biomedical Scientists) [9, 23]. Curriculum mapping can be useful in identifying existing graduate attribute development activities that are not addressed in, for example, learning objectives. It can also identify requirements, opportunities, and potential linkages between years in the curriculum. Importantly, once mapping is complete, a key question is how can the teaching and learning environment be adjusted to focus students on the development of graduate attributes in their domain? Notably, whilst assessments can serve to motivate students to engage in learning, recent data suggests the explicit assessment of graduate attributes may be unpopular with students [24]. Focus group analyses revealed students did not think assessment of graduate attributes would serve as an incentive for engagement [24]. Further, some students felt assessment would engender an increased emphasis on marks and may prove to function as a personal affront [24].

At the outset of this study, we aimed to adopt an assessment literacy approach to help students learn how to read, analyse, and communicate their interpretations of primary research papers. On completion of our teaching, feedback from students indicated this strategy moved our teaching away from a teacher- and domain-centric approach and enhanced student confidence and competence in both the process of assessment and literature analysis. In agreement with previous studies, the data presented here show notable variation in the ability of students to accurately grade work. In contrast to previous work, however, where over or under grading was not

consistent, in this study students tended to award lower grades than faculty [13]. Exploration of this finding, by further discussion of grade differences with students in tutorials, revealed a key disparity between faculty and student perspective. Students often demonstrate a focus on the concept of losing marks and the presence of a final, definitive conclusion as a key requirement for mark reward. To address the above required that we consider the students 'metacognitive' development—how could we facilitate the development of a marker's perspective in students? We now ensure our approach emphasises that faculty adopt a "positive marking" philosophy—rewarding rather than taking away. We also emphasise the importance of considering the audience, the value of contextual information, and that marks are accumulated through the development of clearly communicated, systematic answers. Students are encouraged to reflect on the needs of the audience and answer questions such as: what was the authors question? What did the authors do? What does the data show? What interpretations and conclusions can be drawn? What do I need to communicate? By providing this process for developing their responses, and engaging students in marking answers following the same logic, the assessment literacy approach can help students focus on how to analyse and develop an answer.

At the conclusion of our 2020 teaching, in contrast to previous years, no student feedback relating to the year of publication of the primary research papers and the relationship between tutorials and lectures was received. We ascribe this to the inclusion of an introductory presentation used to explain the aim of the teaching/assessment and the assessment literacy approach. Notably, students did, however, report enhanced confidence in, and the development of, skills and attributes beyond the domain-specific area (infectious diseases). These attributes could be classified according to the UoE graduate attribute framework as enhanced skills in research and enquiry, communication and, importantly, independent learning and exercising personal judgement [19]. By engaging students with standards and expectations, evidence to-date, therefore, suggests assessment literacy can facilitate the engagement with, and development of, graduate attributes.

As an integral part of this work, Miller's pyramid was adapted to show BMS competency development from degree entry to practitioner [18]. This helped us communicate to students where their literature comprehension teaching and assessment fitted into overall BMS competency development. In doing so, it helped us address the need for a "transparent" curriculum and provide students with the opportunity to work towards "declared" objectives and plan for future skill development [25]. Overall, we view this representation as dynamic and envisage it will evolve over time as we receive input from colleagues and other stakeholders (see limitations below). Importantly, to extend this work the pyramid approach facilitated the systematic mapping of UoE graduate attributes to BMS competency development - allowing us to conceptualise graduate attributes in a specific domain context (**Figure 4**). A future objective is to test how this helps us to convey to the students how graduate attribute development can evolve over the degree and what can be expected at different levels.

Importantly, the development and use of the BMS competency pyramid highlighted several key issues. The work described here indicates a requirement for a systematic analysis of our entire BMS curriculum with the aim of identifying requirements and opportunities for graduate attribute development and assessment embedded within or alongside current teaching, learning and assessment activities. In this regard, our work agrees with recent findings showing limited evidence for specific educational approaches driving the systematic development of graduate attributes in UK undergraduate degrees [26]. Several models for curriculum and graduate attribute mapping exist and the activity will have to complement or be part of an ongoing curriculum transformation programme at the UoE [22, 23, 27, 28]. Given our data emphasising the importance students place on graduate attribute development, it would seem prudent that this process is undertaken in partnership with students [29].

Use of the competency pyramid and parallel analysis of student questionnaire responses emphasised a focus on student attribute development related to Research and Enquiry in years 1 and 2 of the BMS degree. This was expected given an early teaching focus on formative activities enabling academic competency and a transition to university. Importantly, analysis of year 2 student questionnaire data revealed a focus on graduate attributes defined as "skills" by the UoE graduate attribute framework [19]. These data, and the variable responses we obtained regarding the long-term impact of competency and graduate attribute development in our focus group, highlight an opportunity for use of assessment literacy throughout our curriculum. As a next step, we plan to explore the use of assessment literacy and regular engagement with the competency/graduate attribute pyramid model in all years to help students acknowledge and reflect on their development. In doing so, they may recognise when changes in, for example, their outlook or mindset occur as they progress through the degree. In this regard, it was notable that in our focus group, one student did remark that they were more "inquisitive" at the conclusion of their studies. Evidence on undergraduate mindset development is limited and studies that have emerged suggest undergraduates do not change mindset over time [30]. Of some concern, are studies that indicate STEM students develop an increasingly fixed mindset as they progress through their studies [31]. A key future objective for our work, therefore, is to explore how we can use assessment literacy and our competency/graduate attribute model throughout the curriculum to help students set and importantly achieve objectives that demonstrate development and promote "growth" mindsets enabling them to take on challenges and achieve success [30]. Notably, a recent study described peer interaction—integral to our assessment literacy approach—as influential in determining student mindsets [30]. Whilst it was not a focus of the work described here, involving students in discussion of assessment, and reflecting on how it has impacted their development, could also be useful as a means of gathering valuable additional insight

into their perspective as partners in the assessment process; in particular in relation to key aspects such as inclusivity and the impact assessment has on student wellbeing [32, 33].

To conclude, as several authors have noted, graduate attributes are not generic and their definition, and how they are perceived, differs between disciplines [21, 34, 35]. To address this, it has been proposed that teaching processes make it clear how aspects of a degree (including assessments) contribute to graduate attribute development. This will help students recognise how their study might prepare them for later work [26]. Models developed to enhance assessment literacy may help to achieve this by engaging students with process, purpose, application of standards and expectations. In doing so, they may be used to enhance skills, aptitudes and dispositions enabling parallel academic achievement and transition to the workplace.

Limitations

There are several limitations to consider when interpreting these data and drawing conclusions. Firstly, the data gathered here was from a single course, at a single institution. Whilst the UoE BMS student cohort is typically drawn from a diverse range of cultural and educational backgrounds, we cannot predict that the findings will be generalisable to other contexts. The study could be strengthened by replication with a more representative sample of undergraduates.

In relation to the study design, a clear limitation relates to the size and composition of our focus group. Students volunteered to participate in this exercise and, therefore, represent a very limited portion of potential respondents. In both the questionnaires and the focus group, we have captured self-reported responses to our teaching. Additionally, in the case of the focus groups, students reported retrospectively. As a result, our data are prone to recall bias and other cognitive biases and may not be representative of the wider student population.

In the comparison of the student and faculty grades, two members of faculty had originally marked the answers analysed in the tutorials. As such, it was not possible to apply statistical testing to enhance the validity of our conclusions in this regard. The study could be strengthened by the addition of further faculty markers. Not only would this strengthen the statistical analysis, but we also anticipate a wider faculty contribution would generate valuable discourse re. what is, and should be, rewarded in an assessment.

At the outset of this project, a key aim was to evaluate the year-on-year effect of the assessment literacy intervention on overall class grades. Ultimately, this was not possible due to changes in delivery of the assessment in response to the COVID pandemic. In 2020, the exam moved from a 90-min invigilated format to an online assessment undertaken over a 24 h period. For both academic and practical reasons, this online delivery method has been retained and, with no like-for-like comparison possible, we have not sought to directly test whether our intervention had a positive effect on cohort grades. Further studies to directly test the impact of assessment literacy intervention are required, however, the similarity of adjacent cohorts cannot be assumed.

In relation to our data analysis, a methodological limitation relates to the mapping of respondent data to the graduate attribute framework. Every effort was made to undertake this in a systematic manner and response classifications were agreed between authors. Notably, however, an absence of, for example, a controlled vocabulary means this aspect of the study may be subject to bias.

The work described here was undertaken using existing definitions of graduate attributes as defined in the UoE graduate attribute framework and described in the literature. This may be considered a limitation, and future studies would benefit from more active dialog with employers with the aim of defining specific competencies and attributes considered desirable in the graduate workplace. This input would be valuable to future curriculum development.

SUMMARY TABLE

What Is Known About This Subject

- Biomedical Sciences degrees must provide domain specific learning and prepare graduates for work and life after their studies.
- Assessment literacy based teaching enables students to use an appropriate, relevant method for any given assessment task.
- An absence of assessment literacy can impede an individual's capacity to learn and can limit inclusivity, equity, and participation in higher education.

What This Paper Adds

- Assessment literacy teaching enhanced student engagement in tutorials.
- Assessment literacy teaching improved confidence in student understanding of standards and in preparation for an assessment.
- Assessment literacy teaching also facilitated graduate attribute development within a domain-specific activity.

CONCLUDING STATEMENT

This work represents an advance in biomedical science because it shows that assessment literacy teaching in a BMS degree may be used to enhance skills, aptitudes and dispositions enabling parallel academic achievement and transition to the workplace.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available per ethics approval. Requests to access the datasets should be directed to KR, kevin.robertson@ed.ac.uk.

ETHICS STATEMENT

The studies involving humans were approved by the Social Research Ethics Group (SREG), Deanery of Biomedical Sciences (sub-group of the Research Ethics Committee, School of Health in Social Science, University of Edinburgh). The studies

were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

KR conceived and conducted the study, collected, and analysed the data and wrote the manuscript. KH performed the study and analysed the data. SR contributed to the development of the study themes, critically guided the study, and reviewed the data. All authors contributed to the article and approved the submitted version.

FUNDING

The author(s) declare financial support was received for the research, authorship, publication of this article. Funding for this Principal's Teaching Award Scheme (PTAS) project was provided by the University of Edinburgh Development Trust. Funding for publication was kindly provided by the Deanery of Biomedical Sciences, University of Edinburgh and Royal (Dick) School of Veterinary Studies, University of Edinburgh.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ACKNOWLEDGMENTS

We gratefully acknowledge that funding for this PTAS project was provided by the University of Edinburgh Development Trust. We wish to thank Dr Allison Wroe, Dr Douglas Roy, and Dr Simon Talbot for their continued, invaluable help in teaching and data collection. We are also grateful to Dr Thamarai Dorai-Schneiders for enabling and supporting changes to teaching practice.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2024.12229/full#supplementary-material

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IBMS Institute of Biomedical Science | BJBS

ORIGINAL RESEARCH
published: 28 March 2024
doi: 10.3389/bjbs.2024.12651

Andragogy in Practice: Applying a Theoretical Framework to Team Science Training in Biomedical Research

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This study is the first to apply the theoretical principles of Malcolm Knowles' theory of andragogy to evaluate data collected from learners who participated in team science training workshops in a biomedical research setting. Briefly, andragogy includes six principles: the learner's self-concept, the role of experience, readiness to learn, orientation to learning, the learner's need to know, and intrinsic motivation. Using an embedded study design, the primary focus was on qualitative data, with quantitative data complementing the qualitative findings. The deductive analysis demonstrated that approximately 85% of the qualitative data could be connected to at least one andragogical principle. Participant responses to positive evaluation questions were largely related to two principles: readiness to learn and problem-based learning orientation. Participant responses to negative questions were largely connected to two different principles: the role of experience and self-direction. Inductive analysis found an additional theme: meeting biological needs. Quantitative survey results supported the qualitative findings. The study findings demonstrate that andragogy can serve as a valuable construct to integrate into the development of effective team science training for biomedical researchers.

Keywords: team science training, biomedical research education, educational theory, andragogy, adult learning

OPEN ACCESS

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Received: *05 January 2024*
Accepted: *11 March 2024*
Published: *28 March 2024*

Citation:
Knapke JM, Hildreth L, Molano JR, Schuckman SM, Blackard JT, Johnstone M, Kopras EJ, Lamkin MK, Lee RC, Kues JR and Mendell A (2024) Andragogy in Practice: Applying a Theoretical Framework to Team Science Training in Biomedical Research. Br J Biomed Sci 81:12651. doi: 10.3389/bjbs.2024.12651

INTRODUCTION

Malcolm Knowles developed the theory of andragogy to provide a framework for understanding the distinct learning patterns of adult learners [1, 2]. Knowles' theory suggests that instructors should understand and attend to the unique aspects of adult learning motivation. Adult learners often balance numerous commitments, and their educational goals are based on well-defined needs [3, 4]. Compared to their younger counterparts, adult learners are frequently more motivated to perform well in their studies and are more oriented towards task completion [5]. In many cases, adult learners choose to advance their education to retain a competitive edge in the workplace, especially in times of economic recession [3]. **Table 1** provides a brief summary of each of the six principles of Knowles' Theory of Andragogy.

Andragogy has been applied to several fields ranging from chemistry [6] to the coaching of "master athlete" swimmers [7]. Moreover, it is useful in several distinct educational fields including

TABLE 1 | The six principles of Knowles' andragogy theory.

Principle	Description
Self-Concept	As a person matures, their self-concept moves from that of a dependent personality to that of a self-directed human being. Children maintain a self-concept of total dependency, but adulthood is characterised by a self-concept of self-direction. Once this psychological maturation occurs, the adult naturally feels most comfortable in situations that allow him or her to self-direct, in an independent way.
Role of Experience	As people mature, they accumulate a growing reservoir of experience that becomes an increasing resource for learning. Unlike children, who define themselves in terms of other people (teachers, parents, siblings, etc.), adults define themselves by their experiences. Experience, in itself, can be a form of expertise that teachers should draw upon and use as a resource for learning.
Readiness to Learn	As a person matures, their readiness to learn becomes increasingly oriented towards the developmental tasks of their social roles and life situations. Adult learners want to learn because of the roles they play in their current stage of life, whether at work or home as parents or spouses.
Orientation to Learning	Traditional pedagogy assumes that young students have a subject-based approach to learning, partly because they do not have much life experience. Andragogy assumes that adults approach learning with a problem-based approach.
Need to Know/Why	Adults often pursue education because they need to know something. Adult learners carefully consider *why* they are learning something. In pedagogy, it is assumed that students will simply learn what they are told to learn. Adults want to understand what they will do with the information in life and how it will benefit them or be of consequence to them if they do not learn it.
Intrinsic Motivation	Adult learners are responsive to some external motivators (better jobs, promotions, higher salaries), but the most potent motivators are internal pressures (the desire for increased job satisfaction, self-esteem, or quality of life).

physical education [8], early childhood education teacher training [9], outdoor science education [10], police training [11], military education [12], and social work [13]. One study explored the value of an andragogical framework in a study of blended learning among part-time adult learners pursuing vocational degrees through distance learning [14]. Another study performed a randomised controlled trial to compare the effectiveness of the experiential learning principle of andragogy in teaching nutrition concepts to culinary arts students and found that experiential learning was more effective [15].

Although andragogy is a useful theoretical lens in a wide variety of fields, it has rarely been applied to medical and health sciences disciplines. One study incorporated andragogical principles through the use of podcasts in undergraduate kinesiology courses [16]. Another promoted the use of andragogy in online nursing education [17]. A 2012 study suggested incorporating Knowles' principles of andragogy into the teaching of medical residents [18]. Another study showed that incorporating learner self-direction in the form of a flipped classroom model yielded higher test scores for Emergency Medicine residents over time compared to traditional teaching methods [19]. Knowles promoted the importance of andragogy in the continuing education of health professionals, given the rapid changes in the field and the mandatory nature of professional education [20]. Another paper, however, argues that the andragogical principle of intrinsic motivation is "simplistic, misleading, and counterproductive" when applied to medical students [21]. We found no existing literature applying andragogy in a biomedical research setting. Furthermore, few studies have explored the utility of andragogy from the perspective of the learners themselves.

Since 2016, the Center for Improvement Science (CIS) at the University of Cincinnati (UC) has offered more than 50 presentations and workshops aimed at teaching biomedical research professionals how to better collaborate on research teams. The CIS operates within a "Science of Team Science" environment that is largely driven by our local National Institutes of Health (NIH)/National Center for Advancing Translational Science (NCATS)-funded Clinical & Translational Science Award (CTSA). The Science of Team Science has been defined as ". . . a new interdisciplinary field . . . which aims to better understand the circumstances that facilitate or hinder effective team-based research and practice to identify the unique outcomes of these approaches in the areas of productivity, innovation, and translation"[SIC] [22]. In order to produce workshops that improve "productivity, innovation and translation" in the work of biomedical research professionals, the CIS has applied the principles of andragogy to team science education since its inception [22]. We use experiential learning methods to assess readiness to collaborate, promote participants' self-reflection, balance didactics with interactive activities, ensure "hands-on" components, explicitly connect learning to practice, and draw on the wealth of team experience in each group of workshop attendees. Andragogy is a valuable learning theory that has been widely studied in other disciplines; however, it has not been applied to the field of team science education. Because we have found it to be one of the most valuable tools in our teaching approach, we examined the usefulness of integrating andragogical principles into team science training workshops, as evidenced by themes from the participants' evaluation data. Given our emphasis on andragogical principles in educational practice, this work used an embedded study design with qualitative evaluation data as the primary focus, but with quantitative evaluation data also analysed to augment the qualitative data [23]. We undertook a phenomenological approach to investigate adult learners' experiences of team science training through the lens of andragogy.

MATERIALS AND METHODS

Participants and Study Setting

Team Science workshops from 2016 to 2021 were offered and promoted through a variety of email listservs, internal electronic newsletters, and websites aimed at UC research faculty and staff. Registration was voluntary for the majority of participants. A small minority were required to attend due to internal grant funding or training programme requirements. Workshops were primarily offered in an in-person setting and lasted 1–3 h. To accommodate COVID-19 restrictions, workshops were reformatted to be virtual and synchronous beginning in March 2020. The education team met weekly during this period to plan and deliver the workshops. Team meetings were multifaceted and included discussions on workshop logistics, content planning, slide and activity development, and a review of feedback from recent workshop evaluations. Importantly for this study, the education team also used these meetings to discuss andragogical principles, to ensure that several principles were incorporated into workshop planning, and to debrief on perceived successes and potential improvements of recent workshops, using both facilitator perspectives and learner evaluation feedback. This study was reviewed by our Institutional Review Board (IRB) and determined not to be human subject research (IRB #2024-0184).

Data Collection

A paper evaluation survey was distributed to each participant at each in-person workshop, and participants were allotted time at the end of each workshop to complete it. Online workshop participants received an electronic evaluation survey link in the chat box at the conclusion of the workshop and via email shortly after the workshop ended. A minor update was made to the online survey instrument to include an additional question regarding the use of technology to achieve the goals of the virtual workshop. All evaluation surveys were anonymous and included Likert-scaled questions asking participants to rate the instructors, workshop content such as activities and examples, and the overall learning experience, as well as five open-ended questions. Although the evaluation instrument was not designed with andragogical principles in mind, these were incorporated into the workshop development process. The evaluation survey was initially developed for the purpose of improving educational programmes. However, the research team questioned whether the incorporation of andragogical theories into the educational programme was valuable for participants' learning. The full evaluation survey instrument is provided in **Supplementary Appendix SA**.

This study used the qualitative data collected from responses to the open-ended questions of the instrument. We also selected a subset of the Likert-scaled questions that represented key andragogical principles. These included the value of the workshop in meeting one's needs (Intrinsic Motivation), the Usefulness of handouts or other "takeaways" (Need to Know/ Why), the Active involvement of participants in the learning experience (Self-Concept), the Use of practical examples (Readiness to Learn), and the Use of activities (Role of Experience, as workshop activities most often occur in small group discussions that focus on participant sharing and peer learning). Data from 6 years of workshop evaluations were combined into one dataset for analysis, with each evaluation marked as having occurred in-person or online.

Data Analysis

A team of five qualitative coders used a deductive approach to analyse the evaluation survey data [24]. The research team applied andragogy as a theoretical framework both to analyse the data and to organise the study findings. Using a modified selective coding process, we sought data that supported the six principles of andragogy [25]. Although the evaluation instrument was not specifically designed with andragogy as a guiding framework, the analysis team sought to code learner responses to open-ended questions according to the principles of andragogy where appropriate and meaningful. Each coder analysed the data independently, and then the team met bimonthly to refine interpretations and resolve any differences between coders.

The research team recognised the difficulty of coding some participants' comments as belonging to one theme or another. For instance, some comments were too short or too ambiguous to capture the underlying issue (e.g., "It was well done"), while other comments touched on multiple themes in the same sentence (e.g., "It was very interactive and engaging. Plus, it helps for people to think about how different people think and interact with each other"). Thus, the analysis team made decisions about how to interpret Knowles' andragogy theory in the context of the workshop evaluation data and developed a codebook that included key words and phrases as examples of a particular theme to help facilitate our analysis [25]. The development of the codebook took place over several months of analysis team meetings in which each andragogical theme was reviewed and discussed, and both general and specific key words and phrases that correlated with a theme were identified. For example, comments that referred to a participant's career stage or role in a team were coded under the theme "Readiness to Learn," since this suggests that a learner's readiness to learn is predicated on their social or professional role in life. Participants' comments about activities that addressed specific problems (such as communication skills or team charters) and that utilised experiential learning that required learners to practise team science skills to solve a problem were coded under "Orientation to Learning," an andragogical principle that relates to adults learning best through a problem-based approach. Fewer than 2% of participants' comments were coded in multiple categories if the comment encompassed more than one theme (e.g., "Something less generic that I can actually apply to my team and current situation" has aspects of three themes: Readiness to Learn, Orientation to Learning, Need to Know/ Why). More often a participant comment could be broken down into multiple themes by phrase or sentence (e.g., "Much more focused on 'what can I do' things and concepts. Take home messages much more tangible." The first sentence of this comment was coded as Intrinsic Motivation, while the second sentence was coded as Orientation to Learning. **Table 2** provides additional information on the key words and phrases that were incorporated into the codebook. This was essential to enabling the team to interpret the theoretical framework consistently within the specific context of the data set. Additionally, the data collected during the in-person workshops (2016-early 2020) were compared to the data collected during the virtual period (2020–21) to identify potential thematic differences that may have emerged as a result of this shift.

TABLE 2 | Summary of the codebook for andragogical themes.

Principle	Keywords or phrases
1. Self-Concept	• Tools to take back to their teams • Tools to do on their own • More time for specific activities, discussions, or topics before moving on • Ability to direct activities, discussions, time allotment
2. Role of Experience	• More general need for discussion-based interactivity • Engaging with other participants • Sharing their own past experiences to learn from each other and build their knowledge
3. Readiness to Learn	• Different career stages/ages in a team • Training specific to their role in a team
4. Orientation to Learning	• Activities that address a specific problem (communication skills, charter) • Experiential learning, providing activities that require them to put TS principles into practice to address a problem • Hands-on activities
5. Need to Know/Why	• How is this information useful, valuable or beneficial to me? • Boring, too introductory, or impractical • Evidence-based
6. Intrinsic Motivation	• Self-improvement • Self-reflection

After deductively coding the evaluation data using andragogy as our theoretical framework, the analysis team inductively analysed the remaining data for themes that fell outside of the constructs of andragogy [24]. Quantitative data were summarised using means and standard deviations.

RESULTS

During the study period, 26 workshops were offered. Participation was voluntary for 23 workshops and required for 3 workshops as part of an institutional grant award. Workshop evaluations were collected anonymously; thus, individual participant demographics cannot be reported. In general, workshops included faculty, staff, and graduate students from UC, UC Medical Center, Cincinnati Children's Hospital Medical Center (CCHMC), and a small number of members from outside the biomedical research community. In total, 363 evaluation surveys were received from participants in the 26 workshops.

Of the 363 evaluation surveys received, 605 unique pieces of feedback data were identified (i.e., individuals responded to more than one open-ended question and sometimes gave more than one response to individual questions). Approximately 85% of the comments provided by the participants were connected to Knowles' theory of andragogy. All six of the themes of andragogy were present in the data set, although there were differences in frequency and emphasis on particular principles. The first five themes listed in **Table 1** were the most frequently coded themes in the entire dataset, including self-directed learning, role of experience, readiness to learn, orientation to learning, and need to know/why. Intrinsic motivation was apparent in the evaluation data but to a much lesser extent.

Interestingly, participant responses to positive questions such as "why would you recommend this workshop to others?", "what did you learn today that you are most likely to use in your work?", and positive "other comments" were largely related to two themes: 1) participants' readiness to learn based on their current professional roles or the roles of those they work with and 2) participants' problem-based attitude to learning. Participant responses towards negative questions such as "why would you *not* recommend this workshop to others?", "what suggestions for improvement do you have?", "what were you hoping would be covered but was not?", and negative "other comments" were most often connected to two different themes: 1) the role of experience and 2) the need for greater self-direction in their workshop experience. Participant responses coded under the need to know/why theme were more evenly spread throughout the evaluation data, with no consistent alignment with negative or positive questions. Deductive themes remained consistent across the complete data set for both in-person and online workshops.

The inductive analysis for themes unrelated to andragogy revealed one theme that participants greatly valued: meeting their biological needs for food, drink, and workshop breaks that allowed them to use the toilet or check in on their personal or professional business. This theme was particularly important in workshops that extended beyond 1.5 h. Given the shift to a virtual format in 2020, we reviewed the data for thematic changes between in-person and online workshops and this inductive theme was the only one no longer present. **Table 3** provides a summary of each theme and representative quotes taken from the data set, with an approximate percentage of distribution within the dataset.

In the embedded mixed methods design, we analysed relevant quantitative data from the evaluation survey to determine whether it supported our qualitative findings. The quantitative data analysis showed that, when asked to rate aspects of the workshops that related to andragogical principles, participants mostly felt that the facilitators did a good-excellent job (scoring between 4 and 5 on a 5-point Likert scale) in addressing these needs. **Table 4** provides the mean scores and standard deviations for the evaluation questions that are related to adult learning theory.

The quantitative evaluation results support the qualitative findings by illustrating that participants felt that the team science workshops addressed key aspects of adult learning theory, and incorporated these aspects very well, based on high ratings in the good-excellent range.

TABLE 3 | Deductive and inductive themes with participant quotes and approximate percent representation and n in the data set (*N* = 605 responses).

Theme % Representation[a] (n)	Participant Quotations
Self-Concept 13% (79)	"I expected more time for hands-on development of a charter; we had 15 min within roughly 1 h. Maybe send pre-work or use less time to lecture, which seemed very basic." "Would have valued deeper engagement with topics, perhaps the follow-up topics." "I'd recommend extending the time by about 30–45 min to allow for deeper engagement in group activities."
Role of Experience 15% (91)	"Good ideas from others." "Catering to expertise of audience. Have them lead discussions of best practices." "More time for participants' personal experiences."
Readiness to Learn 16% (97)	"Workshop was helpful in learning about others' work styles, which is helpful in harmonizing teams of collaborators." "Possibly helpful suggestions for what to do depending on status within the team. I'm very young (grad student) and I think how I work/communicate in the team compared to senior members is very different." "Allow teams to sit, work, talk, discuss together—my team leader and I came together and our time would have been better spent processing content together."
Orientation to Learning 20% (121)	"More concrete suggestions and practical guidelines on how to manage team situations. Had good conversation about how these things are difficult. But what can we do to manage these issues?" "Share more examples of addressing dysfunctions in real life." "More solutions and not just discussing problems."
Need to Know/Why 10% (61)	"Practical and useful info." "Go a bit more in-depth about scientific evidence which supports these concepts." "Shorter, less fluffy, more data-driven. . ."
Intrinsic Motivation 4% (24)	"Much more focused on "what can I do" things and concepts." "It helped to clarify my tendencies on a team." "Recognizing my strengths/weakness and addressing them."
Meeting Biological Needs[b] 5% (30)	"Loved the coffee and lunches!" "Thanks for the coffee/breakfast and workshop!" "Thanks for the great info and snacks!"

[a]*Percentages do not sum to 100%; approximately 2% of data were coded to more than one deductive theme and the remaining 15% were not coded to either deductive or inductive themes.*
[b]*Present in in-person workshop data only.*

DISCUSSION

The results indicate that andragogy is a useful and relevant learning theory to integrate into the development of effective team science training in a biomedical research setting. In this study, training effectiveness was measured by participant satisfaction, as evidenced by quantitative scoring of workshop components and qualitative feedback. These data also fill an important gap in the literature on learning theory as it relates to professional team functioning and the education of work teams in academic health. Adult learning theory has been explored in many disciplines; however, this study was the first to apply andragogy to team science training in an academic health centre through deductive analysis of workshop participant feedback.

Andragogy was well represented in the study data, with approximately 85% of participant evaluation feedback connecting to one or more of the six andragogical principles. Interestingly, participants commented positively on workshop aspects that addressed their readiness to learn and their problem-based attitude towards learning. When asked how to improve the workshop methods, the participants primarily requested teaching methods that addressed their desire for self-directed learning and the discussion of their own and others' experiences as a learning resource. We speculate that this is because the workshop development team adequately addressed participants' readiness to learn and problem-based learning orientation, but less so their need for self-direction and use of experience as expertise. Addressing adult learners' desire for "why" they "need to know" information was a fifth theme that was widely represented in the data set, no matter the question type. Incorporating andragogical principles into training development and implementation is straightforward, requiring an awareness of adult learning principles and a process to ensure that "active learning" occurs during each educational event [26]. Study results demonstrate that learners respond positively to training designed with this theoretical framework in mind.

Our data suggest that the principles of andragogy are important to learners in our workshops; participants expressed their strengths and opportunities for improvement using language that fits within the themes of andragogy. Our findings suggest another important

TABLE 4 | Mean score and standard deviation for selected Likert scale questions (*N* = 363)[a].

Survey item	Mean score (SD)
Value of the workshop in meeting your needs	4.2 (.36)
Usefulness of handouts or other "takeaways"	4.2 (.49)
Active involvement of participants in the learning experience	4.4 (.30)
Use of practical examples	4.3 (.35)
Use of activities	4.3 (.38)

[a]*1–5 scale with 1 being Poor and 5 being Excellent.*

insight related to the application of andragogical principles to the field of team science training, which is that adults who pursue education to improve their work team functioning also value collaborative learning. Collaborative learning is an instructional approach that emphasises the pursuit of shared knowledge by both the instructor and the learners, while also asserting that learning and understanding are social in nature [27]. One study showed that social factors such as interacting with peers and instructors as part of the learning process improved learners' academic performance [28]. Placing andragogy within a larger framework of collaborative learning expands the potential for learning in a complementary way, such that the team science workshop facilitator becomes a co-learner with the workshop participants. The facilitator determines the basic scaffolding to support learning; however, andragogical principles emerge as workshop participants help to direct the specifics of a discussion or learning experience, with both the facilitator and the participants co-creating knowledge as a collaborative team. There are several benefits to collaborative learning, some of which are uniquely suited to team science training because they inherently support several of the andragogical principles that were highly valued by participants in this study [27]. For example, in a collaborative learning environment, learners would be more active participants in the learning process to improve team functioning, and they would engage in self-directed, problem-based activities that rely heavily on learning from their own and other participants' past experiences. By allowing learners to guide the direction of a workshop, they are likely to steer it towards content and discussions that are most useful and interesting to them, and to provide new information that addresses a need in their professional or personal lives, two other key principles of andragogy. However, in an increasingly hybrid or online learning environment, the use of technology to support active, collaborative learning presents challenges to instructors trying to meet the needs of adult learners [29].

Although present in the data set, intrinsic motivation was not a strong theme compared to the other five principles of andragogy. This may reflect the nature of the content of the team science training workshops, which certainly included self-assessment and encouraged self-reflection, but in the context of a team. Our evaluation survey may also lack questions that prompt comments on this motivation. Exploring intrinsic motivation in a different training setting that is more individual-focused, such as wellness seminars, courses aimed at improving technical skills, or leadership and management training might yield different results that suggest that internal motivation is equally important. Although it was not a major theme in this study, intrinsic motivation is an important andragogical principle that also aligns with the collaborative learning approach. Co-creation of educational activities and developing a shared understanding of team science topics would increase the likelihood of satisfying adult learners' intrinsic motivation to learn.

Strengths and Limitations of the Study

This study has many strengths and some limitations. First, it offers an analysis of the importance of andragogical principles in an educational field that was previously unexplored: team science. Using participant feedback as the primary source of data, this study demonstrates that adult learners express their training needs in ways that can be readily connected to andragogy, making it a useful learning theory for educators to consider when designing team science workshops. A limitation of this study is its focus on a training topic that is narrow in scope: team science training at an academic institution. Thus, generalisability to other institutions may be limited. Future research could expand the database to include evaluation data from team science training events at other institutions. Another possible limitation is the data set itself, which is bound to the written evaluation feedback provided by workshop participants. The data collection instrument was not originally designed with andragogy in mind, requiring the research team to identify and connect survey items to andragogical principles *post hoc*. Pre-hoc incorporation of questions specific to andragogy would likely allow for a more robust and comprehensive analysis of how important these principles are to team science trainees and what aspects of the workshop training were most successful in meeting the needs of adult learners. For example, the survey instrument could ask participants to rate how important each principle is to their individual learning, and the extent to which the workshop met each principle. Such targeted feedback would allow our workshop team to adjust content and instructional methods accordingly, increasing the likelihood of training success. Our data set did not include comments from all participants, nor did it include any other data source, such as longitudinal follow-up via survey or interview/focus group. We integrated quantitative data into an embedded study design in an effort to augment the qualitative findings. Finally, our primary method of analysis was deductive in nature, actively looking for themes that were corollary to the six principles of andragogy. Although we did employ an inductive analysis of any data that remained after the primary analysis, qualitative analyses that are deductive are limited by their nature.

The study results point to the importance of having a strong evaluation component in team science training programmes for continuous improvement that accommodates learner needs. Andragogy was found to be a valuable and relevant theoretical lens for interpreting adult learner feedback in a team science education and training context. Future studies that explore the relevance of collaborative learning principles to the needs of adult learners would be useful. Additionally, collecting participant feedback using an evaluation instrument that incorporates andragogy *a priori* may provide more explicit and robust data in relation to our research question.

CONCLUSION

Since its development in the 1970s, andragogy has been applied to many fields of education and professional development. It is a useful and practical theoretical framework that can be applied to almost any adult learning experience, including team science training. Using direct participant feedback, our results show that andragogical principles are important in a biomedical research setting and that instructors should incorporate andragogy into the development and implementation of team science training opportunities in order to

better meet the needs of adult learners. This work represents an advance in biomedical science because it demonstrates that andragogy can serve as a useful theoretical framework when designing team science training for biomedical researchers.

SUMMARY TABLE

What Is Known About This Subject

- Malcolm Knowles developed andragogy theory to provide a framework for understanding the distinct learning patterns of adult learners.
- Andragogy has been demonstrated to be useful in several fields, but not in team science training for biomedical researchers.

What This Paper Adds

- Using learner feedback, we evaluated the usefulness of integrating andragogy into team science training workshops.
- We found both quantitative and qualitative data suggesting that the incorporation of andragogical principles was valued by learners.
- This work represents an advance in biomedical science because it demonstrates that andragogy can serve as a useful theoretical framework when designing team science training for biomedical researchers.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This study was reviewed by the University of Cincinnati Institutional Review Board (IRB) and determined to not be human subjects research (IRB #2024-0184).

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

FUNDING

Work on this manuscript was supported by the CCTST at the University of Cincinnati, which is funded by the National Institutes of Health (NIH) Clinical and Translational Science Award (CTSA) programme, grant UL1TR001425. The CTSA programme is led by the NIH's National Center for Advancing Translational Sciences (NCATS).

AUTHOR DISCLAIMER

The information or contents and conclusions are those of the author and should not be construed as the official position or policy of, nor should any endorsement be inferred by the NIH, NCATS, or the U.S. Government.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2024.12651/full#supplementary-material

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ORIGINAL RESEARCH
published: 04 March 2024
doi: 10.3389/bjbs.2024.12148

Assessing the Efficacy of Active Learning to Support Student Performance Across Undergraduate Programmes in Biomedical Science

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Introduction: Active learning is a useful tool to enhance student engagement and support learning in diverse educational situations. We aimed to assess the efficacy of an active learning approach within a large interprofessional first year Medical Cell Biology module taken by six healthcare programmes across the School of Biomedical Sciences at Ulster University, United Kingdom.

Materials and methods: An active learning approach was developed for weekly formative assessment using Smartwork to design a weekly interactive multiple-choice quiz to reinforce key concepts specifically for each lecture. We tracked and assessed student performance in the module overall and in each element of course work and exam for 2 years prior to and following the introduction of an active learning strategy to engage and support learning for students from all academic backgrounds and abilities.

Results: Full engagement with active learning was significantly associated with an increased overall module performance as well as a significantly increased performance in each element of class test (No engagement vs. Full engagement, $p < 0.001$), exam (No Engagement vs. Full engagement, $p < 0.05$) and coursework (No engagement vs. Full engagement, $p < 0.001$) within this overall total (No Engagement vs. Full engagement, $p < 0.01$). Partial engagement with active learning was associated significantly improved class test (No engagement vs. partially engaged, $p < 0.001$) and coursework (No engagement vs. partially engaged, $p < 0.05$) performance. While a trend toward increased performance in exam and overall module mark was observed, these were not significant.

Discussion: Active learning is a useful tool to support student learning across a range of healthcare programmes taken by students with differing backgrounds and academic abilities in an interprofessional and widening participation setting. Student engagement in active learning was highlighted as a key contributory factor to enhanced student performance in all aspects of assessment.

Keywords: active learning, Smartwork, IPE, student engagement, interprofessional

OPEN ACCESS

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Received: *28 September 2023*
Accepted: *16 February 2024*
Published: *04 March 2024*

Citation:
Lees-Murdock DJ, Khan D, Irwin R, Graham J, Hinch V, O'Hagan B and McClean S (2024) Assessing the Efficacy of Active Learning to Support Student Performance Across Undergraduate Programmes in Biomedical Science. Br J Biomed Sci 81:12148. doi: 10.3389/bjbs.2024.12148

INTRODUCTION

Active learning is described as any activity that involves students in doing and thinking about what they are doing, rather than passively listening [1] and is a valuable tool to increase interactivity and stimulate engagement [2] especially in challenging environments such as interprofessional education (IPE) and widening access and participation (WAP) settings [3]. In these environments active learning can help diverse learners including those from underrepresented backgrounds to stay motivated and engaged in the learning process [4].

IPE encourages the collaborations of health and social care professionals from different disciplines. CAIPE defines interprofessional education (IPE) as "occasions when two or more professions learn with, from and about each other to improve collaboration and the quality of care" [5]. Extending CAIPE's definition, Ulster recognises IPE to include "simulated environments and practice settings to improve collaboration and optimal outcomes" [6]. Learning together improves collaborative working in the future workplace [7] and is driven by evolving models of healthcare delivery within an aging population context and the rising prevalence of chronic health problems, as well as patient safety issues [8]. The delivery of complex healthcare requires a team-based and collaborative approach [8, 9] to deliver improvements in patient outcomes, patient safety, and quality of healthcare which have been linked to interprofessional education and practice [10].

Active learning promotes collaboration and communication closely aligning with the objectives of IPE, encouraging students to work together, improve teamwork and communication skills which are essential in interprofessional settings [11]. It allows lecturers to cater for diverse learning styles, ensuring that learners from various backgrounds and with different preferences can access and absorb information.

Traditional teaching and assessment methods have been identified as barriers to participation for students from backgrounds that may not usually consider a university education [12]. To support the active participation of all learners, active learning can be adapted to accommodate the needs and abilities of all learners, making it inclusive. In IPE and widening participation efforts, inclusivity is essential to ensure that all students can actively participate and succeed [13].

Educators in Higher Education face the challenge of engaging students and the adoption of more active methods of delivering content to students is increasingly recognized as central to the process [14]. Ensuring student participation in active learning involves establishing expectations about what is involved and why we do this. It relies on our ability to design active learning tasks effectively to ensure that students have a role in acquiring knowledge and skills, rather than simply passively receiving information from the lecturer. Active learning promotes a culture of learning, sharing, collaborating, and doing through effective, continuous and active education to prepare students better for the workplace [15]. These innovative developments align with the Ulster Strategy for Learning and Teaching (sLaTe) by providing an environment that ensures students from all backgrounds can successfully achieve learning outcomes that enhance their capability to make a positive and valuable contribution to society and the economy [16].

While courses within the School of Biomedical Science continue to observe very low rates of attrition and excellent progression, we still strive to deliver ongoing enhancement of learning and teaching by creating an inclusive and diverse student learning environments, facilitating authentic independent learning, economically important skills, and intellectual capital.

Scaffolding, in a higher education curriculum, accepts that many students will begin without key knowledge and skills and that they may be used to a more passive, performance focussed approach to learning [17, 18]. The Medical Cell Biology module was traditionally taught using conventional teaching strategies including assigned reading from hard copy texts. To introduce active learning, bespoke reading material was assigned to support individual lectures which was accessed electronically following each lecture using Smartwork (W. W. Norton & Company, United States) in the academic years 2021–2022 and 2022–2023. We chose to implement Smartwork as a framework for active learning to develop banks of questions, quizzes and support materials. Additionally, it can be tailored to allow students to practice problem solving skills and offers the opportunity for a variety of interactive question types, extensive answer-specific feedback and instructor flexibility so questions could be designed to fit the course.

In summary, active learning is crucial for interprofessional education and widening participation because if used effectively it can enhance engagement, address diverse learning styles, increase accessibility, foster critical thinking and supports the active participation of all learners, contributing to more inclusive and effective educational practices.

The aim of this study was to assess the efficacy of the Smartwork active learning tool in supporting performance and attainment of interprofessional students across Biology, Biomedical Science, Dietetics, Food & Nutrition, Human Nutrition and Optometry programmes from a range of backgrounds at Ulster University, United Kingdom.

MATERIALS AND METHODS

Participants

All undergraduate students enrolled in first year undergraduate Medical Cell Biology 20 credit point module from academic year 2019–2020 to 2022–2023, within the School of Biomedical Sciences at Ulster University were offered the opportunity to take part in this study. Students enrolled in this module were taking different degree programmes across the School including Biomedical Science (Pathology), Biomedical Science with Diploma in Professional Practice (DPP), Biomedical Science, Biology, Dietetics, Food and Nutrition, Human Nutrition and Optometry (n = 777; pre-Smartwork years n = 374 and post-Smartwork years n = 403). All Biomedical Science courses were accredited by the Institute of Biomedical Science (IBMS), the Biology programme is undergoing accreditation by The Royal Society of Biology, and Nutrition programmes are accredited by British Dietetic Association, Institute of Food Science &

Technology and Association for Nutrition. All academic staff associated with the Medical Cell Biology module were involved in tracking the assessment and engagement of the students enrolled. Students were then categorised based on degree of engagement with the Smartwork tool for learning. Ethical approval for this study was granted by the Biomedical Sciences Ethics Filter Committee Project Number FCBMS-21-019-A.

Evaluation Methodology

There is a wide range of attainment for first year undergraduate students transitioning to study various programmes across the School of Biomedical Sciences and we aimed to investigate the efficacy of an active learning strategy on performance and attainment in a large interprofessional and widening participation setting.

Weekly reading was assigned to students to read prior to each lecture in the electronic textbook. A weekly formative interactive multiple-choice quiz was designed to reinforce key concepts specifically for each lecture and released to students immediately after each lecture. A mixture of predesigned questions from the Smartwork test bank and those designed by instructors to align with material taught in the course were used. Questions were of a variety of formats and were designed to develop critical thinking skills. Input from students who previously took the module, and results of previous class tests, highlighted where students might experience most difficulties and informed question design. For each lecture, a set of multiple-choice questions was designed to assess students' understanding of the key concepts. The quiz questions were formulated to cover a range of cognitive levels, including recall, understanding, application, and analysis. To ensure diversity and depth in assessment, a combination of questions was drawn from two sources: newly created questions by the course team and existing MCQs available in the eBook platform. Quiz feedback was immediate and crucially included links directly to relevant subsections in the electronic textbook, providing key material to help students understand concepts in which they required further development before repeat attempts at the question.

The online statistic tracking built in within the digital capabilities of Smartwork was used to track student engagement and was categorised based on student engagement as "No engagement" (students who did not attempt any quizzes), "Engaged" (students who attempted some quizzes but not all) and "Full engagement" (students who attempted all quizzes). Average marks of class test, final exam, coursework and overall module marks were compiled based on Smartwork usage of students over academic year 2021–2022 and 2022–2023. An e-mail was sent to all students (post-semester) enrolled in the module for a survey-based questionnaire on the use of Smartwork as a tool for learning enhancement. Students (n = 17) answered aspects of key features that they felt was helpful to successfully complete the novel learning activities. Quantitative data and statistical evaluation allowed further refining and evaluation of the outcomes of this module pre- and post-Smartwork years from data gathered through questionnaires and analysis of assessment outputs.

Statistical Analyses

Data gathered from questionnaire responses (mean ± standard error of the mean) were reported. Statistical analysis was performed using GraphPad PRISM (La Jolla, CA, United States; version 5). Data are presented as mean ± SEM for a given number of observations (n) as indicated in the figures. Differences between groups were compared using one-way ANOVA or unpaired 2-tailed Student's t-test as appropriate. Statistical significance was accepted at $p < 0.05$.

RESULTS

Marks for All Assessments for Last Four Academic Years

All results include assessment marks over four academic years (AY), 2 years pre-Smartwork (AY 2019–20 and AY 2020–21) and 2 years post-Smartwork (AY 2021–22 and AY 2022–23). Class test marks over four academic years is shown (**Figure 1A**). Class test in AY 2019–20 average was 71.01% ± 1.19 (n = 161) whilst in AY 2020–21 the class test average was 81.94% ± 0.64 (n = 206). In the next two academic years, online assessments were introduced (due to COVID protocol) and the active learning strategy including electronic reading and digital Smartwork quizzes were added to the learning methods. Similar results were seen in both AY of 2021–22 and 2022–23 with class test average of 85.16% ± 0.70 (n = 182) and 83.29% ± 0.82 (n = 221), respectively. Similar to the class test, the final exam, coursework and overall module marks over four academic years is shown (**Figures 1B–D**). Exam marks in AY 2021–22 and 2022–23 showed increment m = 73.90 ± 0.90 (n = 164); m = 69.64 ± 0.89 (n = 210) compared to AY 2019–20 and AY 2020–21 m = 88.43 ± 0.59 (n = 182); m = 86.11 ± 0.55 (n = 221). Coursework and overall module marks also showed similar increased trend with an anomaly of coursework marks of AY 2020–21 which had one cancelled assessed practical due to COVID-19.

Overall Module, Final Examination and Class Test Marks for Last Four Academic Years Separated by Courses

Figures 2A, **3A**, **4A** show overall module, final examination and class test marks from AY 2019–20 to AY 2022–23 for each of the various courses within School of Biomedical Science undergraduate program and taking the Medical Cell Biology module. **Figures 2B**, **3B**, **4B** highlight pre- and post-Smartwork marks combined for two academic years. Interestingly, we did not see any change in overall module and class test marks for any course individually. This could be due to different number of students enrolled in different courses. However, final exam marks post-Smartwork significantly increased ($p < 0.05$ to $p < 0.01$) in Biomedical Science,

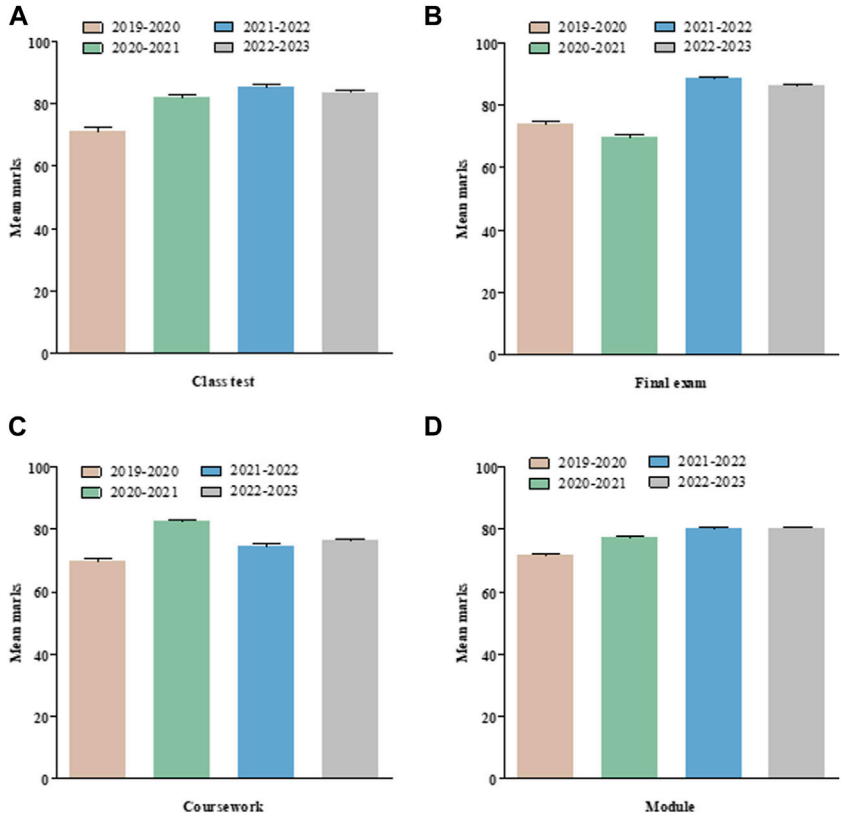

FIGURE 1 | Overall marks for different types of assessment in Medical Cell Biology module. Marks for all assessments for the full cohort over the last four academic years. **(A)** Class test **(B)** Final exam **(C)** Coursework and **(D)** Overall module marks. Values are mean ± SEM.

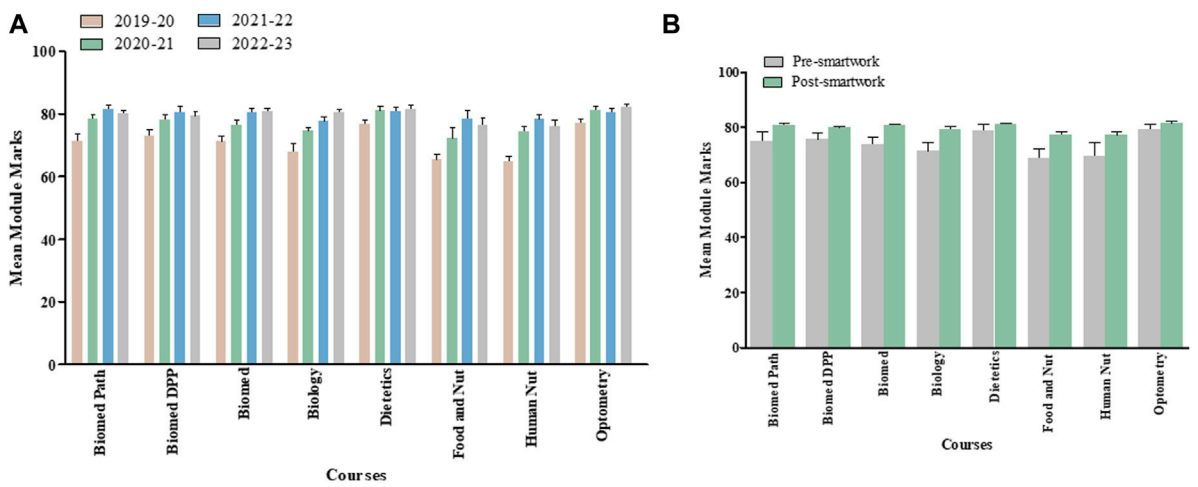

FIGURE 2 | Overall module marks for each cohort within a Medical Cell Biology module pre- and post-Smartwork **(A)** Mean module marks for the last four academic years for each course of study **(B)** Mean module marks pre- and post-Smartwork combined for two academic years. Values are mean ± SEM.

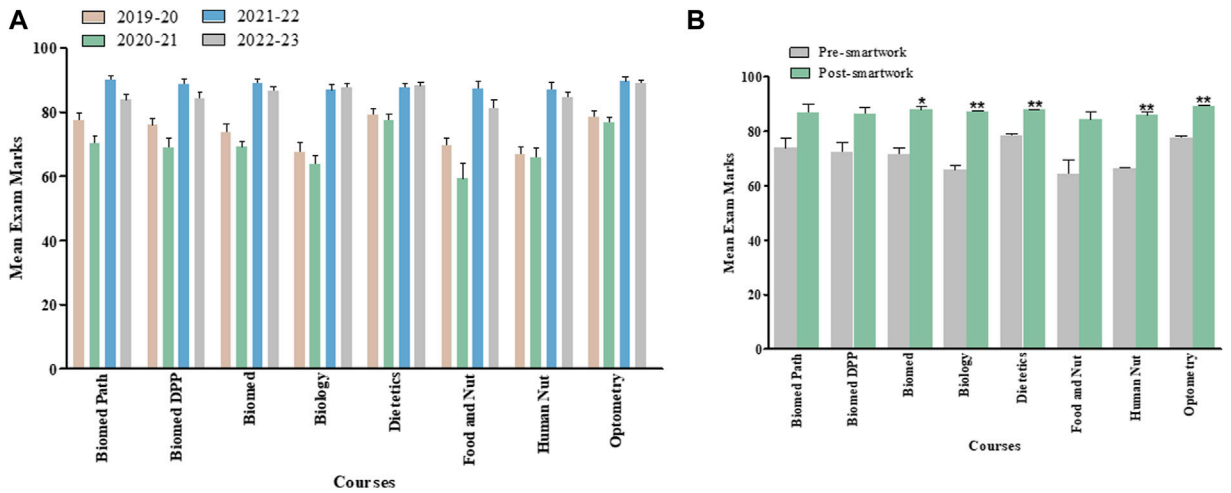

FIGURE 3 | Exam marks for each cohort within a Medical Cell Biology module pre- and post-Smartwork **(A)** Mean exam marks for the last four academic years separated by courses **(B)** Mean exam marks pre- and post-Smartwork combined for two academic years. Values are mean ± SEM.

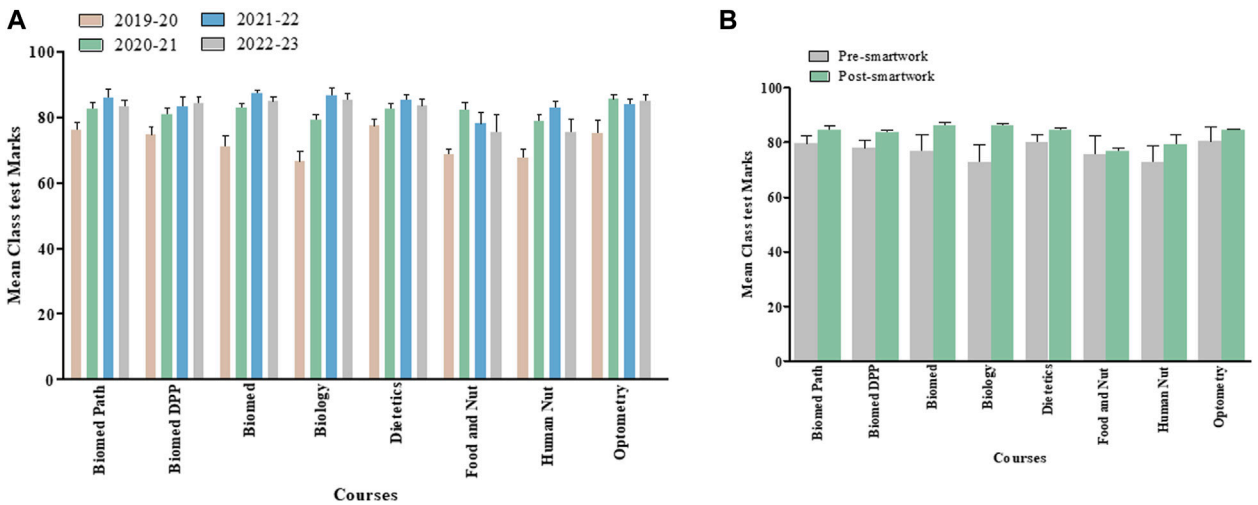

FIGURE 4 | Class Test marks for each cohort within a Medical Cell Biology module pre- and post-Smartwork **(A)** Mean class test marks for the last four academic years separated by course **(B)** Mean class test marks pre- and post-Smartwork combined for two academic years. Values are mean ± SEM.

Biology, Dietetics, Human Nutrition and Optometry courses compared to pre-Smartwork counterparts.

Average Marks and Students Feedback Post-Use of Smartwork

Smartwork engagement was then assessed, and marks were analysed with respect to students' interactions with the weekly digital quizzes (**Figure 5**). Fully-engaged students showed significant ($p < 0.5$ to $p < 0.001$) increment in marks for all aspects of assessment including class test, exam, coursework, and overall module in two academic years (2021–22 to 2022–23). We also observed significant ($p < 0.5$ and $p < 0.001$) improvement in coursework and class test marks. **Table 1** shows detailed student perception to using Smartwork digital quiz for learning enhancement. Post-AY 2022–23, student feedback form was circulated and approximately 78% students believed that the Smartwork quiz helped them to perform better in class tests and almost 74% of students noting Smartwork quizzes were a useful revision tool and aided the understanding of key concepts (**Table 1**).

DISCUSSION

The data reported here indicate that full engagement with an active learning approach is significantly correlated with increased overall performance in a large interprofessional module and a

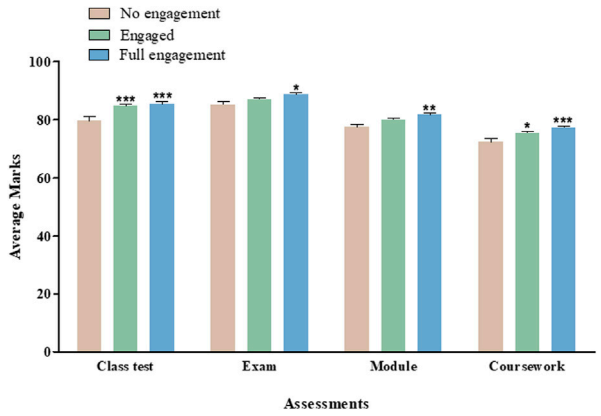

FIGURE 5 | Assessment Marks based on different levels of student engagement with Smartwork. Average marks for class test, final exam, overall module and coursework post-Smartwork combined for two academic years. Values are mean ± SEM.

significantly increased performance in each element of class test, exam and coursework within this overall total. There was also a correlation between partially engagement with the active learning approach and significantly improved class test and coursework performance, however while a trend toward increased performance in exam and overall module mark was observed, these were not significant.

We assessed the overall module performance and for each individual element of assessment for 2 years prior to active learning intervention and 2 years post-intervention for a large interprofessional first year module within the School of Biomedical Sciences (**Figure 1**) which attracts a significant proportion of students from widening participation backgrounds, ranging from 10% to 40% depending on programme. When taking the cohort as a whole, we initially observed no significant difference in mean module overall performance for any programme taking this module (**Figure 2**), when we look at each element individually we observed a significant improvement in exam marks for Biomedical Science, Biology, Dietetics, Human Nutrition and Optometry cohorts, with a general trend towards improvement for the remaining cohorts following the introduction of active learning activities (**Figure 3**). This scale and direction of our findings are in keeping with a meta-analysis of 225 studies comparing exam scores and student performance in undergraduate STEM programmes taught by traditional lecturing versus active learning. Average exam scores improved by ~6% in active learning classes and students were 1.5 times more likely to fail in traditional classes than students taught by active learning [18].

We also observed a smaller, non-significant improvement in class test marks for each cohort (**Figure 4**). In large cohorts, small effects can be challenging to detect statistically, especially if there is substantial variability within the group including diverse academic backgrounds, skills, and study habits. In addition, external factors, such as COVID-19 isolation protocols or unexpected life events, during the semester may have played roles in class test outcomes. Nonetheless, these non-significant results are worth mentioning as they offer potential for designing future studies conducted in large cohorts of students. As the class tests take place twice during the module, each assesses a smaller amount of work than the exam, the benefit of active learning is not as pronounced as for exam performance which assessed all of the module content in one sitting. Class tests may therefore be more manageable particularly for weaker cohorts, suggesting that the main benefit of active learning is through meaningful learning for exam performance [19].

We then examined performance in each element of assessment and in the module overall in students stratified by engagement with active learning. Interestingly, students who fully engaged with active learning performed significantly better across all aspects of assessment and in the module overall compared to those who did not engage. Students who partially engaged in active learning also scored significantly higher in class tests and coursework but not exam or overall module performance compared to those who did not engage at all (**Figure 5**). These results suggest that active learning promotes academic attainment in all elements of assessment reflective of recent studies including the finding that active learning encouraged higher student motivation, participation in class and improved academic performance in a Chemical Engineering course at University of Madrid [20]. There are many possible reasons for the observed improvement in performance, following introduction of active learning, in addition to engagement, however the main additional advantage may be that this method allows learning to be broken down into manageable

TABLE 1 | Detailed student perception and feedback to using Smartwork digital quiz for learning enhancement.

Question	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree
1. I understood how to access the Smartwork quiz platform	52.63%	26.32%	15.79%	5.26%	0.00%
2. I found the Smartwork quiz easy to navigate and use	42.11%	36.84%	15.79%	5.26%	0.00%
3. I enjoyed using Smartwork quiz	26.32%	36.84%	10.53%	26.32%	0.00%
4. I found the level of difficulty of the questions asked in quiz approriate	31.58%	42.11%	21.05%	5.26%	0.00%
5. I felt that Smartwork quiz were a useful revision tool for class tests	36.84%	36.84%	15.79%	10.53%	0.00%
6. I felt that Smartwork quiz helped me to understand key concepts within the module	36.84%	36.84%	10.53%	10.53%	5.26%
7. I felt the Smartwork quiz helped me to perform better in class tests	47.37%	31.58%	5.26%	15.79%	0.00%

chunks as students are directed to small sections of relevant text if they fail to answer a question correctly. Providing manageable chunks of information has been identified as a key strategy to foster an inclusive educational environment [21]. We also cannot rule out the possibility that there was some bias in student engagement with the Smartwork tool, with more motivated students choosing to engage with and complete assessments. Other reasons for limited student engagement with the weekly online quizzes may be due to potential factors including user-friendliness of the online platform or unfamiliar interfaces may deter students. Additionally, the perceived relevance of the quizzes to overall course objectives and assessments when other modules do not have similar tools could influence student motivation.

Feedback from students engaged with active learning was largely positive. Of those that responded and who were engaged with active learning, over 73% report that it was a useful revision tool for class tests and helped to understand key concepts being taught while over 78% felt that the active learning helped them perform better in class tests (**Table 1**) and this is reflected in the results above.

One of the main advantages of this study is that it was conducted within a large interprofessional education and widening participation setting, where we could observe the effects of the active learning intervention in cohorts of varying academic abilities. Optometry, Dietetics and Biomedical Science Pathology programmes are highly competitive and attract students with higher average tariff entry points compared to students from other programmes taking this module. When looking at each cohort individually we observed that there was increased performance particularly in the sessional end of term exam following the introduction of Smartwork for both academically strong cohorts (e.g., Optometry and Dietetics) as well as weaker cohorts such as Biology, suggesting that active learning enhances performance independent of student background or course of study.

Limitations of this study include that it was conducted during years impacted by the COVID pandemic. While we cannot definitively exclude the possibility that student performance was impacted by COVID-19 pandemic in 19/20 and 2020/21, we remain confident that these results are reflective of student attainment in previous years as a university-wide audit of exam marks was carried out to ensure that student performance was not significantly impacted in these years compared to those preceding, providing reassurance that these 2 years pre-Smartwork years included in our study are representative of further previous years' exam performance. Although, we did not collect any formal data of the impact of COVID-19 lockdown, rapid transition to the use of online educational tools may have impacted student's learning and teacher's adaptability to digital pedagogy. However, further comprehensive studies need to be conducted, including further cohort(s) of students to unravel the true impact of COVID-19 on teaching and learning. Further similar studies involving other courses within the University will also strengthen our findings and may answer some of the limitations highlighted. In addition, assessing student's overall performance comparing to other modules to focus on other external factors including educational adaptation during COVID using the online assessments warrants a separate comprehensive study.

The presented study shows positive correlation between student engagement with weekly online quizzes and improved final grades. This outcome may be attributed to several factors which include that the quizzes served as an effective informal assessment tool, allowing students to regularly gauge their understanding. Moreover, this contributed to enhanced self-learning which can be challenging for first year Undergraduate student cohorts. Finally, students who engaged with the quizzes mentioned reduced anxiety associated with exams. However, while this study demonstrated the correlation between active learning engagement and improved performance, further studies are required to definitively establish causation. In conclusion, active learning is a useful tool to support student learning across a range of healthcare programmes taken by students with differing backgrounds and academic abilities in an interprofessional setting. Students come from different backgrounds with widely diverse needs. Our study encourages use of active learning tools as an effective way to bridge the gap between student's educational background and the content more accessible for their understanding.

SUMMARY TABLE

What Is Known About This Subject

- Active learning engages students in hands-on activities and critical thinking, fostering interactivity and enhancing participation.
- Active learning promotes collaboration and communication which are essential in interprofessional settings.
- Diverse learning styles, increased accessibility and critical thinking are supported by the active participation of all learners, contributing to more inclusive and effective educational practices.

What This Paper Adds

- Assessment of the efficacy of the Smartwork active learning tool in supporting performance and attainment of interprofessional students from different backgrounds with widely diverse needs.
- Our study encourages use of active learning tools as an effective way to bridge the gap between student's educational background and the content, making it more accessible for their understanding.

CONCLUDING STATEMENT

This work represents an advance in biomedical science because it shows that active learning is a useful tool to support student learning in healthcare programmes taken by students with differing backgrounds and academic abilities in an interprofessional setting.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving humans were approved by the School of Biomedical Sciences Ethics Filter Committee Project Number FCBMS-21-019-A. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

DL-M, conceived the study. DL-M, DK, RI, VH, and BO'H conducted the study, collected data, and wrote the manuscript. DK and JG analysed the data, performed statistical analysis, gathered feedback for analysis and wrote the manuscript. SM contributed to the development of the study themes, critically guided the study and reviewed the data. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2024.12148/full#supplementary-material

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ORIGINAL RESEARCH
published: 20 February 2024
doi: 10.3389/bjbs.2024.12017

Measuring the Impact of Incorporating Case Study Presentations Into Applied Biomedical Science Placement Workshops for Trainee Biomedical Scientists

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Introduction: Successfully completing the Institute of Biomedical Science (IBMS) registration portfolio is essential to becoming a Health and Care Professions Council (HCPC) registered Biomedical Scientist. In the West Midlands, a unique collaboration between four universities (Aston, Wolverhampton, Coventry, and Keele) and local NHS Trusts supports student placements and portfolio development. The universities support Training Officers in delivering components of the registration portfolio through the delivery of eight combined placement workshops. These have been designed to align to the IBMS registration portfolio and help students meet the HCPC Standards of Proficiency. This study aimed to evaluate the effectiveness of a redesigned workshop where students generated and presented medical case studies to peers, academics, and training leads.

Materials and Methods: The three phases of the case study intervention included a pre-intervention survey, academic-led sessions focussing on medical case presentations and delivery of the presentation followed by a post-intervention survey.

Results: Analysing survey responses pre- and post-intervention, students demonstrated enhanced confidence in their understanding of clinical conditions ($p<0.0001$), connecting lab findings to diseases, and in delivering a case presentation to their peers ($p<0.001$). Students reported an increased confidence in structuring case presentations and their critical thinking ability ($p<0.0001$). All students agreed engaging with the case study workshop improved their ability to communicate knowledge of scientific concepts orally. Thematic analysis revealed that the case presentation deepened students' understanding of multidisciplinary teams. 98% of respondents agreed patient communication should be integrated into Biomedical Sciences courses and 85% would like to see case study presentations embedded into the curriculum.

Discussion: Combined placement workshops are an integral part of the Applied Biomedical Science placement journey. Case study presentations are clearly a valuable teaching and learning tool to nurture and develop key transferable skills and competencies in conjunction with Biomedical Science expertise. The collaborative approach in the West

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Received: 07 September 2023
Accepted: 07 February 2024
Published: 20 February 2024

Citation:
Bashir A, Dudley K, Rana KS, Wilkins K and Pallett R (2024) Measuring the Impact of Incorporating Case Study Presentations Into Applied Biomedical Science Placement Workshops for Trainee Biomedical Scientists. Br J Biomed Sci 81:12017. doi: 10.3389/bjbs.2024.12017

Midlands effectively prepares graduates with essential pathology knowledge, skills, and a completed IBMS registration portfolio. This study highlights a successful framework for a collaborative partnership with local NHS trusts that has allowed the completion of numerous pathology placements and could be adopted by other universities delivering accredited Biomedical Science courses.

Keywords: IBMS registration portfolio, biomedical science, HCPC SOPs, case study presentation, collaborative working

INTRODUCTION

To work as a Biomedical Scientist within an NHS laboratory, individuals must be registered with the Health and Care Professions Council (HCPC) [1]. Candidates must complete an Institute of Biomedical Science (IBMS) registration training portfolio in an IBMS approved training laboratory. This allows the candidates to demonstrate that they meet the HCPC Standards of Proficiency (SOPs) [2] and have developed the knowledge and skills required to work as a state registered Biomedical Scientist. Following a successful portfolio verification, individuals can be awarded the IBMS certificate of competence, enabling candidates to register with the HCPC.

There are two main routes for UK candidates wishing to complete their IBMS registration portfolio. The first route entails completing a 3-year IBMS accredited Biomedical Science undergraduate degree programme and seeking a trainee Biomedical Scientist position post-graduation. The second route involves the candidate completing an integrated placement year at the end of the second year of study. The Applied Biomedical Science route allows students to complete their IBMS portfolio prior to graduating [3].

Globally, it is well known that obtaining a placement within a medical setting can be difficult [4]. Reasons behind this difficulty can be due to medical workforce shortages, a lack of training leads, and high workloads impacting training delivery and capacity [5]. Specifically, within the UK, the NHS is facing its largest staff shortage in recent years with a need for fully qualified staff [6]. The pressure to hire fully qualified staff limits the number of available trainee Biomedical Scientist positions available to graduates. This makes the Applied Biomedical Scientist placements very competitive and are regarded as being highly prestigious.

The Role of a Successful University-Pathology Partnership for Placement Delivery

The relationship between higher education institutions (HEIs) and local NHS laboratories varies across the United Kingdom. A recent survey was distributed via the practice educator network to NHS pathology laboratories which sought to collect data related to graduate employability skills [7]. A major finding of this study identified that only 52% of pathology laboratories were involved in university employer liaison groups. Through the data, it was highlighted that some liaison groups were only meeting annually to discuss placement opportunities. Furthermore, comments were made about graduates not having a sound understanding of the importance of laboratory accreditation through the United Kingdom Accreditation Service (UKAS) and the essential role of pathology services in providing patient care [7].

As a Higher Education provider, the key to obtaining trainee Biomedical Scientist placement posts for students is creating a close relationship with local laboratory managers and practitioners [8]. Within the West Midlands, there is a unique partnership between four HEIs (Aston University, Wolverhampton University, Coventry University and Keele University) and the local NHS Trusts. This partnership was initially forged by Yvette Taylor, a Senior Biomedical Scientist and the training lead at Birmingham Children's and Women's Hospital. Yvette was central to creating links between local hospitals and universities, to establish the West Midlands Training Officer (WMTO) group, a bi-monthly forum to facilitate training-related discussions. Furthermore, these universities and hospitals are involved in a University Employer Liaison Committee (UELC) which meets at least three times a year to discuss placement student performance, portfolio progress, verification and future placement opportunities, in addition to tailored support provided by the universities in response to Training Officer needs. In order to further support Training Officers, each of the universities involved in the UELC host a Train the Trainer (TTT) day. Programmes have included portfolio verification training for new verifiers, discussion of appropriate evidence pieces and changes to HCPC SOPs [2]. An element of this partnership has been to support Training Officers in delivering components of the registration portfolio thus making this a "symbiotic relationship," as all parties are supporting each other equally [8]. The four universities deliver a series of combined placement workshops that have been designed to align to the IBMS registration portfolio and help students meet the HCPC Standards of Proficiency.

University Support Provided for Placement Students

The trainee Biomedical Scientist placements offered by the NHS Trusts within this unique partnership are specifically open to students from five universities, following the recent addition of Staffordshire University. The process has been streamlined over several years, with Aston, Wolverhampton and Coventry universities having contributed to the process for student applications (including the design of the application form), pre-placement laboratory audit form and combined placement workshop programme. Currently, the combined placement workshops are compulsory for students enrolled across all universities within the partnership. Students benefit from a

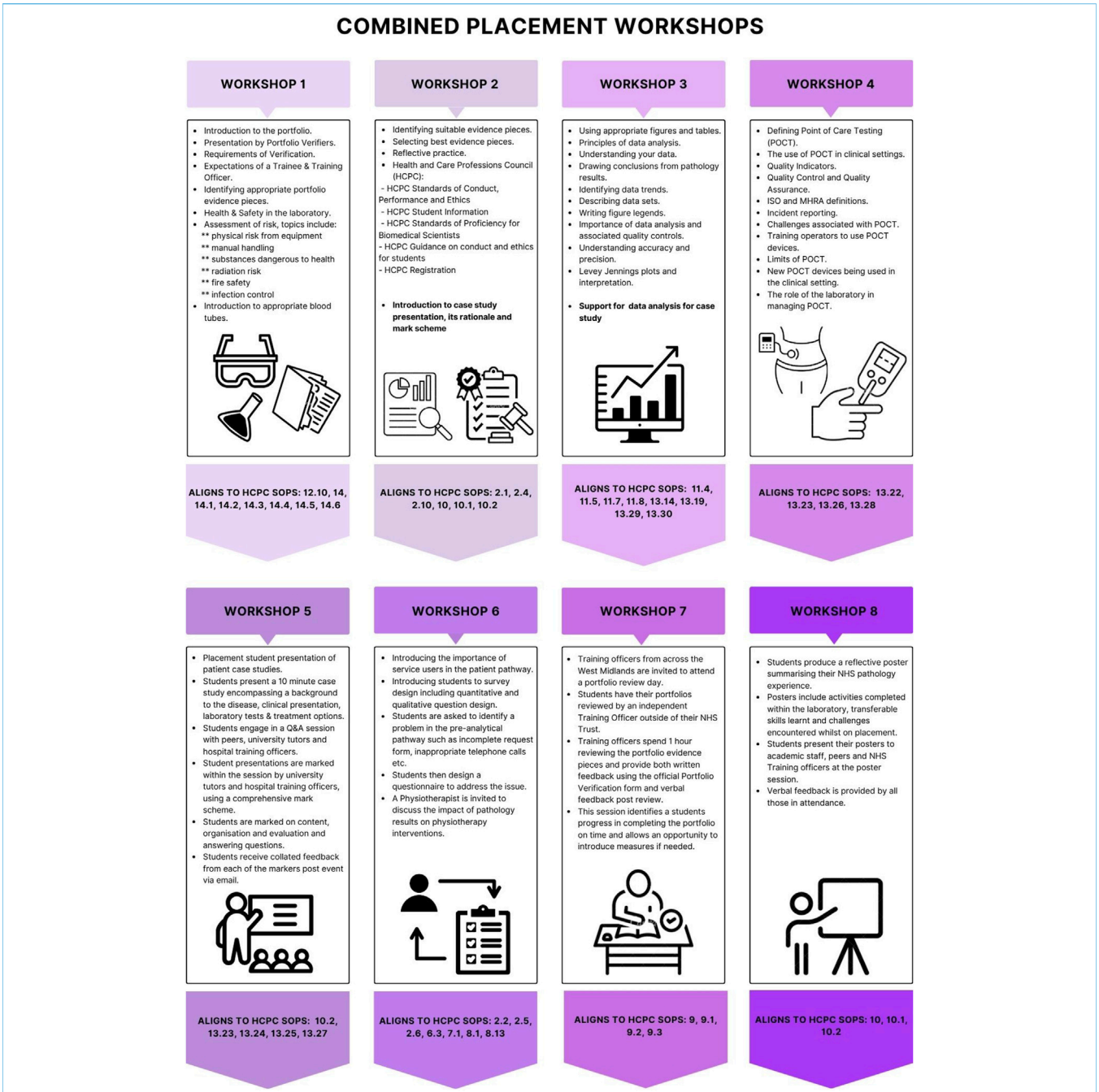

FIGURE 1 | Details of the eight combined placement workshops delivered across the placement year to support the completion of the IBMS registration portfolio with corresponding 2023 revised HCPC SOPs for Biomedical Scientists.

collaborative delivery approach, whereby the universities share the delivery of the workshops to support the ~30 students whilst on placement.

Students wishing to undertake trainee Biomedical Scientist placements are mentored through a series of pre-placement workshops to build the skill set required to work in pathology laboratories [7]. These include CV writing, placement application support, and mock interviews. Students are further supported with core skill development through attending pre-placement laboratory workshops, including microscopy, pipetting, preparing solutions, carrying out dilutions and basic diagnostic testing [9]. Students are also provided with a session led by local Training Officers which covers professional conduct and requirements of a registrant, dealing with sensitive data, patient confidentiality and effective communication. These pre-placement workshops are delivered by individual HEIs in

November with students applying for placements with local NHS trusts the following March/April to begin the sandwich placement in September.

The Significance of Developing Case Studies Within Biomedical Science

Originally, the HEIs delivered six combined placement workshops. Recently, a further two workshops have been introduced to include case study preparation to further align to the IBMS registration portfolio and help students meet the revised 2023 HCPC SOPs [2, 3] (**Figure 1**).

The first two workshops include a range of topics such as introducing students to the registration portfolio, expectations of HCPC registered professionals, health and safety in the laboratory, and appropriate evidence pieces. Workshop 3 focuses on data analysis and interpretation, whilst workshop 4 centres around point of care testing (POCT) and quality assurance. Workshop 5 requires students to present a patient case study to their peers, training officers and academics. Workshop 6 focuses on the central role of service users, focusing upon a specific example of how a physiotherapist utilises diagnostic laboratory test results to treat patients. Workshop 7 provides an important opportunity for training officers to review portfolio progress. As part of this workshop, students are required to bring their portfolios and an external training officer provides feedback on evidence pieces. The final workshop in the series requires students to present a poster which summarises their placement experience (**Figure 1**).

Further Embedding Case Studies Into the Biomedical Science Curriculum

One key factor that has been emphasised throughout the redesign is to further embed the significance of understanding case studies within Biomedical Science. Prior to re-designing the case study workshop, students were required to independently construct and present a case study presentation at one of the host universities. Historically, feedback from the Training Officers who marked the case study presentations demonstrated varying levels of success and engagement from students. For example, some presentations failed to discuss the laboratory tests, how they are performed and the importance of the results on the patient pathway. Another issue highlighted pre-design of the workshops was students expressed transport difficulties to attend one of the host universities within the West Midlands region. This meant that some students could not attend the entire workshop and ultimately missed out on this educational experience. To address these issues and better support all students, the case study combined placement workshop was redesigned to be delivered virtually and more structure was provided for constructing and presenting medical case studies.

The aim of this study was to evaluate the success of preparing trainee Biomedical Scientist placement students to effectively construct and evaluate a medical case study, that was delivered to a virtual audience of student peers, academics and training leads. The survey sought to determine whether the format was effective in deepening a student's understanding of the importance of pathology services within the delivery of a multi-disciplinary team working together for modern patient care.

MATERIALS AND METHODS

Placement Opportunities Within the West Midlands

Each year the number of placement opportunities for trainee Biomedical Scientists in the West Midlands varies depending on the laboratory training capacity. **Table 1** shows the number of positions that have been available over the past 3 years. The four universities put on a series of combined placement workshops throughout the year to support Training Officers and trainee Biomedical Scientists to complete the IBMS registration portfolio. These workshops are delivered to all students across the four universities and have compulsory attendance.

Case Study Workshop Re-Design

To improve understanding of disease conditions, laboratory diagnosis and treatment this pedagogical intervention was introduced in the year 2020. Students who choose to participate were required to read a Participant Information Sheet and complete the online consent form prior to taking part in the study. Ethical approval for this survey was covered by the original three universities in the West Midlands working group (Aston University Ethics #1734, Wolverhampton University Ethics #3693 and Coventry University Ethics #1258). Throughout the 3 years, responses from participants across the now five contributing universities have been gathered.

The research was conducted in three phases. In Phase 1, we determined the students' current understanding of medical case presentations and their associated benefits through the completion of a pre-intervention questionnaire using the Online Survey tool [10] (**Supplementary Material S1**). In Phase 2, a session was delivered to support students' understanding of the benefits of medical case presentations and to support the development of their own medical case presentations via Microsoft Teams. Students were required to include disease aetiology, laboratory tests performed to support diagnosis and the specific role of the student in the diagnosis pathway. Students needed to discuss the laboratory results for the patient, in addition to treatment. Students also needed to highlight where relevant the role of the multidisciplinary team in patient care. Students then had a 6-week period to construct their case presentations, where they were able to gain support from university academics and their training leads. In Phase 3, all students were allocated an online time slot to deliver a short presentation to the group via Microsoft Teams (5 min presentation and 5 min for questions and comments from the audience). Finally, students were invited to complete a post-intervention questionnaire, which determined whether their

TABLE 1 | Placement opportunities within the West Midlands between 2020 and 2023, and survey completion rates.

Year	Number of trainee BMS positions in the West Midlands	Total number students who completed the survey
2020–21	20	12 (70%)
2021–22	19	17 (90%)
2022–23	30	19 (63%)

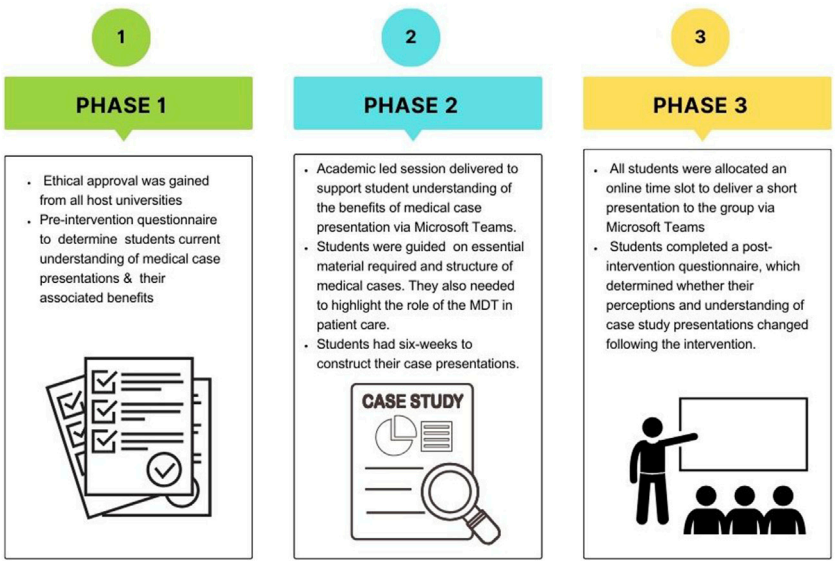

FIGURE 2 | The three phases of the case study intervention. This includes a pre-intervention survey, academic-led sessions focussing on medical case presentations and delivery of the presentation followed by a post-intervention survey.

perceptions and understanding of case study presentations changed following the intervention (**Figure 2**).

Training Officer Feedback

Pathology Training Officers who recruit students through the West Midlands Applied Biomedical Science Placement process were invited to provide feedback on the combined placements workshops and training provided by the universities.

Data Analysis

Quantitative data gathered from the case study evaluation survey was reported as mean ± standard error of the mean and Median. Likert Scale responses were converted to a numeric format (4 = confident, 3 = slightly confident, 2 = somewhat confident and 1 = not very confident) prior to statistical analyses using non-parametric methods. For all pre and post case study data, a Wilcoxon signed-rank test was conducted using IBM-SPSS Statistics version 26. Statistical significance was set at $p < 0.05$. Free text comments were analysed via thematic analysis using the Braun and Clark Framework to identify significant themes [11].

RESULTS

A total of 48 students who engaged in the case study workshop completed the pre and post survey over 3 years [2020–21 ($n = 12$), 2021–22 ($n = 17$) and 2022–23 ($n = 19$)]. All survey responses were anonymous to avoid any form of bias (**Table 1**).

Free Text Responses for Thematic Analysis

Pre-Survey

In the pre-case study workshop, students were asked what skills they thought were necessary to effectively deliver a case study presentation. Student responses included confidence, public speaking, oral and written communication, maintaining eye contact, time management, organisation, active listening, and critical thinking.

A free text option question was included to gauge a better understanding of the importance of the need for clinical data interpretation as part of case study presentations, (Q23). In total, 77% ($n = 44$) of the students answered question 23. Some student responses fit into multiple themes and once the responses were analysed the four finalised themes identified were categorised as shown in **Figure 3**. The most prominent themes identified were:

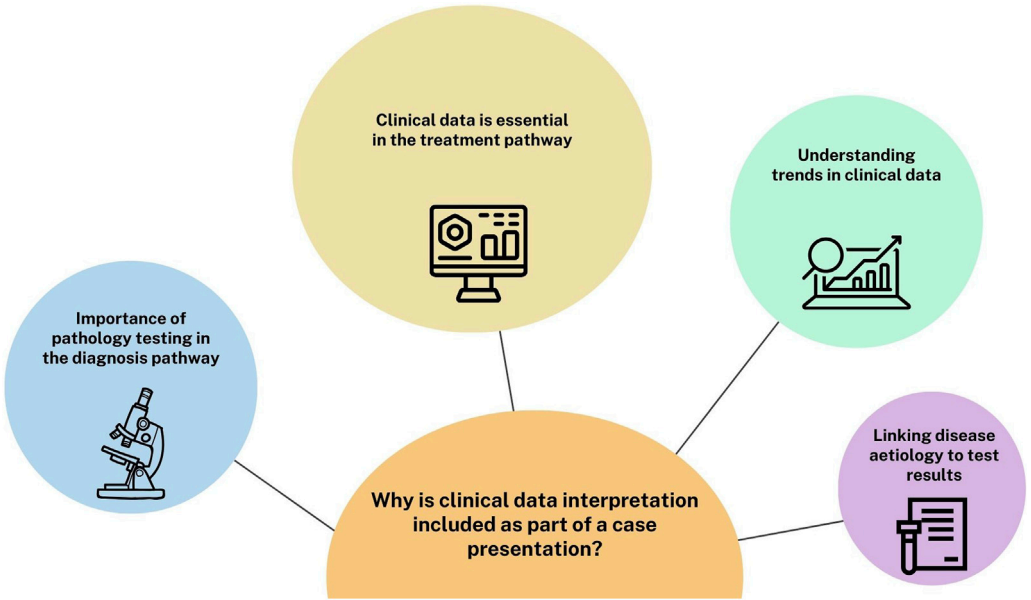

FIGURE 3 | A thematic analysis of open-text responses to the importance of clinical data interpretation as part of case study presentations. This question was included in the pre-intervention survey. Four major themes were identified, and the occurrence of each theme is represented by the size of each circle in the schematic. Several students open-text responses contained more than one theme.

1. Clinical data is essential in the treatment pathway.
2. The importance of pathology testing in the diagnosis pathway.
3. Understanding trends in clinical data.
4. Linking disease aetiology to test results.

Specific comments included:

> "As a Biomedical Scientist it's important to have a good understanding of how the data relates to a patient and the care they receive"
>
> "Clinical data interpretation is included to show how medical professionals reach the conclusion of a specific condition/disease/syndrome. It also provides knowledge to those listening to the presentation who may not be aware a syndrome/disease/condition"
>
> "It is important to analyse the findings in patient results and linking this to the clinical details of the patient. To interpret clinical results, the case study can come to a possible conclusion with the type of disease being identified and methods of treatment prescribed to the patient to relieve their symptoms"
>
> "Clinical data interpretation is included as it gives greater context to the case, being able to visualise severity and relate this to the aetiology and the patient"
>
> "Interpretation enables the audience to gather an idea of how results link to diagnosis and disease pathophysiology. Applies knowledge to clinical situation"

The case study presentations included a wide range of clinical conditions, linked to the discipline the student undertook their placements in. Many of these conditions students would not have encountered in such depth during their undergraduate studies prior to placement. Examples of such conditions include Small Bowel Neuroendocrine Tumour; Autoantibodies-ANCA Associated Vasculitis and Pure Red Cell Aplasia. These clinical case studies are relevant to pathology disciplines that students must study to graduate from an IBMS-accredited degree. Students have a limited opportunity to rotate to other disciplines during their placement year and this case study workshop created an opportunity to learn about multiple pathology disciplines and health conditions in one session (**Figure 4**). Assessors were from a range of backgrounds with representatives from Biochemistry, Haematology, Immunology, Cellular pathology, and Microbiology.

Students Report an Increase in Transferable Skills Post-Workshop

Students were required to complete two short surveys, one prior to the case study workshop and one following their case study presentation. Student responses were coded into scores (4 = confident, 3 = slightly confident, 2 = somewhat confident and 1 = not very confident) and reported relative to their perceived confidence prior to engaging with the case study workshop.

Students self-reported an increase in confidence in their understanding of a range of diseases/disorders diagnosed in the laboratory and linking test results produced in the laboratory to diseases/disorders ($p < 0.0001$). Furthermore, students reported feeling more confident in giving a case presentation to their peers, ($p < 0.001$) as well as their overall confidence in public speaking ($p < 0.05$). Students demonstrated increased confidence in their ability to structure a case presentation and their confidence to think critically ($p < 0.0001$).

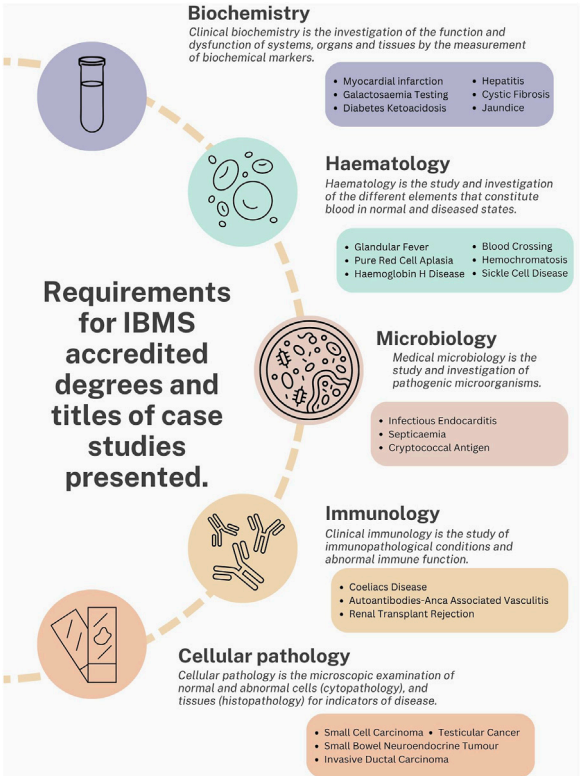

FIGURE 4 | Examples of clinical conditions covered by students during case study presentations. These are presented with the relevant disciplines the students completed their placements in, which are also mapped against the IBMS requirements for graduate learning on an IBMS-accredited program.

As part of the post-case study presentation survey, students were asked a series of questions. Most notably, if they felt engaging with the case study workshop improved their ability to communicate knowledge of scientific concepts orally. A total of 85% of respondents strongly agreed and 15% agreed with this statement. Furthermore, all students (100%) agreed or strongly agreed that working through the case study workshop improved their understanding of biological basis of disease. Finally, 46% of respondents strongly agreed and 54% of respondents agreed that following the completion of the case study workshops, students felt better placed to establish links between theoretical content and clinical practice. As shown in **Figures 5A–C**, all respondents (100%) either agreed or strongly agreed that the workshop improved these areas.

The case study workshop was successful in developing skills in using scientific resources, reflective thinking and clinical patient pathways**.** Additionally, 55% of respondents strongly agreed and 45% of respondents agreed that the case study presentation opportunity deepened their understanding of the topic through scientific sources. All students (100%) agreed or strongly agreed that the case presentation enhanced their reflective and critical thinking. Finally, all students (100%) agreed or strongly agreed that following the completion of the case presentation they had a better understanding of the whole patient pathway from sample collection and processing to the treatment of the patient. As shown in **Figures 6A–C**, all respondents (100%) agreed or strongly agreed that the case study strengthened each of these areas.

Furthermore, students had the opportunity to complete a free text box question related to **Figure 6**. In addition to their responses, a majority of respondents (95%) reported that the case study presentation increased their subject specific knowledge related to their discipline, whilst also deepening their understanding of the role of multidisciplinary teams.

Post Survey Open Ended Questions

In the post-case study workshop survey, students were asked what aspects of preparing and delivering the case study presentation

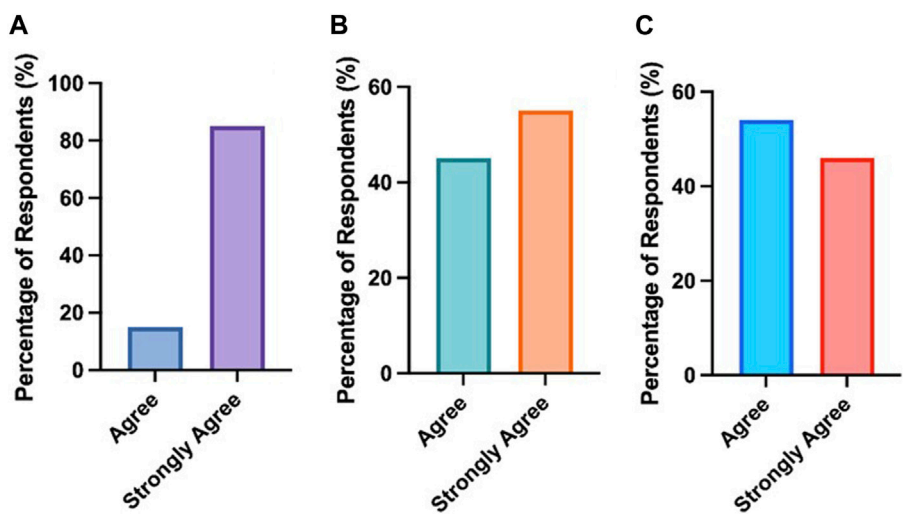

FIGURE 5 | All students agreed that engaging in the case study workshops enhanced **(A)** their ability to communicate knowledge of scientific concepts orally, **(B)** their understanding of the underlying biological basis of the disease and **(C)** helped them establish the link between theoretical content and practice.

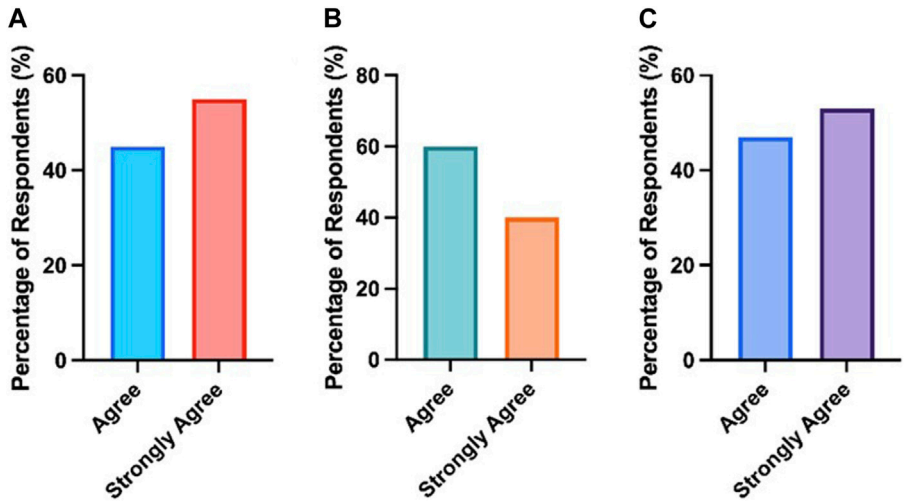

FIGURE 6 | All students agreed that engaging with the case study workshops enhanced **(A)** their understanding of the topic using online resources/books/review papers **(B)** their development of reflective and critical thinking and **(C)** understanding of the whole patient pathway from sample collection and processing to the treatment of the patient.

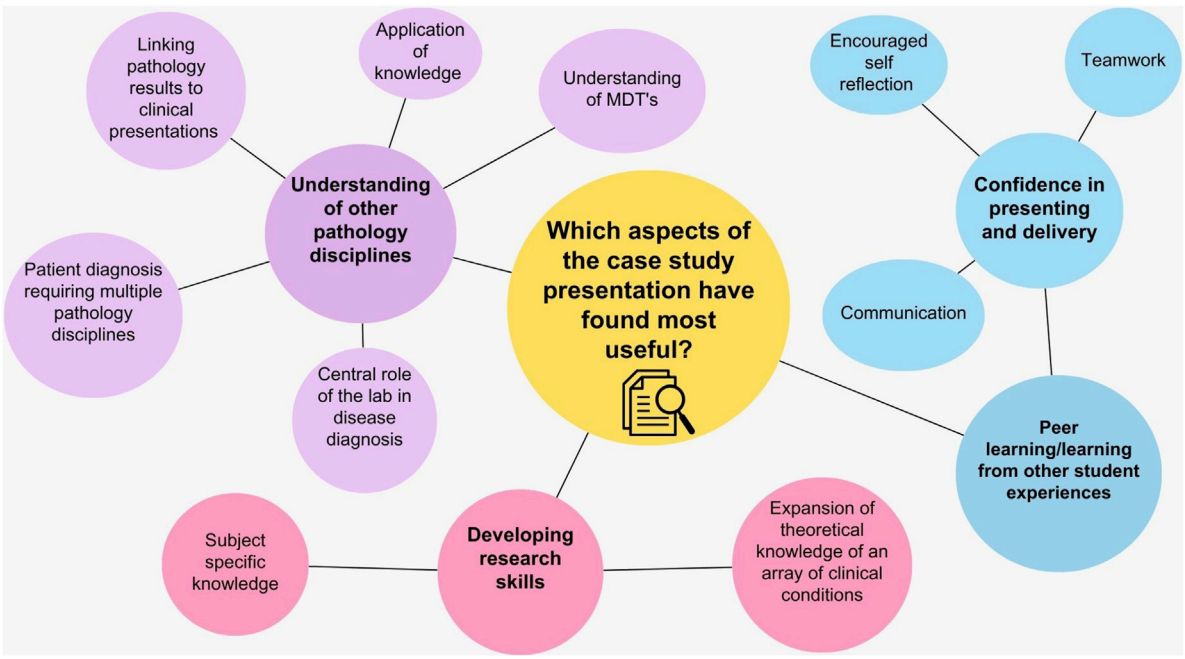

FIGURE 7 | A thematic analysis of open text responses to the aspects of the case presentation that students found most useful. This question was included in the post intervention survey. Fifteen major themes were identified, and the occurrence of each theme is represented by the size of each circle in the schematic. Several students open-text response contained more than one theme.

they enjoyed and found to be most useful (**Figure 7**). Fifteen major themes were identified, with the four most prominent themes being:

- Development of research skills
- Understanding of other disciplines
- Peer learning/learning from other student experiences
- Confidence in presenting and delivery

Specific comments from students included:

"Researching has been invaluable in gaining more in-depth understanding. Presenting has helped me build my confidence"

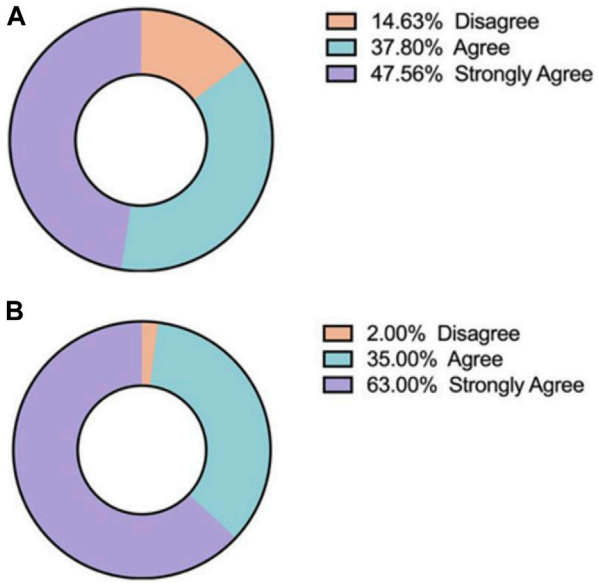

FIGURE 8 | The majority of students agreed that **(A)** they would like to see more of their Biomedical Science course delivered through case presentations and **(B)** skills such as patient communication should be integrated into Biomedical Science courses.

"Gaining valuable knowledge on patient diagnosis through different laboratories and also how you have to merge and require other laboratory testing to treat a patient"

"Doing the research in a multidisciplinary team, working together to solve a case"

"I found the research aspect most enjoyable especially liaising with staff in different departments to hear about their contribution to a patient's treatment process"

"you learn so much from case presentations and being able to watch a range of different presentations covering lots of diseases, which I used to reflect my own presentation including what went well and didn't go so well"

"Pulling a case study together across departments and reading medical reports has helped me deepen my understanding in Biomedical Science"

"I enjoyed learning about other diseases from different disciplines from the other presenters"

"I really enjoyed following a single patients journey from the onset of the health implication all the way through to the patients recovery"

"Using this opportunity to speak to Clinical scientists, Consultants etc people outside the lab that have roles in the patient pathway"

Concluding the questionnaire, students were asked to reflect on the effectiveness of case study presentations and whether undergraduate degree programmes should introduce students to case study work, either sooner or make it an integral component of the taught material. A total of 84% of respondents either strongly agreed or agreed with this statement. Equally, students were asked to consider the importance of patient communication awareness, to which 98% of respondents either strongly agreed or agreed that patient communication should be integrated into Biomedical Sciences courses (**Figure 8**).

Feedback From Pathology Training Leads

Training Officers were asked to provide comments regarding the combined placement workshop provision, training sessions and the collaborative network within the West Midlands. Feedback was positive, and some comments included:

"The student placement workshops are of great benefit both to the placement student and the Training Officer. The student has the opportunity to meet and get to know fellow placement students from different universities and by attending the workshops they have some evidence to meet the required standards in the portfolio. This is particularly useful giving them a case study that they have to present to their peers and the workshops provide them with opportunity to gain learning with and from other healthcare professionals in order to meet the required standard in the portfolio" ~ **Senior Training Lead Clinical Chemistry**

"The TTT sessions and combined placements workshops have reduced disparity across employers to ensure consistency in the delivery of training and assessment. Over the years the combined placement workshops have developed and enhanced considerably due to this development of a strong collaborative working with Healthcare professionals within the West Midlands" ~ **Training Officer Lead in Blood Sciences**

"Following the train the trainer sessions I have been able to introduce new elements into my training plans that have aided both students working in the laboratory and practitioners. I now ensure students visit clinics on placement, so they know the importance of the test result for the patient. I like how the combined placement workshops align to different sections of the portfolio and provide students with a range of evidence pieces" ~**Training Lead in Microbiology**

DISCUSSION

The IBMS registration portfolio is a vital tool that underpins professional growth, compliance with Standards of Proficiency and ultimately HCPC registration [1]. The portfolio functions as a prerequisite to work within the NHS as a Biomedical Scientist, bolstering career opportunities whilst contributing to the integrity of healthcare services. Local NHS pathology laboratories and HEIs within the West Midlands have forged a unique symbiotic partnership to enable Training Officers to

TABLE 2 | A Wilcoxon signed-rank test to compare student responses pre- and post-case study presentation.

Question	Survey	*N*	Median	Interquartile range	Significance
How confident are you in your understanding of the range of diseases/disorders diagnosed in your laboratory?	Pre	48	2	1	$p = < 0.0001$
	Post	48	4	1	
How confident are you linking a test result produced in the laboratory to a disease/disorder?	Pre	48	3	1	$p = < 0.0001$
	Post	48	4	2	
How confident are you communicating/speaking in public?	Pre	48	2	1	$p = < 0.05$
	Post	48	3	2	
How confident do you feel about giving a case presentation to peers and colleagues?	Pre	48	2	1.5	$p = < 0.001$
	Post	48	3	2	
How confident do you feel in your ability to structure a medical case presentation?	Pre	48	2	2	$p = < 0.0001$
	Post	48	4	2	
How would you rate your critical thinking?	Pre	48	2	1	$p = < 0.0001$
	Post	48	2	0	

N = *number of responses. Mean = Mean of Likert response on a scale of 1–4.*

successfully support trainee Biomedical Scientists to gain registration during their placement year, consequently making them verified to work within the NHS. It is, therefore, imperative that students embarking upon a placement opportunity are well prepared but equally supported during the placement to ensure all-rounded development and successful verification. In a bid to achieve this, HEIs within the West Midlands group have designed a series of combined placement workshops, delivered throughout the placement year, aiding students to collect evidence which can be used to support the registration portfolio.

Feedback from Training Officers on case presentations from previous years highlighted that students were not including clinical data effectively. Therefore, academic leads decided to develop the existing case study structure by incorporating a pre-survey to identify students' preconceptions of the importance of including clinical data (**Figure 3**). One of the major themes identified from this was students felt clinical data was core to treating patients effectively. This was followed by an interactive workshop that covered the requirements of creating and presenting a medical case presentation. Students were provided with a list of section headings that they needed to include as part of the case study construction, with the inclusion of clinical data from their laboratory being highlighted as a particularly important component. Students had the opportunity to choose a case that interested them and for which they were able to access details such as the patient history, clinical notes, diagnosis details and the treatment patients required. Although the Quality Assurance Agency for Higher Education (QAA) have guidance on subjects that need to be taught as part of a Biomedical Science degree, the disease conditions covered within these modules may vary depending on the academic expertise [9]. Through this placement workshop students were able to learn about a magnitude of clinical conditions across the pathology disciplines that they may not typically cover in an undergraduate degree (**Figure 4**). The data comparing student responses pre- and post-case study presentations highlights that students who engaged with the case study workshops reported an increase in self-perceived confidence in; understanding diseases and disorders diagnosed in the laboratory, linking test results to pathological conditions, delivering case studies/medical presentations, confidence in public speaking and critical thinking (**Table 2**). Furthermore, quantitative analysis revealed that students also deemed case presentations as an effective means of establishing links between theoretical concepts and practical application, whilst improving students' understanding of the patient pathway (**Figures 5**, **6**).

A plethora of pedagogic literature elaborates on the potential benefits of adopting case studies into higher education learning [12–16]. More specifically, case studies are one of the most frequently used teaching and learning activities within biology [17, 18]. Students enrolled on a Biomedical Science degree must be able to demonstrate proficiency in interpreting clinical case studies and be able to apply their subject knowledge regarding the aetiology, symptoms and laboratory results of a specific condition, in order to reach a suitable diagnosis and suggest appropriate treatment [9]. In addition, the HCPC highlight the importance of incorporating case studies within the Biomedical Science curriculum (SOP 10.2) [2]. The implementation of case studies functions to serve both accreditation requirements but also a vital tool in developing well-rounded undergraduate students.

Post-Survey Thematic Analysis

In addition to identifying the transferable skills students developed through the case presentation, academics wanted to better understand the aspects of the case study presentation that students enjoyed the most (**Figure 7**). Through thematic analysis, one of the most prominent themes identified was that students enjoyed developing their research skills. The development of research skills remains a central component of a Biomedical Science degree [19], particularly within the final year undergraduate research projects [9]. In addition, research and competence-based skills are much sought after by graduate employers [20].

As part of developing research skills, students highlighted that the case study presentations improved their critical thinking skills and overall, the series of placement workshops enhanced student

performance in completing the IBMS registration portfolio. Literature suggests that case studies allow students to develop their critical analysis skills and improve student performance [21]. Other work has highlighted that case study presentations encourage students to become reflective practitioners and enhance their problem-solving skills, in addition to allowing students to participate in group discussions [22, 23]. The case study presentation provided students with an opportunity to reinforce their subject-specific knowledge in addition to expanding their understanding of a range of clinical conditions that they may not have encountered in their degree programme. Biomedical Science undergraduate degrees require students to apply their subject knowledge to the interpretation of clinical case studies [14]. It is acknowledged that the quality of the patient's information delivered during a case presentation is determined by the extent to which the presenter has understood the clinical problem [24].

Transferable abilities such as critical thinking, problem-solving, and communication hold significant value across the NHS. While a Biosciences degree yields students with a solid grounding in scientific know-how and specialized technical skills pertinent to the field, transferable proficiencies extend beyond domain-specific knowledge. These proficiencies empower individuals to adjust, excel, and contribute proficiently in diverse professional settings. An assessment by Noah and Aziz underscores a notable contrast between the proficiencies essential for students to stand out in the job market and those prioritised by HEIs in their curriculum [25]. The Government Office for Science has issued a report offering foresight into the trajectory of skills advancement and continual learning [26]. The report accentuates that the current work landscape is organized around profiles or roles that necessitate, alongside scientific and technical acumen gained through university education, the cultivation of a range of competencies. Correspondingly, evidence suggests that the swiftness with which graduates acclimate to their professional roles hinges on the calibre and kind of proficiencies amassed during their formal education.

Case studies promote active learning and facilitate the development of both analytical and critical thinking skills [12, 16, 27, 28]. Critical thinking is an essential skill of any undergraduate student and is a necessary skill of Biomedical Scientists, who use critical thinking to interpret laboratory test results and to problem solve [14, 29]. Furthermore, the public presentation of the case study has improve students confidence in public speaking, which is a sought out in the job market [25, 26]. Case studies also enable students to see the relevance of a given topic, and remember detail and facts [30], whilst helping to improve their knowledge and confidence [31]. Case studies are also a reflective opportunity and the use of short case study presentations as featured within this study have several advantages and have been shown to improve the clinical reasoning processes of the presenter. Advantages include [1] shortening the presentation requires abstraction of information, possibly leading to better problem representation [2]; it is time-efficient; and [3] it stimulates more informal interactions with the facilitator and the audience [24]. Case studies and scenario-based activities are key components of active learning and increase a student's knowledge and understanding [32, 33]. Students should be supported to develop their skills with case presentation during their development as autonomous practitioners as suggested within this study.

Multidisciplinary Teams Within the NHS

Another major theme identified was that students enjoyed acquiring an understanding of other pathology disciplines outside of their assigned placement laboratory. The role of a multidisciplinary team is to bring together healthcare professionals from different fields and expertise to diagnose and treat patients [34, 35]. In preparation for the case study workshop, students were encouraged to gain permission where possible to attend a multidisciplinary team meeting relating to the case they were presenting. Literature suggests that regular multidisciplinary team meetings help to deconstruct the complex nature of disease conditions [36]. Effective collaboration and clinical proficiency play crucial roles in clinical positions, contributing to the reduction of unjustified differences in care, enhancement of patient safety, mitigation of healthcare disparities and preservation of resources. Relatively recently, NHS pathology laboratories have aimed to meet these Standards of Proficiency by aligning their workflow into "super-labs," essentially housing a variety of pathological disciplines into one building. This approach to delivering clinical care highlights laboratories no longer work *in silo*, therefore, to effectively diagnose a condition numerous disciplines work in unison to deliver effective healthcare. With an increasing emphasis on working collaboratively in healthcare, the importance of it is highlighted through the delivery of case study workshops.

The case study platform encouraged placement students to interact with a wide range of professionals across the hospital setting and allowed them to meet HCPC Standard 9.3 concerning *contributing effectively to work undertaken as part of a multidisciplinary team* [2]. This reminded students that a patient diagnosis is reliant upon multiple pathology disciplines working together to treat and diagnose a patient. It also highlighted to students the specialisms and opportunities available to them following graduation.

Furthermore, students enjoyed learning from their peers. Peer learning is defined as being a collaborative approach to learning and teaching involving students learning with and from each other [37]. Literature suggests that peer learning is a widely used and well-known tool often used effectively in higher education to facilitate deeper processing and long-term retention of knowledge [38]. Peer learning has also been shown to help alleviate anxiety in students who are presenting and many students who participated in the case study workshop highlighted upon reflection that they felt more confident in presenting [39].

The data presented here corroborates the critical need to infuse soft skills into student development and has been demonstrated by the inculcation of case study learning into placements. This frontward approach embodies the core principles of the NHS Long Term Workforce Plan [40] which pragmatically aims to reform NHS organisations by enhancing efficiency through varied work methods and training approaches,

constructing more versatile teams with adaptable competencies, and transforming education and training to produce a larger workforce.

This case presentation workshop data demonstrates that not only did students enhance their scientific knowledge and transferable skills but they also enjoyed engaging in this activity as part of their educational journey. As academics it is difficult to always find the balance between creating necessary tasks for students to meet learning objectives and for those assessments to be engaging and interesting to students. Consequently, students reported that they would like the inculcation of case study presentations, into their respective undergraduate programmes, as it was considered an effective learning strategy, particularly in the context of clinical modules (**Figure 8**).

A Novel Symbiotic Partnership the West Midlands

Several healthcare-oriented courses such as Medicine, Nursing, Midwifery, and Audiology incorporate obligatory placements as an integral part of their degree programmes. It is worth noting that while compulsory placements are a common feature in the healthcare setting, placements are not mandatory for Biomedical Science courses. Placements constitute a pivotal component of the educational journey, facilitating students in acquiring practical skills and knowledge that not only align with their academic pursuits but also foster their professional growth. The duration of these placements varies according to the specific requisites of each course. Securing positions for trainee Biomedical Scientists poses challenges primarily stemming from limitations in laboratory capacity, constraints on training time allocated for students, the availability of experienced trainers and more recently no allocated funding for BMS students on placement.

Training leads in the West Midlands, identified the pertinent training concern and a lack of graduates applying with necessary skills to work as BMS and subsequently initiated the establishment of the West Midlands Regional Training Group (WMTO). Over time, this initiative culminated in a collaborative partnership with HEIs within the local vicinity. The local hospitals identified training leads and were able to offer several placement opportunities which were advertised to local universities through the WMTO. Training officers have stated "*The HEI's collaboration with each other and the local hospitals has enabled us to produce some excellent and extremely employable Biomedical Scientists.*"

Limitations and Future Work

The number of placement opportunities varies annually and is dependent upon the laboratory capacity to host students. On average there are approximately 20–30 vacancies that are advertised, thus the number of students participating in the workshops is naturally impacted. Although all students completing an Applied Biomedical Science placement have to attend the compulsory combined placement workshops, completion and return of the survey was optional. Over the last 3 years, a total of 71% of respondents completed and returned the surveys, with surveys usually generating a response rate of 30%–40% [41]. Perhaps offering financial incentives would further increase the number of survey responses collected. Furthermore, students are undertaking unpaid placements and would welcome financial incentives [42].

As part of the post-case study survey, 98% of respondents wanted patient communication to be integrated into Biomedical Sciences courses. Despite the challenges of recruiting patient service users for Biomedical Science, Aston University has successfully created a service user event that includes patients, consultants and care providers in their curriculum [19]. Incorporating patients into the curriculum reinforces to Biomedical Scientists that each result is linked to the diagnosis or treatment pathway. Similarly, the inclusion of clinical case study presentations also highlights the importance of test results for the patient. Many students also presented their case studies at lunchtime seminars at their NHS Trust to a wide audience of Consultants, Medics, Biomedical Science staff, Nurses and healthcare workers, receiving outstanding feedback for their contributions. Therefore, we encourage all accredited Biomedical Science programmes to create opportunities to include patient voices and emphasise the importance of pathology test results within the patient journey.

Whilst the current combined placement programme is extensive and covers numerous HCPC SOPs (**Figure 1**), the West Midlands Training Officers have indicated that they would like universities to develop an interprofessional learning (IPL) workshop to foster multidisciplinary collaboration and help meet associated HCPC SOPs. Therefore, plans are underway for 2023–24 to include an IPL session discussing diabetes that incorporates Nurses, patients and Biomedical Scientists. This will be valuable in creating an opportunity for multiple professionals to work together to effectively treat patients. Furthermore, the schedule of workshops is re-examined annually to ensure they are meeting the required HCPC SOPs.

The model presented within the West Midlands successfully produces graduates who are equipped with the necessary pathology knowledge, skills and a completed IBMS registration portfolio. This partnership between HEIs and local NHS trusts within the West Midlands is a unique approach created to support students through this process. This allows graduates to register with the HCPC, thus addressing the skills shortage in the workforce. We encourage other regions to create training officer groups and to develop strong partnerships between local HEIs and pathology laboratories, with the end goal of establishing a fruitful placement programme.

CONCLUSION

Combined placement workshops have formed an integral part of the Applied Biomedical Science placement journey over the last 10 years within the West Midlands. Case study presentations are a valuable teaching and learning tool to nurture and develop key transferable skills and competencies in conjunction with Biomedical Science expertise. Through engaging in the combined placement workshops

and completing training in an NHS pathology laboratory, graduates in Biomedical Science elevate their attractiveness to potential employers, with a notable emphasis on the NHS. The innovative approach adopted in the West Midlands involves a collaborative model that effectively prepares graduates with essential pathology knowledge, skills, and a completed IBMS registration portfolio. This study highlights a successful framework for a collaborative partnership with local NHS trusts that has allowed the completion of numerous pathology placements and could be adopted by other HEIs delivering accredited Biomedical Science courses.

SUMMARY TABLE

What Is Known About This Subject

- Registered Biomedical Scientists need to have completed the IBMS registration portfolio.
- Many universities offer an integrated Biomedical Science programme in which students complete the portfolio on placement.
- Across the UK there are not many examples of strong relationships between HEIs and local NHS laboratories.

What This Paper Adds

- Showcases a unique collaborative partnership between four HEIs and local pathology laboratories in the West Midlands.
- The revised case study combined placement workshop meets HCPC SOPs and fosters development of key transferable skills.
- The combined placement workshop series develop skills and knowledge required to complete the IBMS registration portfolio.

CONCLUDING STATEMENT

This work represents an advance in biomedical science because it showcases a unique partnership between HEI's and NHS laboratories allowing successful placement completion for trainee BMS.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving humans were approved by the Aston University Health and lLfe sciences ethics committee, Wolverhampton University ethics committee and Coventry University ethics committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

AB conceived the study and AB/KD designed the research approach and survey. KD collated the data sets. AB, KR, KW, and RP analysed the data and wrote the manuscript. AB, KR, KW, and RP edited, read and approved the submitted version. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ACKNOWLEDGMENTS

Thanks to Dr. Azra Khan at Coventry University for her support in delivering the case study workshop and Dr. Rebecca Harrison from Keele University for the addition of the data analysis workshop to support case study delivery. Without the support of university placement leads and training officers, the case presentations would not be successful. A special thanks to all the training officers within the West Midlands network who have provided excellent training and have been pivotal in providing Biomedical Science trainee positions.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2024.12017/full#supplementary-material

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BJBS

ORIGINAL RESEARCH
published: 15 December 2023
doi: 10.3389/bjbs.2023.11891

Group Assessments to Help Build Online Learning Communities in Biomedical Science Distance Learning Programmes

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Introduction: Biomedical Science distance learning courses offer flexibility in study while in employment. Asynchronous and self-learning approaches are common within such courses and often student-student interaction is limited. The aims of this study were to establish learning communities, develop confidence in participating in online teamwork and foster an appreciation of transferable skills including digital capabilities through remote group activities.

Materials and Methods: Two cohorts of students (n = 20/n = 21) were enrolled in a microbiology module of an IBMS accredited MSc distance learning course. Groups of 4–5 students produced a digital output relating to current global infection-related issues, namely, assignment 1, production of a slide deck, which peers could use as learning resources and assignment 2, a voiceover PowerPoint debate, and infographic, voting assessment and peer/self-marking. Students also prepared reflections using written format and a FlipGrid video-recording. A qualitative content analysis was conducted on reflections from all students. Students completed a pre- and post-assignment survey focused on the development of transferable skills for the biomedical sector.

Results: Students' skills and confidence increased following completion of the group assignment, as evident from the pre- and post-questionnaire responses, namely, possession of digital skills and digital creation abilities (29% v 83%), applying for jobs which require digital skills (54% v 89%), talking about examples of using digital media during job interviews (21% v 78%) and demonstration of creativity during assignment tasks (33% v 90%). Critical thinking was more commonly demonstrated during the debate in comparison to the slide deck activity (p = 0.001). The importance of developing digital skills, was higher following completion of the group activities (p = 0.03). Students reflected on the value of the group activities in relation to knowledge acquisition (85%, 86%), collegiality (70%, 71%), digital skills development (80%, 90%), the fact that the activities were enjoyable (70%, 67%) and the development of peer interaction and support (50%, 67%) in relation to assignment 1 and 2, respectively.

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Received: *04 August 2023*
Accepted: *28 November 2023*
Published: *15 December 2023*

Citation:
Millar BC, Purkis H, Moore JE, McClean S and Lowery CJ (2023) Group Assessments to Help Build Online Learning Communities in Biomedical Science Distance Learning Programmes. Br J Biomed Sci 80:11891. doi: 10.3389/bjbs.2023.11891

Discussion: Increasingly digital technologies are being used in the healthcare sector resulting in updated HCPC Standards of Proficiency. This study highlights that virtual group activities promote the establishment of supportive learning communities and the development of transferable skills including digital capabilities for application within the biomedical science workplace.

Keywords: debate, distance learning, digital skills, e-learning, group work, learning communities, online, microbiology

INTRODUCTION

The origins of education delivered by distance learning trace back to the 18th century, when on 20 March 1728, the *Boston Gazette*, advertised teaching and tutoring on the subject of shorthand, which Professor Caleb Phillips delivered by correspondence [1]. Numerous authors have described the history of distance learning in depth [1, 2] but it is of interest to note that, within the United Kingdom, during the 1840s, Sir Isaac Pitman established the first correspondence teaching school. Pitman delivered not only shorthand teaching, but also assessment and feedback using distance learning as he sent postcards to students on to which they would transcribe passages from the Bible and return, by post, for correction [2, 3]. Globally, correspondence education expanded, during the 19th century, with a significant event occurring in 1858, when the University of London pioneered the delivery of global degree level education by correspondence distance learning education [4]. The most subsequent notable development over 100 years later in relation distance learning occurred on the 23 April 1969, when the Open University (OU) was established by the Royal Charter [4]. According to Royal Charter "*The objects of the University shall be the advancement and dissemination of learning and knowledge by teaching and research by a diversity of means such as broadcasting and technological devices appropriate to higher education, by correspondence tuition, residential courses and seminars and in other relevant ways, and shall be to provide education of University and professional standards for its students and to promote the educational wellbeing of the community generally*" [5]. The OU became the world's first university solely devoted to distance learning and in its first year, 1971, enrolled approximately 24,000 students, offering courses to

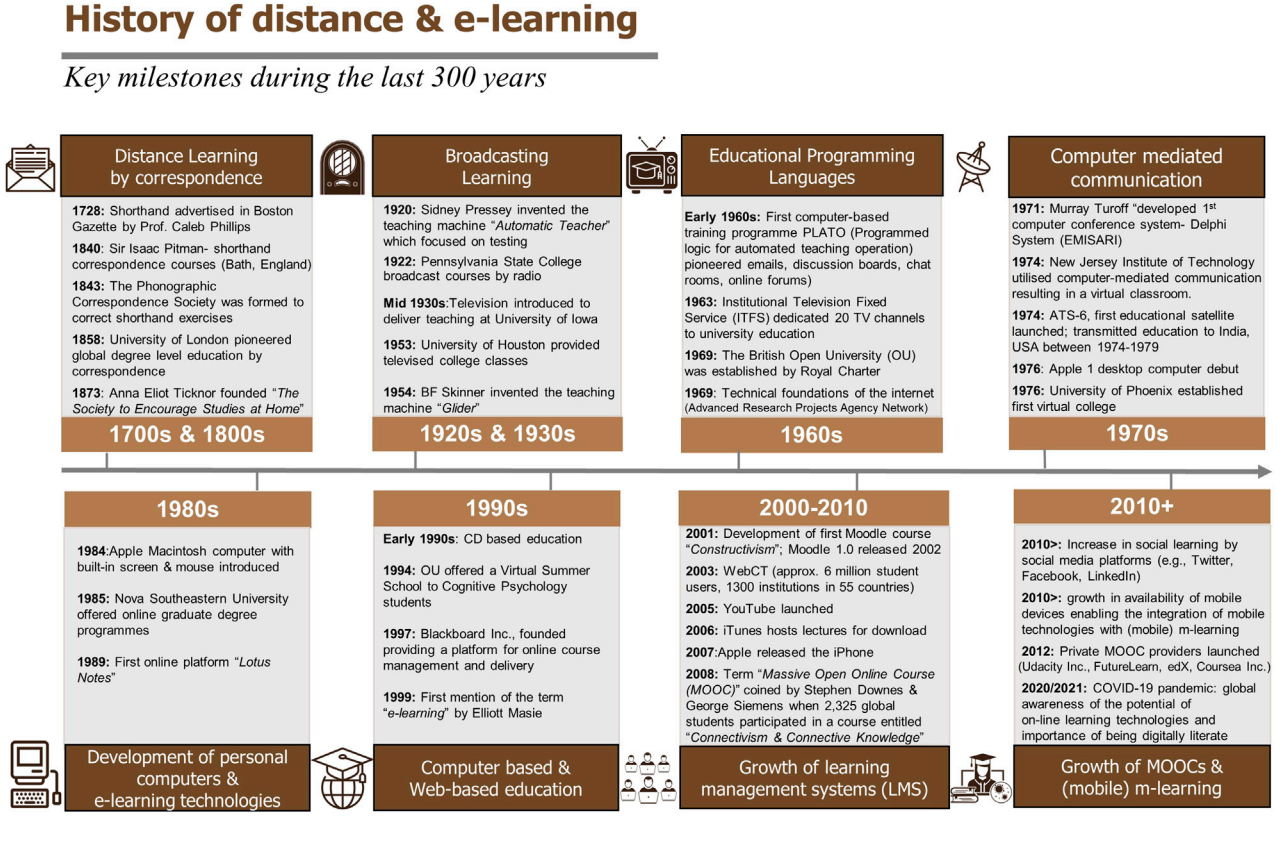

FIGURE 1 | A timeline of key milestones relating distance learning and e-learning. Footer Sources of information used to construct this timeline [6–10].

FIGURE 2 | The 17 Sustainable Development Goals (SDGs) adopted by all United Nations Member States [11] and the three primary goals which distance learning makes a substantial input.

students with all abilities and disabilities which were primarily delivered by correspondence and television [1].

As technology advanced so did the mode of delivery, the number of education providers globally and the range of educational programmes offered remotely (see **Figure 1** for historical milestones in distance and e-learning) [6–10]. The most significant impact was associated with the development of digital computing technologies including the internet and the World Wide Web, which led to online distance learning (e-learning) delivery [1] which has now significantly replaced the previous media of delivery, namely, correspondence, phonograph, radio, telephone and television, particularly in countries with good communication and digital infrastructure [6]. Online platforms and e-learning management systems have transformed the current approach that education providers have taken with the majority offering both blended learning and fully online distance or e-learning education.

Distance learning addresses all 17 UN sustainable development goals (SDGs) (**Figure 2**), by creating innovative solutions through education, to each of these goals by varying degrees [11], but particularly three of these goals, namely, 1 (No Poverty), 4 (Quality Education) and 5 (Gender Equality) (**Figure 2**). Access to education has been described as an avenue out of poverty [12]. Distance learning may help alleviate educational costs by staying at home, thus avoiding travel costs to educational institutions, accommodation costs, as well as remaining at home to undertake employment around asynchronous learning platforms. However, poverty can itself

TABLE 1 | Advantages and challenges of e-learning distance learning educational programmes.

Advantages	Challenges
Flexibility • Family, work, personal commitments • Asynchronous life-long learning opportunities	Training requirements • Navigation and training relating to online platform • Ethics, equality, diversity and inclusion and acceptable use policies when online
Inclusive • Available to everyone irrespective of situations/special needs which may not permit traditional in-person requirements	Expectations • Support and feedback from tutors ad hoc- realistic expectations need clarified • Pastoral care essential
Access • Greater access to higher education • Multidevice access (phone, tablets, laptop, desktop computers)	Isolation and engagement • Limited opportunities to engage with peers • Limited social and peer support • Reluctant to activate microphones and cameras when online
Saving Time and Money • No requirement to commute or live on campus • Access to online library facilities, e.g., e-textbooks, e-journals	Internet Access • Poor, limited or no bandwidth • Access may be limited in institutions such as healthcare settings • Technical support outside working hours essential
Media Diversity • Text, video, animation, interactive quizzes, discussion forums, webinars, resource sharing platforms	Delivery of teaching materials and resources • Interactive teaching and guidance required by tutors • On-line formative activities required rather than self-taught
Community learning • Global learning opportunities • Multi-national and multicultural perspectives	Time-management • Due to work and personal commitments time management is essential to discipline learning and assessment activities
Choice • Wide selection of courses available worldwide	Time difference • When online live activities timetabled consideration of student time zones, e.g., record sessions
Digital Skills development • Opportunities to develop digital competencies during teaching and assessment activities	Academic Integrity • Universities require policies and guidelines to support assessment, e.g., guarantors, plagiarism and artificial intelligence checking software

impede learning by contributing through a vicious cycle of poor digital access and connectivity within the domestic setting. If digital access can be secured and maintained, e-learners may avail of multiple free web-based resources, but which may not award academic credentials on successful completion. Socio-political factors are important considerations for the introduction and development of distance learning. Komba (2009) concluded that education is an important tool for socio-economic development and a key factor in strengthening human capabilities and reducing poverty in an increasingly globalized world [13]. Distance learning plays a significant contribution to SDG4 (Quality Education). A study from Thailand concluded that for SDG4 to be met, then distance learning requires a quality digital infrastructure of connectivity to allow for sustainable learning [14]. Distance learning may also play a crucial role in helping reduce gender inequality. A study from Tanzania showed that Open and Distance Learning had a crucial role in promoting gender equality and women through empowerment by widening access of education for both women and men and hence improving their socioeconomic and political status [15]. The study showed that the majority of women enrolling did so as it was the only means that they could learn, sustain their career

and simultaneously care for their family [15]. A further study from the Philippines made an important point that web-based applications are gender-neutral, which may support the uptake of distance learning [16]. Likewise, Margolis and Fisher 2002 suggested that online education methods are non-sexist and more gender-inclusive [17].

Distance learning programmes are chosen by students for a variety of reasons however it must be acknowledged there are several challenges associated with the delivery of such programmes both for the course team and the student, which need to be addressed (see **Table 1**). In recent times, the COVID-19 pandemic has forced a root and branch re-examination of provision and capabilities of digital infrastructure and an opportunity to horizon scan to anticipate current and future needs within universities and colleges, as well as within junior, middle and senior schools. It created a watershed relating to the hegemony of physical teaching over distance learning. The barriers and challenges of such "*emergency delivery*" of educational programmes have been extensively reported [18], particularly in relation to the training and final year research project assessments of students enrolled in biomedical science degree programmes [19, 20].

For many individuals, however, online distance learning education has been and still is a personal choice both pre- and post-pandemic, particularly in relation to postgraduate programmes. Within Ulster University, prior to the pandemic, between 2008 and 2019, 4,000 students graduated with an on-line degree/short course qualification from 109 available e-learning courses, supported by 100 part-time e-tutors. More than 70% of these students were enrolled within the Faculty of Life and Health Sciences, indicating the value and interest in distance learning programmes within this discipline area.

Successful completion of the Institute of Biomedical Science (IBMS) accredited MSc degree programmes both on campus and via distance learning, provide eligible IBMS members an opportunity to be recognised as Chartered Scientists [21] and offer a valuable opportunity to promote career progression. As of March 2021, seven universities offer 28 IBMS accredited postgraduate distance learning educational programmes [21]. In relation to the biomedical science postgraduate distance learning courses at Ulster University, enrolment generally comprises of mature allied healthcare professionals who are working fulltime and have various life commitments. As such, distance learning courses offer the required flexibility to enable individuals to balance such commitments whilst furthering their education [22].

It is essential that students enrolled on e-learning programmes are delivered a quality and valuable teaching experience which helps equip them with the knowledge and relevant skills to enable them to be valuable contributors within the workplace and society. The "Know-Do-Be Theory" of education which resulted from UNESCO Commission, "Education for the Twenty-first Century," is the cornerstone when designing the curriculum and specific learning outcomes and as such direct the key aspects of what needs to be assessed [23].

In the module in this study "Advances in Clinical Microbiology," it is essential that students, who are generally currently allied healthcare professionals in this discipline specific modality, gain a knowledge of the rapid evolving issues such as antimicrobial resistance, vaccinology and emerging pathogens of global concern, which contribute to "*making the material alive to students*" [24], as well as the development of automated, digital and molecular diagnostic platforms which are transforming the clinical microbiology service. The fourth pillar of "Know-Do-Be Theory" i.e., learning to live together is particularly important in terms of distance learning where students from diverse geographical locations and backgrounds must learn to live and study together and treat others with value and respect [23]. Also, of particular relevance in the twenty-first century holistic model of education is the opportunity to develop competencies and employability skills [25] which is of particular importance in relation to the Integrated Design Framework [26]. Such Biomedical Science online educational programmes at Master's level also provide students from the biomedical science sector the opportunity to expand and develop competencies aligning with the 2023 updated Health and Care Professions Council (HCPC) standards of proficiency (SOPs), particularly in relation to digital skills and new technologies, leadership, and equality, diversity and inclusion [27]. In addition, the World Economic Forum has detailed the most critical 16 "21st-century skills" required by students to support them as they seek and further their careers in a "technology-mediated world" [28].

A primary disadvantage of e-learning is the minimal opportunities for face-to-face interaction which in turn can impact on students in terms of course satisfaction, engagement, communication, psychology and a lack of sense of community [29]. Distance learning students can often feel isolated due to the temporal separation from both their tutor and peers [22], hence it is important to foster the establishment of online learning communities. The curriculum of the "Advances in Medical Microbiology" module embraces global issues and developments within clinical microbiology and this module provides healthcare professionals with life-long learning opportunities to professionally develop their knowledge of the various emerging issues and developments in clinical microbiology and infectious diseases [30]. This curriculum coupled with an international enrolment, provides a valuable environment for global engagement which should be harnessed so that students can appreciate by learning from each other the real-life impact of the curriculum content from different perspectives across the globe. Interaction of students has been reported as a key element in designing any e-learning activity in general. Various approaches have been used to embed online community interaction and engagement with the e-learning course content, such as collaborative projects, discussion forms and peer evaluation [24]. Although discussion forms are embedded in many online platforms such as Blackboard, learning experiences are more enhanced when a variety of media, i.e., written, visual and verbal, are used to communicate in an online student group [24].

The aims of the development and execution the virtual group assessments described in this paper were to establish an authentic, valid and competency-based group assessment which aligned

TABLE 2 | Group assignment topics and activities.

Assignment 1: Slide Deck with slide notes (presentation using Blackboard Live Sessions optional).	
Group	**Topics**
1	Ebola virus: *"An ongoing challenge to prevent further global outbreaks"*
2	Measles morbillivirus: *"Tackling Re-emergence: vaccine failure or vaccine phobia?"*
3	Human papillomavirus: *"A vaccine necessary for all sexes"*
4	Human immunodeficiency virus: *"An HIV vaccine- is the end in insight or are there still barriers to overcome?"*
5	Poliovirus: *"Successful elimination or concern: emergence of vaccine-derived polioviruses"*
Mark allocation	**Activities**
10% (Group mark)	Strategy on a page
30% (Group mark)	Preparation of a Slide Deck (20 slides)
10% (Group mark)	Preparation of a Reference List
10% (Personal mark)	Personal slide content and preparation
20% (Personal mark)	Assessed Group Discussion Board
10% (Personal mark)	Written reflection
10% (Personal mark)	Audio-visual reflection shared with module members
Assignment 2: Debate Presentation using voiceover PowerPoint, Infographic, Voting.	
Group	**Topics**
1	*"Antimicrobial resistance is of a greater global concern than emerging/re-emerging pathogens."*
2	*"Automation will result in a better service with manual approaches within diagnostic clinical microbiology becoming obsolete."*
3	*"The availability of recent novel meningococcal vaccines will result in the eradication of meningococcal disease."*
4	*"Molecular diagnostics within clinical microbiology is superior to culture-based approaches which will become redundant."*
5	*"Prevention is better than cure- vaccines rather than novel antimicrobials are the future for combating infectious diseases."*
Mark allocation	**Activities**
Formative	Strategy on a page
40% (Group mark)	Debate presentation and Summary Infographic
20% (Group mark)	Robust and current sources of information, accurate referencing of slides/list
10% (Personal mark)	Peer-mark
10% (Personal mark)	Self-mark
20% (Personal mark)	Assessment and voting on other group debates with justification
Separate assignment	Written reflection and audio-visual reflection (Completed at end of module after completion of all assignments)

with the learning outcomes of the module (see **Supplementary File S1**). This group activity was designed to establish learning communities culminating in the creation of a digital output which would permit the assessment of all six levels of Bloom's Taxonomy [31]. The development of the creative outputs and their subsequent sharing and evaluation by peers coupled with the consequential validity of the assessment on student learning, would provide students the opportunity to expand microbiology discipline specific knowledge. Additionally, this would promote the development of transferable digital, reflective and social competencies, such as communication, collaboration leadership and respect of others [32].

MATERIALS AND METHODS

Assessment Design

Two group-based e-learning assessments constructively aligned with the learning outcomes of a discipline specific 30 credit point module (BMS 858- Advances in Medical Microbiology; **Supplementary File S1**) in part fulfilment of an IBMS accredited distance learning MSc programme in Biomedical Science. Assignments were constructed to promote and enable 1) the establishment of online learning communities; 2) development of specialism-specific knowledge relating to clinical microbiology and 3) development of transferable skills including critical thinking, communication, collaborative team and digital skills. Throughout the group activities students were provided with e-tutor support to help direct the students to reliable resources and practical guidance on the use of the various digital platforms and tools which were required for these activities.

Group Activity 1

The first group activity was conducted during November/December 2019, i.e., prior to the COVID-19 pandemic. Twenty students enrolled in this module. The group assignment focused on viral pathogens. Each group of four students was given a named virus which was of current clinical interest due to several factors including epidemiology, clinical significance, vaccine properties and availability. Each group was given a specific aspect/problem to focus on and was asked to critically examine this aspect in light of current peer-reviewed research and global policies established by respected

institutions, e.g., WHO, Government Bodies. The topics and assignment components are detailed in **Table 2**.

For assessment purposes, students were requested to collectively prepare a slide deck, slide notes and accompanying reference list relating to their assigned topic. Initially, groups prepared a strategy on a page of how the group was going to approach the assignment, detailing how and when they would meet, the various responsibilities of the members of the group, sources of information and internal group deadlines. Following feedback from their e-tutor, the groups executed their strategy plans. The final slide deck was shared with all members of the module to enhance their knowledge of the five subject areas and provided a further source of information to help prepare students for the end of modular examinations. Students were not required to prepare a voice over presentation, however two groups wished to deliver a live oral presentation via Blackboard Ultra, to their e-tutor on completion. All students were also asked to communicate with their group members using assessed group discussion forums throughout the preparation stages. Having completed the group task, students were asked to personally reflect using written format and prepare an audio-visual reflection to share with their peers. Audio visual reflections were recorded using the digital tool FlipGrid [33].

Group Activity 2

The second group activity was conducted during November/December 2020, i.e., during the COVID-19 pandemic and following analyses of the previous academic year's activity. Twenty-one students enrolled in this module. The group assignment focused on global topical and debatable issues in clinical microbiology. The topics and assignment components are detailed in **Table 2**. This form of group assignment task was to encourage students to expand their critical evaluation skills rather than solely presenting fundamental knowledge of specified subject areas. The implementation of further digital skills were embedded to enhance students' digital communication skills by including both verbal and visual formats to prepare a digital output which was engaging, critical, informative and concise.

In this assignment task, students were placed into groups of four or five and were asked to retrieve and critically analyse scientific literature to evaluate the assigned topic. A strategy on a page was prepared and the e-tutor provided feedback as was the case in assignment 1. The completed assignment output took the form of an online debate and groups were required to create a PowerPoint recorded audio-visual presentation of the debate together with a summary infographic and reference list. Subsequently, all debate presentations and infographics were uploaded to the module portal and students were asked to examine these and vote on which side of each of the motions they supported, also providing a justification. When all group work was completed, each member of the group provided a peer-mark and self-mark in relation to the contribution of individuals during the group task (see **Supplementary File S2** for the peer-/self-marking template). At the end of the module, students were asked to personally reflect using written format and prepare an audio-visual reflection to share with their peers. Audio visual reflections were recorded using the digital tool FlipGrid.

Evaluation Methodology

This ethically approved study [Ulster University procedures for research involving human subjects (FCBMS-19-091)] comprised of a mixed methods approach to evaluate the introduction of virtual group assessments. Qualitative data was gathered through reflective feedback and was used to evaluate the assessment outcomes in terms of experiences, skills development and an appreciation of employability skills. Quantitative data and statistical evaluation allowed further refining and evaluation of the outcomes of this project from data gathered through questionnaires and a content analysis of the reflective outputs [34].

Surveys

Prior to commencing group activities and subsequently following completion of these activities, all students enrolled in the module were invited to complete a voluntary pre- and post-skills evaluation, which comprised of a 5-point Likert Scale questionnaire (**Supplementary Files S3, S4**). Responses from students who provided written consent were analysed. For statistical analyses, qualitative Likert responses were assigned values 1–5 as detailed in the survey questionnaires (**Supplementary Files S3, S4**). The pre- and post-questionnaires provided students the opportunity to quantitatively evaluate their skill development during their undergraduate degree, and assignment tasks in relation to problem solving, critical thinking, creativity, group coordination, preparation of digital media and digital communication. The questionnaires also provided students the opportunity to quantitatively assess the importance of transferable skills development in relation to securing employment and career progression within the biomedical science sector.

Qualitative Data Content Analysis

A content analysis was performed on the reflective writing of each student [35]. Categories were constructed focusing on pre-assignment apprehensions, challenges encountered, value of group activities, skills developed and personal feelings and attributes on completion of the final group output.

Statistical Analyses

Statistical analyses were performed using non-parametric methods. For all data, a Kolmogorov-Smirnov test for normality was conducted prior to a Kruskal-Wallis test and *post hoc* by Dunn's multiple comparisons test for related groups which were not normally distributed. Statistical significance was set at $p \leq 0.05$. Chi-square and Fisher's Exact tests were also conducted. All analyses were conducted using GraphPad Prism 10 for Windows, Version 10.0.0 (GraphPad Software, Boston, United States).

RESULTS

Surveys

The uptake rate of the pre- and post-group assignment surveys for the Group Activity 1 was 80% (16/20) and 52% (11/21)

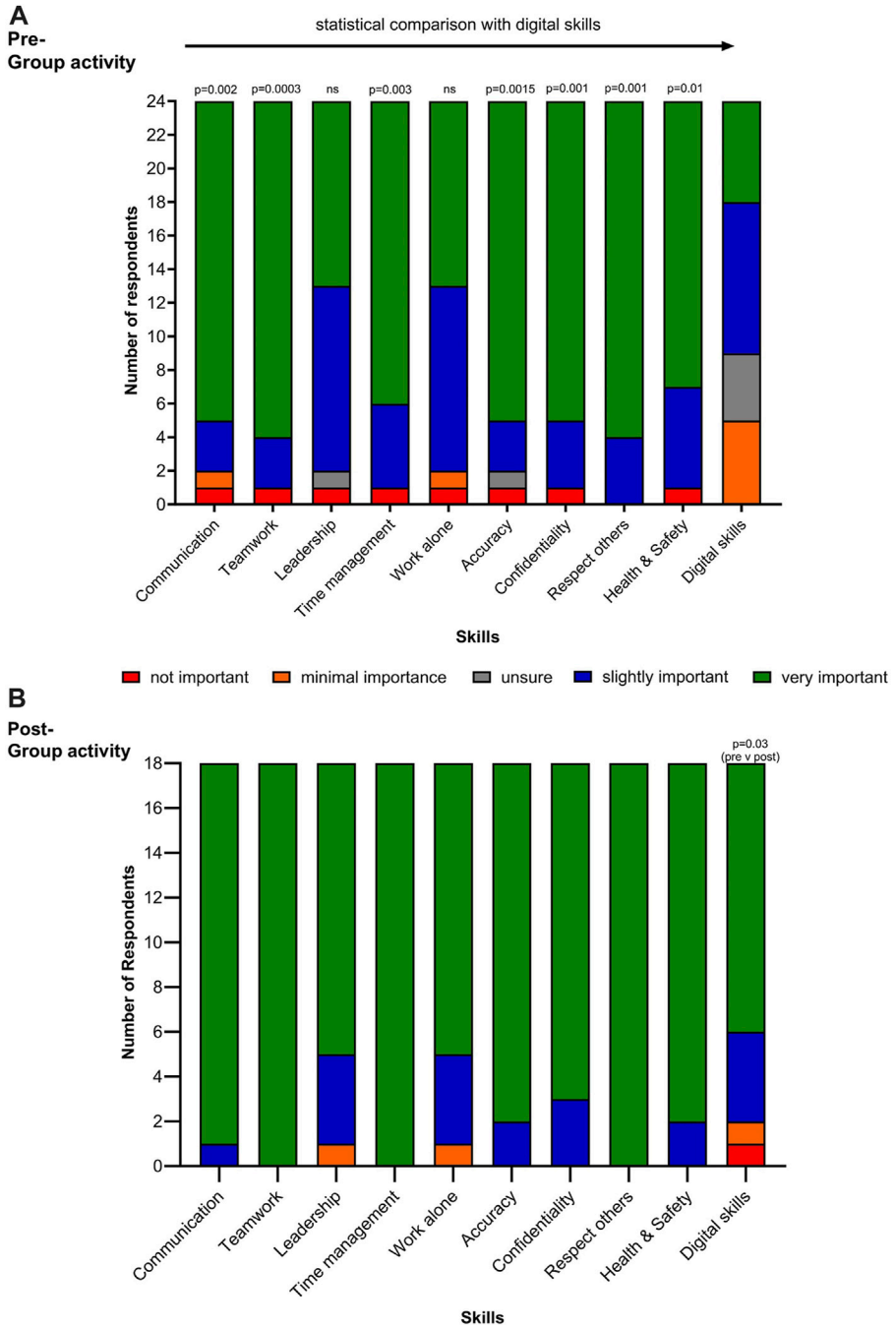

FIGURE 3 | Respondents evaluation of the importance of developing work-related skills during postgraduate study to help secure a job in the biomedical science sector: **(A)** Pre-Group assignment activities (n = 24; statistical significance is noted between digital skills and other transferable skills) and **(B)** Post-Group assignment activities (n = 18; statistical significance was only noted between pre- and post-Group assignment activities in relation to digital skills).

respectively. The uptake rate for the pre- and post-assignment surveys for the Group Activity 2 was 38% (8/21) and 33% (7/21), respectively.

Responses (n = 24) to the pre- and post-questionnaire in relation to the importance of developing work-related skills during postgraduate study to help secure a job in the biomedical science sector is shown in **Figures 3A, B**, respectively. In relation to the pre-assignment survey, there was a significant difference in responses indicating a lower importance being attributed to digital skills development than skills development with respect to communication (p = 0.002), teamwork (0 = 0.0003), accuracy (p = 0.0015), confidentiality

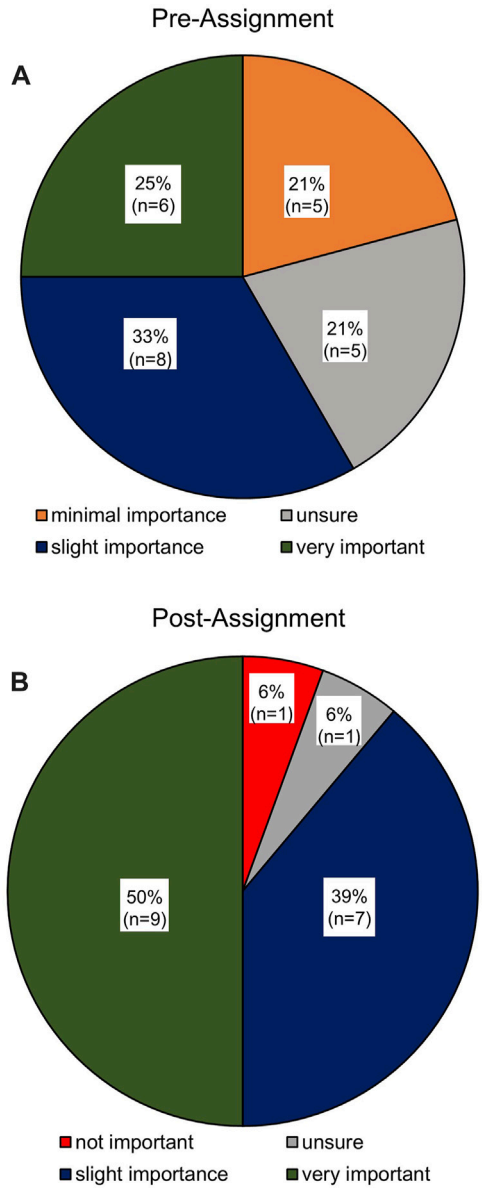

FIGURE 4 | Respondents evaluation of the importance of digital skills to employers within the biomedical science sector. **(A)** Pre-Group assignment activities (n = 24). **(B)** Post-Group assignment activities (n = 18). A significant increase in importance (p = 0.04) placed on relevance to digital skills following the completion of the assignment tasks.

(0.001), respect for others (p = 0.001) and health and safety (p = 0.01).

No significant difference was evident in the skills which respondents believed were essential to develop during postgraduate study in relation to job acquisition versus job progression (**Supplementary File S5**).

In relation to the post-assignment survey (n = 18), there was a significant difference in responses in relation to an increased importance being attributed to digital skills development (p = 0.03) than indicated in the pre-assignment responses. Although there was a trend towards an increased importance, to the development of other skills, these were not significantly different.

Figures 4A, B, pre- and post-assignment, respectively, demonstrate a significant increase in importance (p = 0.04) on the relevance of digital skills to prospective employers, following the completion of the assignment tasks.

The infographic shown in **Figure 5** summarises respondents pre- and post-assignment responses and indicates that following completion of group tasks, there was an increase in respondents indicating that they had the digital skills and abilities of digital creation which employers seek and that more students would apply for a job that requires digital capabilities. An increased range of digital platforms and digital tools were utilised during the group assignment activities with an increase in the number of respondents who indicated they had demonstrated creativity and innovation during the group task compared to during their undergraduate degree.

From the responses to post-group assignment questionnaires in relation to a comparison between two group activities, it was shown that there was a statistical increase in the proportion of respondents (p = 0.001) who strongly agreed that they developed their critical thinking skills during the debate activity in comparison to the slide deck activity (**Figure 6A**), with no statistical difference in relation to creativity (**Figure 6B**). In comparison with the slide deck activity, following completion of the debate activity, more respondents indicated that they would apply for a job requiring digital skills (p = 0.02) and that they would be confident in talking about examples of a range of digital media skills during job applications and interviews (p = 0.01) (**Figures 6C, D**).

Qualitative Data Content Analysis

Following a content analysis of students' reflections [Group Activity 1 (n = 20); Group Activity 2 (n = 21)] a statistical comparison of common themes was conducted using a Fisher's exact test with Odds ratio and is shown in **Table 3**. In relation to statistically significant differences between the two assignment tasks, there was a higher proportion of students who completed the debate activity who initially expressed concern about a group activity (p = 0.001) and indicated difficulties with time commitments to meet (p = 0.004). Within the debate cohort a greater proportion reported developing leadership (p = 0.045) and critical evaluation skills (p = 0.045). In the Slide Deck cohort, there were statistically more students who reflected on their collaboration/teamwork skills (p = 0.028). All students reflected that their initial pre-assignment concerns were alleviated during completion of the group tasks with approximately 70% of students reflecting on the collegiality during the group activities. Most students acknowledged the knowledge gained (85%, 86%) and the skills developed in relation to digital platforms and digital tools (80%, 90%) during the group assignment activities, slide deck preparation and debate, respectively. Students reported that the group activities were an enjoyable experience in relation to the slide deck preparation (70%) and debate (67%). In the case of the debate activity, 62% of students reported that they had developed confidence in performing future tasks both in academia and

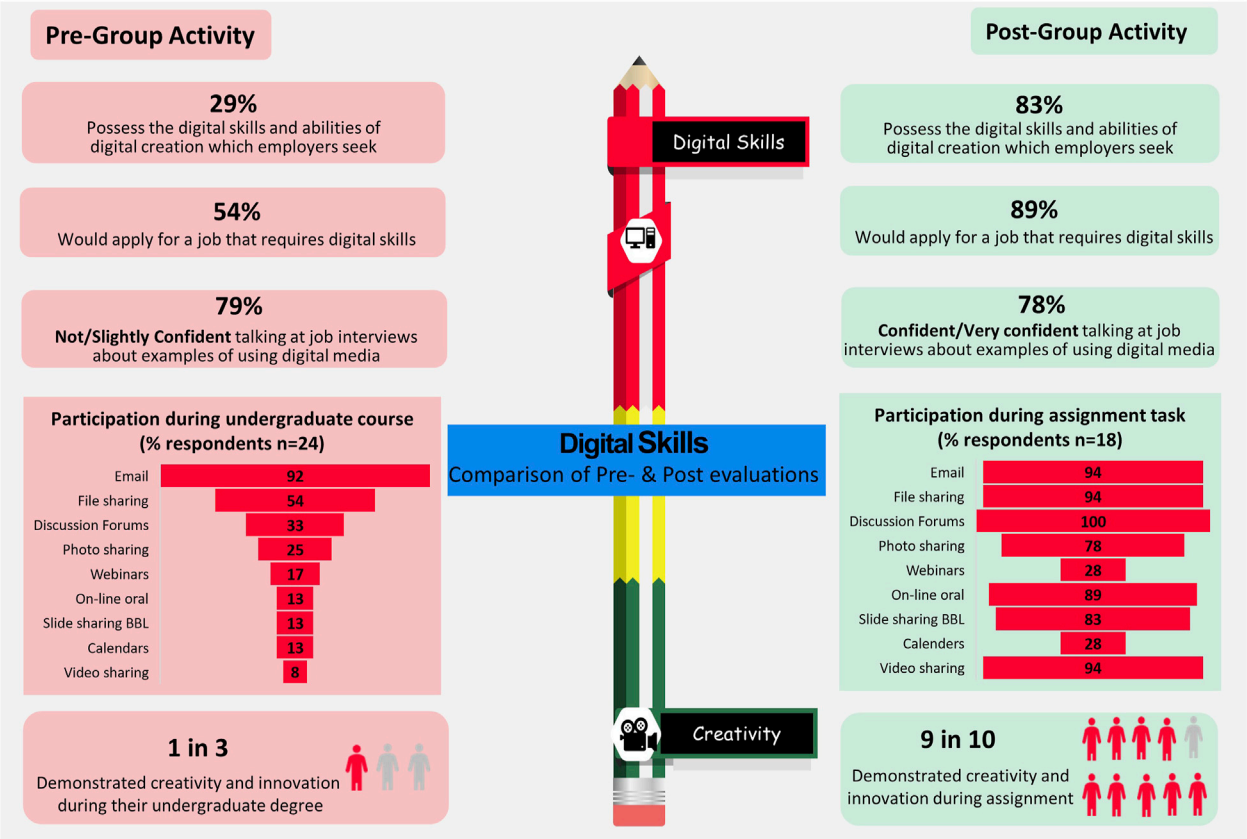

FIGURE 5 | Infographic of a comparison of key areas which improved following students completing the group assignment activities.

education which would require the skills they had developed (**Table 3**; **Figure 7**).

DISCUSSION

Online group assessment, requires extensive planning, assignment design and access to student support to ensure effective strategies are in place to counteract any challenges faced by academic staff or students when undertaking such activities [36]. This form of assessment was considered in this current study, as it ultimately fosters student negotiations in relation to co-construction and constructive conflict, leading to a mutual cognition resulting in the development of deeper learning and interpersonal skills, all of which are relevant within professional practice [37]. Furthermore, a group-based activity helps to establish an on-line learning community promoting "*team engagement*" and "*collaborative creativity*" [38], which encourages an "*interaction-knowledge network*" and a sociocognitive approach to learning by aligning to real-life collaborative scenarios.

In the case of the current group assignments, students acknowledged the opportunity to execute their creative skills (**Figure 6B**) and the group activities fostered good teamwork, building a collegiality which resulted in successful attainment of the assessment learning objectives and the construction of a final product which students felt proud of (**Table 3**). The pinnacle of Bloom's modified taxonomy is creativity, which these group activities promoted, however, it has been reported that students of biomedical science may not realise creative opportunities [39]. Educators, therefore, have a responsibility to define creativity and innovation; particularly where this applies to the learning outcomes through assessment, enabling students to recognise and harness their creative abilities and appreciate the value of these skills in terms of employability [39]. Educators must also be mindful when designing group activities, that dominant members do not negatively impact on the activity of their peers [38]. From the student reflection in relation to these assessments, this did not however appear to be an issue, in contrast students reflected they were encouraged and supported by their peers and felt great pride for their co-produced digital output (**Table 3**).

The challenges which have presented in the integration of online groupwork need to be acknowledged and have been discussed in a recent systematic review by Donelan and Kear [36]. Several of these challenges were identified during the two group assignment activities, namely, i) initially prior to the commencement of the group activities, students were

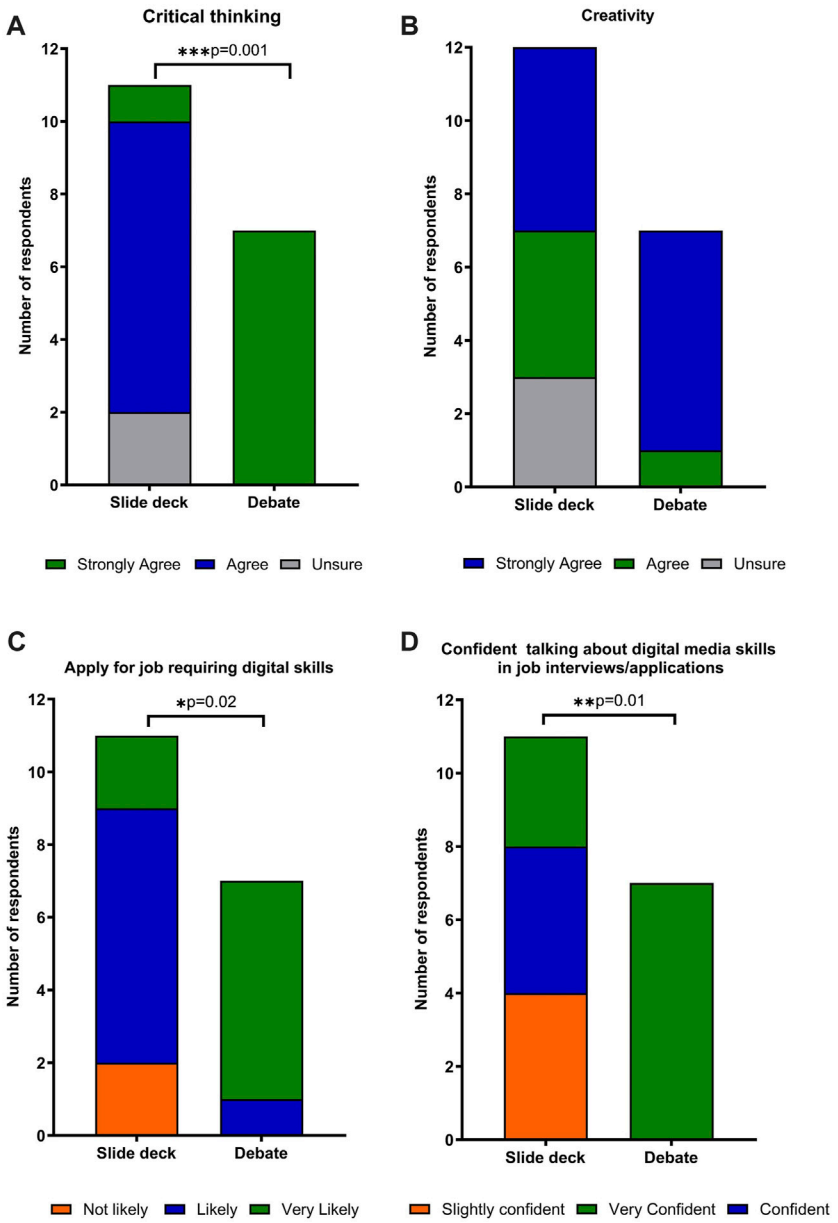

FIGURE 6 | A comparison of respondents' views after completion of the two group assignment activities in relation to **(A)** demonstrating their critical thinking skills; **(B)** demonstrating their creative skills; **(C)** likelihood of applying for a job requiring digital skills and **(D)** confidence in talking about examples of using a range of digital media in job applications and interviews.

concerned that not all group members would participate equally, however such fears were rapidly dispelled once the members of the group made initial contact; ii) scheduling and time issues impacted on the ability to hold virtual meetings in real time and iii) anxiety was reported in relation to having to work with strangers in a remote situation (**Table 3**). Students overwhelmingly however, valued the group assessments and many reported that these activities promoted them to take on leadership roles, both within the assessment and subsequent translation within the workplace.

Donelan and Kear [36], concluded that although the literature identifies numerous challenges, for which strategies have been developed to address, there are two fundamental areas which are a priority for consideration, namely, i) that initially all aspects of the group activity are carefully designed supplying students with detailed guidance and preparation and ii) the groups' relationships are supported throughout the duration of the activity [36]. It was therefore essential, academics robustly developed an assignment plan (**Figure 8**) and that early in the module clarity was provided to students in relation to i) which

TABLE 3 | Quantitative analysis of students' reflections following group assignment tasks.

	Slide deck (Total = 20) % (*n*)	Debate (Total = 21) % (*n*)
Pre-assignment apprehensions		
• Logistics and difficulties of working as a group online	35 (7)	62 (13)
• Working with unknown individuals	35 (7)	19 (4)
• Group activity	—	43 (9)[a]
• Not all group members would participate equally	30 (6)	29 (6)
• Unfamiliar with digital platforms/tools	30 (6)	24 (5)
• Debate	—	19 (4)
• Reliability of internet	5 (1)	—
• Timely feedback from others	5 (1)	—
• Unsure where to start	5 (1)	5 (1)
• Prefer to work alone	5 (1)	10 (2)
• Co-dependence to achieve assessment mark	5 (1)	5 (1)
• Volume of work	—	10 (2)
• Different time zones	—	19 (4)
Challenges		
• Time to meet as a group due to other commitments	65 (13)	19 (4)[b]
• Time management	25 (5)	48 (10)
• Unfamiliar with digital platforms/tools	30 (6)	24 (5)
• Discussion boards- responses not in real time	20 (4)	—
• Responsibility- not wishing to let the group down	20 (4)	5 (1)
• Apprehensive regarding audiovisual recording (FlipGrid)	10 (2)	5 (1)
• Reluctant to turn on camera when communicating remotely	10 (2)	—
• Limited public speaking/presentation skills	—	14 (3)
• Lack of creative thinking skills	—	5 (1)
Value of the group activity		
• Knowledge gained	85 (17)	86 (18)
• Enjoyable experience	70 (14)	67 (14)
• Collegiality	70 (14)	71 (15)
• Interesting	65 (13)	52 (11)
• Peer interaction and support in general	50 (10)	67 (14)
• Importance of inclusivity and others' viewpoints/abilities	45 (9)	52 (11)
• Continual professional development	25 (5)	38 (8)
• Learnt from others	10 (2)	24 (5)
• Relevant topics	15 (3)	10 (2)
Skills developed		
• Digital platforms/tools	80 (16)	90 (19)
• Communication	75 (15)	52 (11)
• Collaboration/Teamwork	75 (15)	38 (8)[c]
• Time management	50 (10)	62 (13)
• PowerPoint	45 (9)	62 (13)
• Organisational skills	25 (5)	29 (6)
• Reflective Practice	20 (4)	38 (8)
• Using literature search tools	15 (3)	10 (2)
• Leadership	5 (1)	33 (7)[d]
• Critical evaluation	5 (1)	33 (7)[e]
• Presentation/public speaking	—	38 (8)
• Flexibility	—	14 (3)
• Problem solving	—	14 (3)
• Creative thinking	—	5 (1)
• Decision making	—	10 (2)
Personal feelings/attributes		
• Confidence	35 (7)	62 (13)
• Proud of achievement/final product	30 (6)	43 (9)

Statistical significance as per Fisher's exact test.
[a]p = *0.001 (Odds ratio 0.000; 95% CI 0.000–0.316).*
[b]p = *0.004 (Odds ratio 7.893; 95% CI 1.973–26.78).*
[c]p = *0.028 (Odds ratio 4.875; 95% CI 1.355–18.84).*
[d]p = *0.045 (Odds ratio 0.105; 95% CI 0.009–0.778).*
[e]p = *0.045 (Odds ratio 0.105; 95% CI 0.009–0.778).*

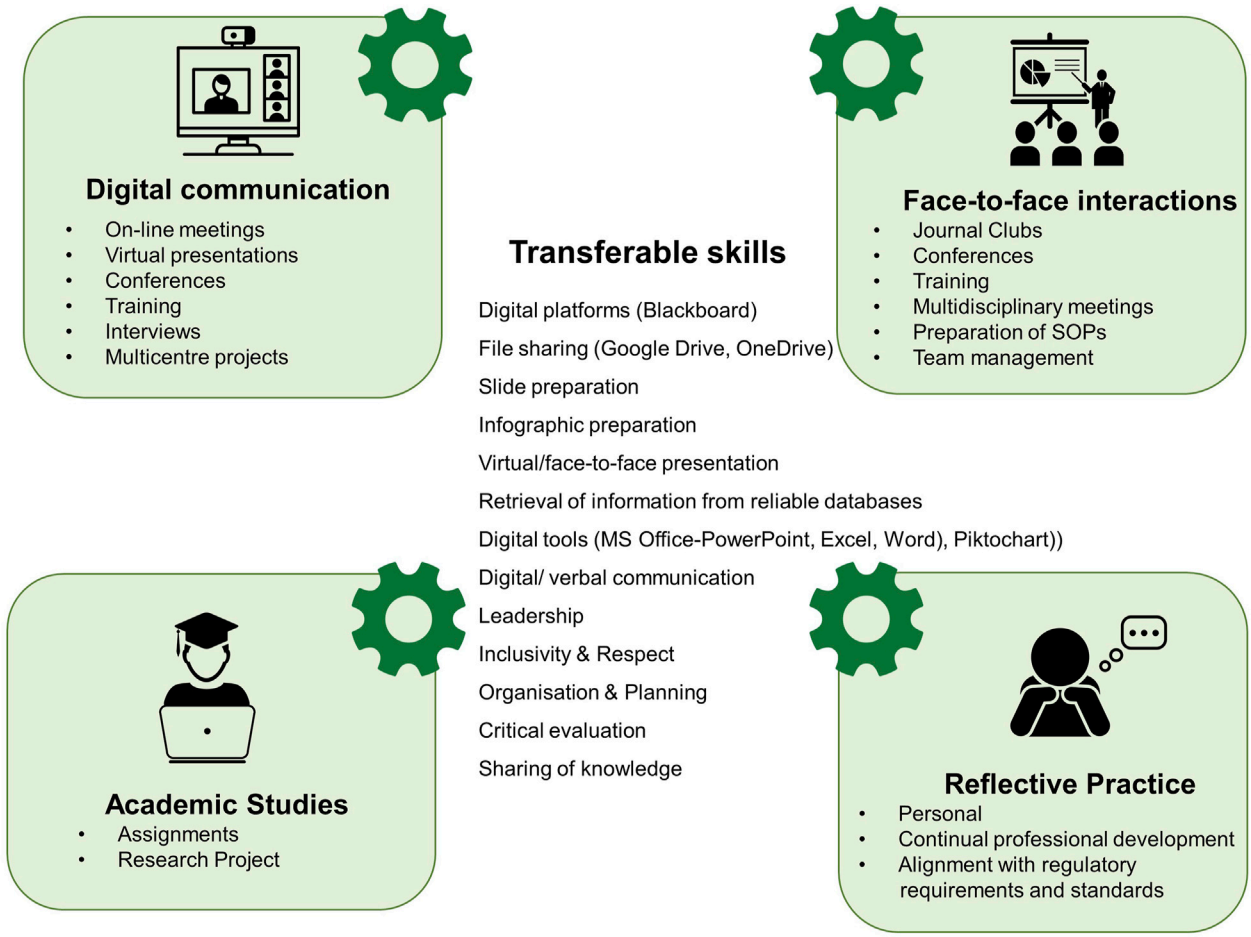

FIGURE 7 | Areas where students detailed they would use the skills and knowledge gained during the group assignment activities.

aspects of the group activity were being assessed, i.e., individual/group contribution, ii) details regarding the process and tools used to prepare the final product and that e-tutor support was available throughout the process to offer guidance. Such clarity helped to alleviate any concerns students may have had relating to the assignment task. This approach is also transferable to online group debates in other healthcare and non-healthcare educational programmes.

To guide developments relating to assessment, it is important to critically appraise evidence-based practice approaches and assessment guidelines in conjunction with the students' voice, gathered by means of local student feedback and reflections to help mould the final product into an engaging, challenging, criterion-referenced assessment. Such assessment embeds the translation of relevant pedagogical theories; particularly those of Anderson and Krathwohl's modification of Bloom's Taxonomy [40] and Biggs' constructive alignment [41], into educational practice, to help students become effective learners. Following the assessment of the first group activity in which student cohorts prepared a slide deck on topical issues in clinical microbiology, it was considered by the course team that although the students enjoyed the activities and their knowledge of the subject area was enhanced, a more critical appraisal of the topics could have been promoted. Additionally, in relation to the group 1 assessment activity, two groups were proud of their achievements and although not compulsory, wished to orally deliver their slide deck via a live Blackboard Ultra session. As such, the group assignment was reconstructed to include a recorded oral presentation in a debate style format to ensure a positive student experience focusing on higher order thinking processes and competencies, as well as summative and formative learning approaches to help prepare students for the workplace environment [25, 32].

Debate incorporates constructivist pedagogies and offers a platform for students to express and consider diverse thoughts and ideas [42]. This activity has been used effectively in face-to-face teaching to develop and assess higher-order cognitive and communication skills, stimulating interest and confidence and acquire knowledge in microbiology [42–44]. On-line debate encourages group interaction in an innovative and a more engaging manner using digital communication and presentation rather than the use of traditional discussion

FIGURE 8 | Virtual group debate assessment plan.

forums [45]. Indeed, students reflected that they found the use of discussion forms frustrating as these forums did not allow communication in real-time (**Table 3**). If conducted asynchronously, on-line debate could permit a more critical evaluation of the scientific evidence before constructing a response, thereby providing a pedagogical strategy promoting reflexivity [46]. On-line debates have not been used extensively as an assessment model which may be due to the fact that their coordination and evaluation requires significant input particularly if delivered via Blackboard Discussion Forums [47], as such it was decided that the delivery of these online debates would be by means of an audio-visual format, namely, voice over PowerPoint. Careful consideration was required in relation to the logistics and digital tools required within the online setting. With provision of the appropriate digital platforms and tools and e-tutor guidance, students successfully delivered their voice over debates, which resulted in an improvement in utilising critical thinking skills in comparison with the preparation slide deck in the first group activity (**Figure 6A**).

The challenge associated with developing assessment is to ensure it is effective and fair to all students and staff, as recently considered within JISC's report [48], "*The future of assessment: five principles, five targets for 2025.*" This report examined how new technologies, namely, digital tools and platforms, can improve and ensure assessment is authentic, accessible, automated, continuous and secure, resulting in students having a fulfilling learning experience, as they develop skills and character during their education and for future employment. Online group activities offer an ideal environment for students to develop their leadership, time-management, collaborative and organisational skills but most importantly digital communication and digital creation skills all of which are central to the success of online group activities as well as a skill set transferable to the workplace [36].

While this study has focused on the evaluation of the development of microbiological knowledge and transferable skill development, when embedding a new form of assessment, it is of utmost importance to provide students with feedback. Feedback and more effectively feedforward coupled with clear instruction is an important aspect of assessment and the meta-cognitive experience [49, 50] contributing to students becoming effective learners by correction and development. The initial

submission of a group strategy, enabled students to receive feedback which they could then subsequently feedforward into the development of their final output.

Such feedback guides students to understand requirements in terms of their understanding and demonstration of knowledge and promotes development through reflection, thinking, reading and writing [51]. In the case of distance learning students, feedback is a source of intrinsic motivation [52]. Consideration is required when delivering feedback in relation to a group activity to ensure all students fully appreciate and value the feedback in terms of both their own performance and in relation to group performance. Feedback in the form of peer assessment provides an opportunity to challenge students cognitively and highlight areas which deviate from the standards required [53] and should be considered in group-based assessment. A number of feedback modalities both written and verbal may be used to support students' varied needs and preferences [49]. Students report a preference for written feedback [54], although verbal and face-to-face feedback are considered more personal and thorough [55]. In the case of these assignments, the e-tutor delivered personal written feedback and general audio-visual feedback to the complete cohort of students. Overall, whether feedback is written or verbal, it is important to ensure the tone and language used is not derogatory but offers valid, balanced, personal and motivational advice linked to learning outcomes which students can respond to in order to promote improvement [56].

Reflection is of fundamental importance to all allied healthcare professionals and is central to their continual professional development. Many education providers of biomedical science programmes have embedded reflection into their assessments [57, 58]. Reflection can take many forms, visual, written, audio, etc. and valuable resources are available for healthcare professionals and academics to promote to their students [59–61]. Within these assessment tasks, two modalities of reflection were incorporated, namely, written and a reflective video. The reflective video was prepared using the free Microsoft app FlipGrid (now known as Flip), a social learning community app, which educators globally have used to create safe online groups for students to communicate and convey their thoughts and ideas using short video messages [33]. FlipGrid has been used in all levels of education to promote student engagement and discussion [62]. In relation to higher education, FlipGrid has been used to promote scientific communication and enhance oral skills [63]. It has been used both by students and academics and has the potential to help build online educational communities [63]. FlipGrid has also been used to facilitate and improve critical reflection by collaborative online interactions in a undergraduate Sports Coaching degree programme [64].

Students in this study who used the FlipGrid to reflect reported that this digital tool was easy to use and that they enjoyed being able to see that they were part of a larger group of individuals who had the same successes, challenges and reflective thoughts as their peers, with only two students (2/41) indicating that they found the recording of a reflective video challenging and stressful. It should be noted however, that FlipGrid also provides the opportunity to make audio posts and students can use a still image or avatar image if they do not wish to reveal their face [65]. Further studies are required to fully examine the potential of utilising FlipGrid to promote e-learning communities and asynchronous interactive discussions in the discipline of biomedical science.

In addition to the knowledge acquisition gained during the completion of these two group activities, it was evident that the skills which students developed were of particular value in relation to digital platforms, digital tools and digital communication. These are important skills to develop, particularly in relation to the updated HCPC Standards of Proficiency (SOPs), effective from 1 September 2023, which have emphasised the need to be able to keep up to date with digital skills and new technologies, namely, 7.7, which addresses effective communication "*Registrants must use information, communication and digital technologies appropriate to their practice*" [27]. Both of these group-based activities were conducted prior to the updating of the SOPs and it is interesting to note that prior to the assessment tasks students attributed a lower importance to the development of digital skills than skills development with respect to communication, teamwork, accuracy confidentiality, respect for others and health and safety. This highlights the importance of embedding and highlighting where such digital skills are useful within the healthcare setting and the biomedical science sector [66]. Within this study, students reflected and acknowledged areas where they had already used or would potentially use such digital skills in their workplace (**Figure 7**). It must also be acknowledged that the majority of students enrolled in this distance e-learning postgraduate programme did not actively participate in using a range of digital platforms and digital tools in their undergraduate programmes (**Figure 5**) with many unfamiliar with the full potential of PowerPoint and some students had never used this tool. Educators should, therefore, actively seek opportunities to embed digital skills and digital communication skills in both undergraduate [57] and postgraduate biomedical science degree programmes which are IBMS accredited and/or HCPC approved. Additionally, the use of digital tools in e-learning programmes, enhances engagement with the discipline specific content, provides motivation in relation to learning and assessment activities, and promotes communication between students and their peers as well as tutors [30]. Furthermore, from this study, the group-based activities fostered students' confidence in taking on leadership roles and instilled an appreciation of the importance of inclusivity of other's viewpoints and abilities, which aligns with the updated HCPC Standards of Proficiency in relation to equality, diversity and inclusion, namely, 5: "*recognise the impact of culture, equality and diversity on practice and practise in a non-discriminatory and inclusive manner*" [27].

Study Limitations

The primary limitation to this study was the small number of students participating in each of the group assessment tasks. It

must however be acknowledged that the number of enrolled students in each cohort did not exceed approximately 20 as this is a specialism module in an e-learning distance learning MSc programme. Additionally, uptake rates of the pre and post surveys particularly in relation to the second group assessment relating to the debate was low. This potentially was influenced by the fact that these students were active healthcare professionals delivering a microbiological diagnostic service during the peak of the COVID-19 pandemic and time was of a premium due to their healthcare, compulsory academic and personal commitments. It is widely reported the uptake rate of such online surveys is low, (30%–40%) [67], which is in the range of the second group activity survey responses (38% and 33% pre-and post-survey responses, respectively), with that of the first activity much higher (80% and 52% pre- and post-survey responses, respectively). This is unfortunately, a common fact of conducting surveys as has been highlighted recently by Bahir et al. [58]. In future questionnaires could be delivered using anonymous polls during live sessions by the digital tools such as Mentimeter [68] or incentives could be provided to increase uptake [58, 69]. Nevertheless, the embedding of these group assessments and their value to students in terms of developing transferable skills and building online communities is evident and the findings offer other educational providers an insight into novel approaches to developing group assessment in e-learning distance biomedical science degree programmes. Future work could focus on the co-creation of distance learning group activities, particularly debates, to address the challenges raised and promote further student engagement.

CONCLUSION

In conclusion, online distance learning group activities are possible to implement if aligned with learning outcomes and clear instruction and support are provided. Although students and staff may find embedding such group assessments into the curriculum difficult, the benefit in terms of student experience is valuable. Students have an opportunity to build learning communities and have peer support, as well as develop specialist knowledge and key transferable skills, namely, digital competencies. Online debate formats improve students' critical evaluation skills and promote a novel online approach to teaching and assessment which students find interesting and enjoyable.

SUMMARY TABLE

What Is Known About The Subject?

- The availability of IBMS accredited biomedical science distance learning degree programmes is increasing.
- Distance learning students can often feel isolated due to the temporal separation from both their tutor and peers.
- The revised HCPC SOPs emphasise the need to be able to keep up-to-date with digital skills and new technologies.

What This Paper Adds

- Group-based assessments improved students' knowledge and development of digital skills.
- Completion of digital outputs from group-based activities were regarded as enjoyable experiences.
- Students developed transferable digital skills and confidence during online group activities, realising the importance of digital competencies in the healthcare sector.

SUMMARY SENTENCE

This work represents an advance in biomedical science because distance learning group assessments promoted online learning communities and the development of key transferable digital skills.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further enquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving humans were approved by the Ulster University procedures for research involving human subjects (FCBMS-19-091). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

BCM conceived, conducted the study, collected and analysed the data and wrote the manuscript, HP developed the questionnaires and study approach. JEM, CJL, and SMcC contributed to the development of the study approach and reflection of assessment activities. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2023.11891/full#supplementary-material

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ORIGINAL RESEARCH
published: 29 November 2023
doi: 10.3389/bjbs.2023.11680

A Cytomegalovirus (CMV) Case Study to Promote Interprofessional Learning (IPL) Between Audiology and Biomedical Science Students in Higher Education

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Modern and effective patient care requires specialist healthcare professionals working together. Interprofessional learning (IPL) seeks to provide opportunities for different healthcare disciplines to learn with, from and about each other. This study focused on the delivery and evaluation of a cytomegalovirus (CMV) case study workshop to facilitate IPL between two Health and Care Professions Council (HCPC) regulated courses: Biomedical Science and Audiology. The 2 h online workshop consisted of 1) defining the roles, responsibilities and skills of the two healthcare professions, 2) the structure of the Biomedical Science and Audiology departments, 3) routes to HCPC registration, 4) core curriculum of both degree programmes and 5) interpreting interdisciplinary data related to a CMV patient case. The workshop was interactive, with the virtual learning environment promoting peer discussions and the use of online polling. Student responses were collected through an online questionnaire. A total of 108 respondents completed a post-event survey and Mann-Whitney *U* tests revealed there were no significant differences in the responses between the two student cohorts in response to each of the survey statements ($p > 0.05$). A total of 82.4% of students agreed that they need to know the role of other healthcare professionals for their future practice, whilst 84.2% agreed that the CMV case study was a good format to facilitate effective IPL. A total of 93.5% of respondents recognised the importance of both professions in diagnosing a patient with CMV. Thematic analysis identified four common themes, including appreciation of shared roles, recognition of similarities in registration pathways, working together to provide holistic patient care and the role of clinicians in the patient journey. This novel collaboration between Biomedical Science and Audiology facilitated effective IPL whilst meeting the interprofessional education HCPC requirements. Collaborative working is an essential component of delivering effective patient care and allied healthcare degrees need to provide opportunities within their curriculum to foster this. We hope this study encourages other higher education institutes to expand and develop their current IPL activities to include a broader spectrum of healthcare courses.

Keywords: interprofessional learning, audiology, biomedical science, higher education, patient care

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Received: *13 June 2023*
Accepted: *15 November 2023*
Published: *29 November 2023*

Citation:
Bashir A, Pallett R, Rana KS and Hussain S (2023) A Cytomegalovirus (CMV) Case Study to Promote Interprofessional Learning (IPL) Between Audiology and Biomedical Science Students in Higher Education. Br J Biomed Sci 80:11680. doi: 10.3389/bjbs.2023.11680

INTRODUCTION

Modern healthcare is truly multidisciplinary in nature, requiring many highly skilled healthcare professionals working together to provide effective patient care [1]. Advancements in pathology over recent decades have helped to transform the diagnostic pathway, allowing healthcare professionals to better identify and treat conditions. Patients are presenting with increasingly complex conditions and co-morbidities which require multidisciplinary approaches to care. In many specialities such as oncology, endocrinology and palliative care, there are established teams that directly impact the patient pathway. However, other healthcare professionals often work and learn in silo, without developing an understanding of the roles of other healthcare professionals and how collaboration can improve patient outcomes [2].

Within the higher education setting, IPL between nursing and medical programmes is well established and interprofessional education (IPE) is an essential component of the curriculum of subjects allied to health. Numerous publications have shown how interactivity develops key skills, such as fostering collaboration, improving communication and shared decision making and improving one's understanding of their role and responsibilities and the role and responsibilities of others [2–4]. Ultimately, IPE aims to improve the quality of care provided to patients by creating a more integrated and collaborative healthcare team.

Recognition of IPL by the Health and Care Professions Council

The importance and value of IPL within the healthcare setting is well recognised, yet there has been a lag with regard to its implementation within undergraduate healthcare programmes such as Audiology and Biomedical Science. The Health Care and Professions Council (HCPC) accredit both aforementioned programmes and requires students enrolled on these courses to have opportunities to undertake IPL in order to "learn with, and from, professionals and learners in other relevant professions" [5]. As the importance of IPL is mandated by the HCPC it has been incorporated into both BMS and Audiology modules and programme specifications respectively. Students need to be able to "*explain, in an integrated manner, the importance of service users and the role of a multidisciplinary team in the delivery of effective patient care including inter-professional learning*".

Biomedical Scientists (BMS) are involved in up to 95% of all clinical pathways [6] and yet this was traditionally under-recognised by both patients and other pathology service users [7]. The COVID-19 pandemic helped to put the profession of a Biomedical Scientist into the public eye, with individuals recognising the key role of laboratory scientists in the diagnosis, monitoring and treatment of patients. Whilst recent studies have evaluated the effectiveness of IPL between Biomedical Scientists and other healthcare programmes in a traditional face-to-face setting [8] and virtual learning environments [3], to our knowledge no other studies are exploring the value of IPL between a laboratory-based Biomedical Scientist and a patient facing Audiologist.

The Value of IPL Between Biomedical Scientists and Audiologists

Audiologists play a central role in identifying, assessing, and treating hearing problems and balance disorders [9]. Whilst it may appear at first glance that there is little overlap between the two professions, there are many commonalities related to their role in providing effective patient care. Audiologists play a central role in diagnosing patients with hearing disorders, several of which are a result of bacterial and viral infections. One cause of hearing loss in children is cytomegalovirus (CMV), which can be transmitted to the foetus during pregnancy or delivery. It has been estimated that 1 in 200 babies are born with congenital CMV infection [10] and 10%–15% will have long-term health problems, including sensorineural hearing loss [11]. Testing for CMV viral infection and confirmation of its diagnosis is performed by a Biomedical Scientist, whereas the initial hearing screens and referral are performed by an Audiologist.

Thus, this study aimed to create and assess the effectiveness of an online IPL workshop involving final year Biomedical Science students and first-year Audiology students. The workshop focussed on a patient case study involving CMV and sought to improve awareness and understanding of both healthcare roles whilst highlighting the role of each profession in diagnosing and treating patients with a CMV infection.

MATERIALS AND METHODS

Creation of a Virtual IPL Workshop

A 2 h online workshop was designed and co-delivered by academics between the Department of Audiology and the School of Biosciences at Aston University, United Kingdom. The preferred method of delivering the workshop was online in order to increase student engagement and to promote fruitful cross disciplinary interactions based on previous success. The workshop included fifteen first-year Audiology students and ninety-three final-year Biomedical Science students. In the context of IPL, year 1 Audiology students were designated to collaborate with final-year Biomedical Science students. This IPL activity was set to coincide with the curricular focus of Year 1 Audiology students, who were at a stage in their program where they were learning fundamental knowledge pertaining to screening principles and the underpinning principles of CMV assessment processes. Final-year Biomedical Science students were selected for this IPL activity as they complete clinical modules by this stage. Furthermore, as part of this module, students learn about NHS structure and specific HCPC requirements related to IPL and multidisciplinary working, prior to entering the graduate healthcare workforce.

To promote IPE, the workshop included five key areas of delivery, which consisted of 1) the distinct roles and skills of an Audiologist and a Biomedical Scientist, 2) the structure of Audiology and Pathology departments, 3) routes to HCPC professional registration, 4) core components of an Audiology

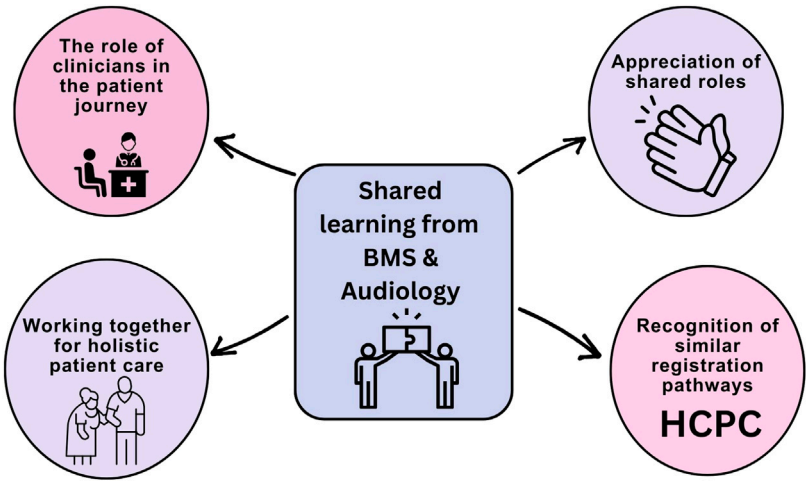

FIGURE 1 | Steps involved in the design, delivery, and evaluation of the IPL workshop.

and Biomedical Science degree and 5) interpreting data relating to a CMV patient case study. The workshop was delivered using the virtual learning environment (VLE) Blackboard Collaborate platform (Blackboard, Washington DC). Using the breakout room function, students were assigned into seven mixed profession groups. The workshop was led by academic staff, with students participating through the use of the chat, audio and polling functions of the VLE. The IPL was co-created with academics from Biomedical Science and Audiology and the steps involved in the design, delivery and evaluation are detailed in **Figure 1**.

Cytomegalovirus Case Study

Students were presented with a case study of a patient who contracted CMV during the last trimester of her pregnancy and was concerned that she had passed the virus on to her baby during delivery. The case provided a background to congenital CMV, its mode of transmission, virulence and the probability of the newborn baby developing sensorineural hearing loss. The case study then discussed CMV testing within the pathology laboratory, including the sample types required, the diagnostic tests performed in the virology and cytology laboratories, highlighting positive test results. The final part of the workshop introduced Audiology components, including hearing screening, the hearing pathway, sensorineural hearing loss and defining key terms such as "screening," "sensitivity" and "specificity."

IPL Activity Booklet

A four-page activity booklet was created using constructive alignment. Teaching-focused lecturers involved in the IPL activity design and delivery from two different disciplines. The workbook was co-created to allow students from both subjects to "lead" on content as per their specialist knowledge. This was intended to allow students to appraise their roles and apply integrative understanding of subject-specific content to peers from different backgrounds. This process was informed by Bloom's Taxonomy principles [12].

The workbook was uploaded onto the VLE ahead of the workshop. Each activity was designed for students to identify and highlight commonalities and differences between the two professions. The booklet contained three tasks for the students to undertake. Activity 1 required students to work in mixed groups and assign key skills and roles that are typically attributed to either or both professions. Activity 2 required students to detail the key steps required to become an HCPC registered healthcare professional in the NHS. Activity 3 required students to interpret diagnostic data for both Audiology and Biomedical Science, with students explaining the purpose of each test to the other healthcare professional. The transferable skills gained through completing each activity are detailed in **Figure 2**.

Data Collection and Analysis

Student responses following the IPL workshop were collected through a ten-item online questionnaire (Online Surveys, JISC, Bristol, United Kingdom). The survey was approved by the Health and Life Sciences Research Ethics Committee (Project #1494). Informed consent was built into the online survey prior to respondents accessing the survey. All responses to the survey were anonymous and participation was voluntary. The survey was advertised post-workshop using the VLE and remained open for 1 week.

Open and closed questions were included as part of the survey design and results were analysed both quantitively and qualitatively. To collate participants' views of the IPL workshop and IPE, a five-point Likert scale was used to collate responses, which ranged from "strongly agree" to "strongly disagree."

The Likert-scale responses were converted into a numerical format. Responses between the two student cohorts (Biomedical Science and Audiology) were compared using Mann-Whitney *U* tests. A non-parametric test was chosen as the data is ordinal and assumed to not have a normal distribution. All statistical analysis was performed using GraphPad Prism version 8.0.2 (GraphPad Software, United States). Statistical significance was determined by $p < 0.05$.

Free text responses allowed students to elaborate as to what they taught other students and what they learned from other

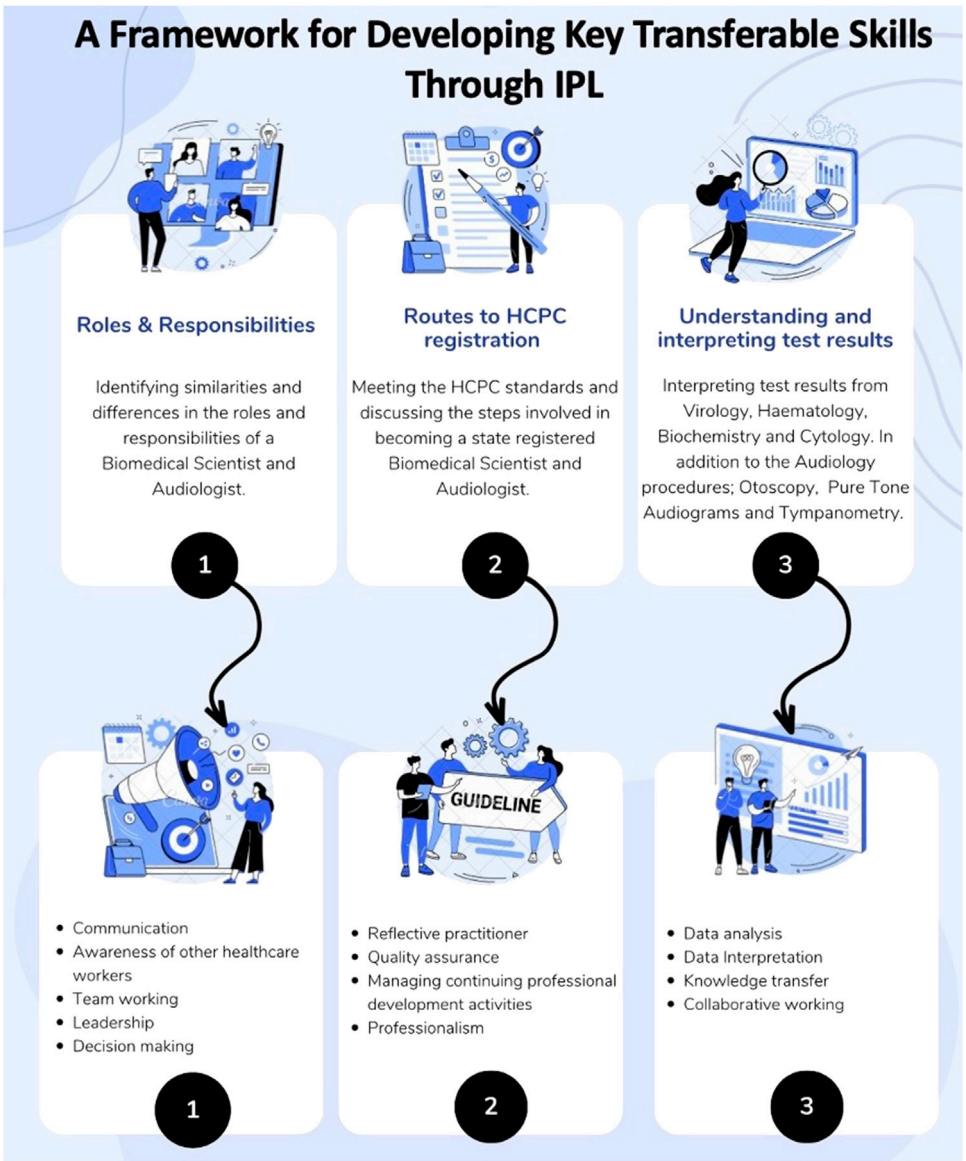

FIGURE 2 | Details of the three IPL activities and the associated core transferable skills students developed.

students. Furthermore, free-text responses built an understanding of the student's experiences of IPL and were analysed using thematic analysis [13]. The data was read multiple times by the first author to identify initial themes and this was repeated by all authors for triangulation, prior to a coding framework being developed and applied to the data set. The final themes were then agreed upon collectively.

RESULTS

A total of 108 students who were enrolled on first year Audiology and final year Biomedical Science degrees at Aston University participated in the workshop and completed the survey.

Interactive Polling and Chat Function

During the workshop, interactive polling was deployed using a tool on Blackboard Collaborate, and on average there was ~81% engagement across the three questions. The responses were anonymous, therefore the numbers responding from each programme could not be identified. Question 1 focussed on HCPC registration for both courses and 85% of students engaged with the poll. Question 2 focussed upon BMS pathology testing for viruses, highlighting the steps involved in PCR testing (engagement 88%) and question 3 was centred around audiology terminology (engagement 70%). Furthermore, students were able to use the chat function and as well as their microphone to both ask questions and answer questions.

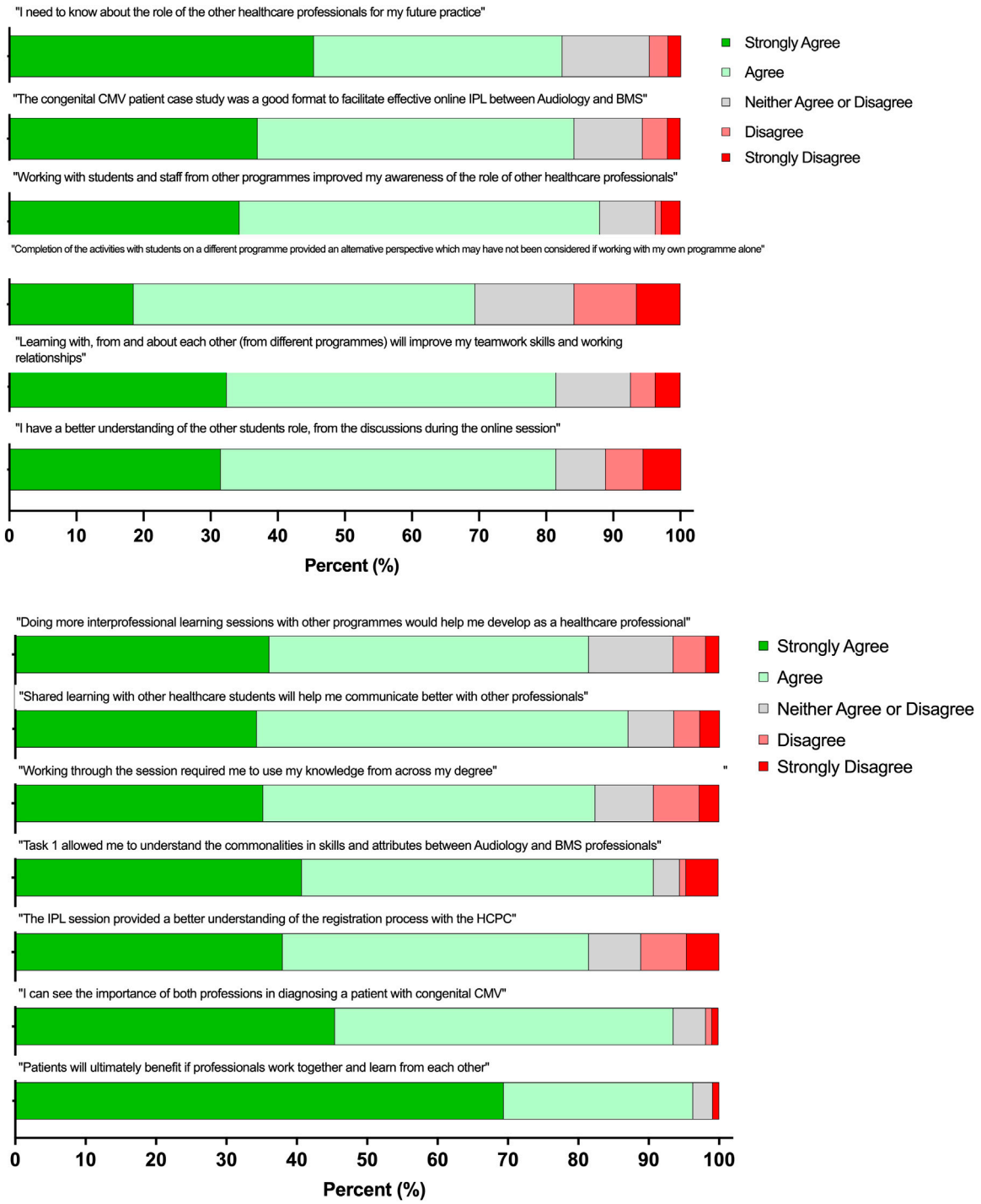

FIGURE 3 | Student survey self-reported responses to the online IPL workshop (n = 108). A five-point Likert scale was used to answer each statement, with 1 = strongly disagree and 5 = strongly agree ± the standard deviation (SD). A Mann-Whitney U test was used to determine statistical significance (*$p < 0.05$) between the two student cohorts.

Response to Post Workshop Survey

Participants responded to a series of statements relating to IPE and its role in the healthcare setting (**Figure 3**). Overall, a positive response was received from both cohorts, with 84.61% of students stating that they agreed or strongly agreed with all the statements. A Mann-Whitney U test was used to determine statistical

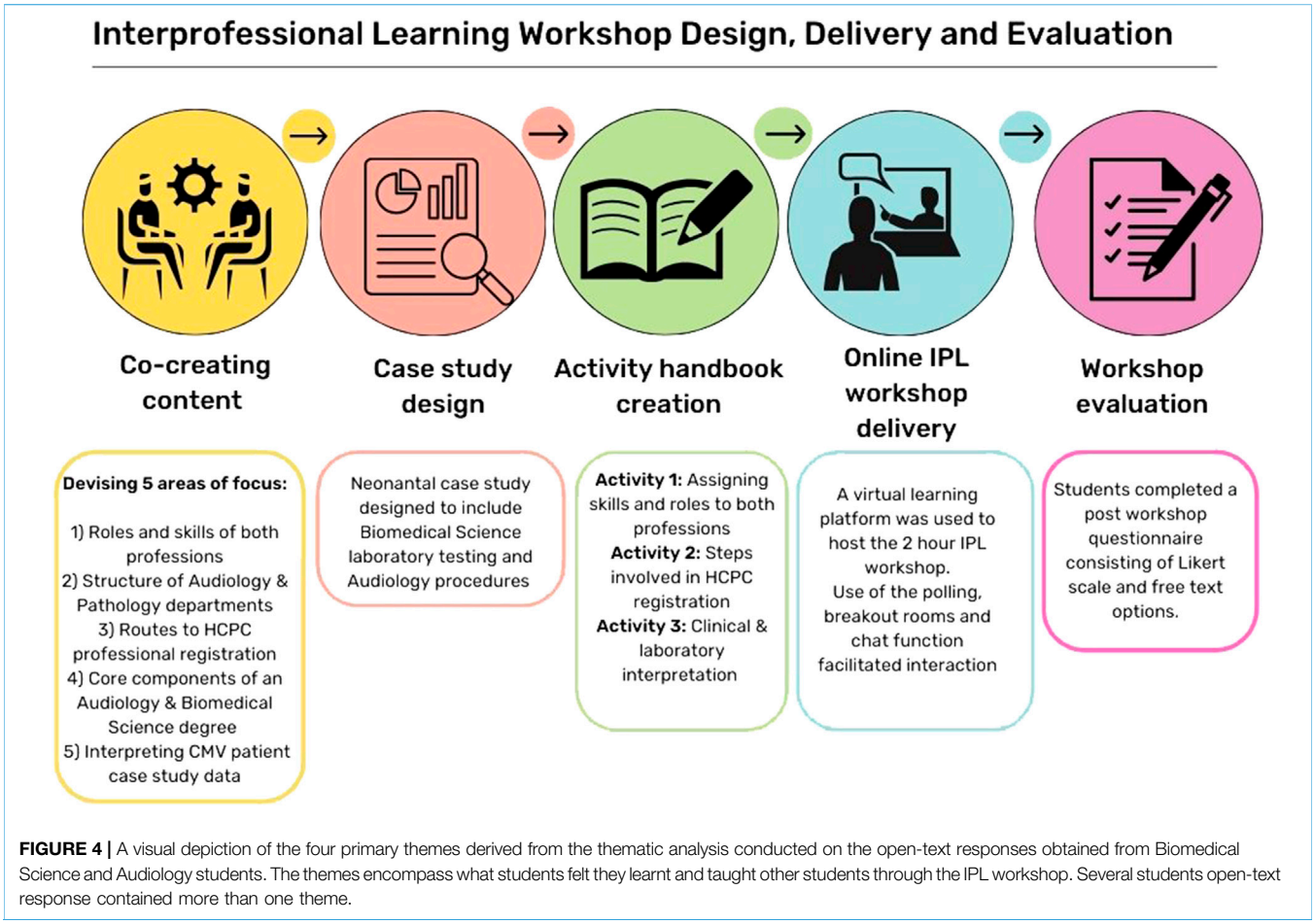

FIGURE 4 | A visual depiction of the four primary themes derived from the thematic analysis conducted on the open-text responses obtained from Biomedical Science and Audiology students. The themes encompass what students felt they learnt and taught other students through the IPL workshop. Several students open-text response contained more than one theme.

significance ($p < 0.05$) and no significant differences were observed in the responses between the two student cohorts in response to any of the survey statements.

Over 82.4% of respondents "Agreed" or "Strongly agreed" that they need to know about the roles of other healthcare professions for their future careers, whilst 84.2% of respondents "Agreed" or "Strongly agreed" that the CMV congenital patient case study was an effective format to facilitate effective IPL (statements 1 and 2). A total of 88% of respondents stated that working with students and staff from other programmes improved their awareness of the role of other healthcare professionals (statement 3). A total of 69.4% of respondents reported that completing activities with students enrolled on the other healthcare programme provided an alternative perspective which they may not have considered outside of the IPL workshop (statement 4). Over 81.5% of respondents stated that the IPL workshop improved their communication, teamwork and working relationships, in addition to both cohorts learning with, from and about each other (statements 5, 6 and 8). Over 81.5% of respondents reported that the online workshop encouraged the application of subject specific knowledge, identified commonalities between the two professions, improved understanding of professional registration and recognised the value of both a Biomedical Scientist and an Audiologist in the diagnosis of a patient with CMV (statements 9, 10, 11 and 12). Finally, 96.3% of respondents "Agreed" or "Strongly agreed" that patients ultimately benefit from interprofessional working and 81.5% of respondents would welcome further opportunities to undertake IPL activities (statements 7 and 13).

Free Text Responses for Thematic Analysis

To gain further insights into the experiences of the students undertaking the workshop, thematic analysis was carried out on two open-text responses. For question 6 – "*What did you learn from the students on the other programme?*" and question 7 – "*What did you feel you taught your peers when sharing your ideas or experience?*" 99% of the students responded (n = 107). The answers to these two questions were combined and analysis was conducted and four major themes were identified 1) the role of the clinician in the patient pathway, 2) appreciation of shared roles and responsibilities, 3) recognition of similarities in HCPC registration pathways and 4) the importance of working together to provide effective patient care (**Figure 4**).

Theme 1: Appreciation of Shared Duties and Roles

Respondents recognised similarities and differences in the roles and duties that each profession carries out. This included specific testing

for diagnosis purposes, but also calibration and communication across disciplines. It was the first time these students had met and they reflected on the shared roles the two professions had.

Comments included:

> "I recognise similarities in the roles of Biomedical Scientists and Audiologists and differences related to their specialities"
>
> "I learnt a lot about how to become a registered audiologist and what their role requires"
>
> "Both professions carry out calibration of equipment"
>
> "Their role in healthcare and how some tasks overlap"
>
> "I gained another perspective of diagnosing and treating patients"
>
> "I feel like I helped them understand the importance of our role in the healthcare setting"

Theme 2: Recognition of Similar Registration Pathways

Respondents reported having a better understanding of not only their own registration routes but that of the other profession. They also recognised the importance of registration, the purpose of CPD and enhancing practice and the similarities in course accreditation.

> "That all healthcare professionals go through a similar pathway in terms of career progression from university onwards."
>
> "How our courses and professions are more similar than they are different in terms of requirements."
>
> "How closely related our standards are while being part of different programs."
>
> "Their registration pathway and the similarities of the two roles"

Theme 3: Working Together for Holistic Patient

Respondents realised the importance of their work and how it directly benefits the patient. Whilst Biomedical Science students do not have face-to-face interactions, they were able to highlight the role they play in patient care. The authors of this study consciously chose a relevant pathology (CMV) to highlight the involvement of both professions in newborn screening processes in the NHS. Both cohorts of students reflected on their roles within healthcare systems (e.g., the NHS) and how they contribute to effective patient care.

> "Learnt more about the audiology profession and how we can work with them as BMS for better patient treatment"
>
> "Importance of IPL and healthcare professionals working together for the patients"
>
> "I learnt how BMS can work together with audiologists to deliver effective patient care"

Theme 4: The Role of Clinicians in the Patient Journey

Respondents stated they had a better appreciation for how their roles contributed towards multi-disciplinary working. Students were able to showcase their roles whilst also reflecting on the value of their professions in the diagnosis pathway. Communication was highlighted as a key skill in delivering patient care.

Comments included:

> "I feel like I helped them understand the importance of our role in the healthcare setting"
>
> "Their specific roles and contributions to society and how we all eventually can work as a team to help the lives of others."
>
> "The audiology pathway and how important multidisciplinary work is for diagnosis."
>
> "How the interactions between both BMS and audiology and work together to obtain a diagnosis"
>
> "How various blood tests can help with the diagnosis even if it's related to audiology"
>
> "Importance of communication and teamwork"

Students were also asked to provide three descriptive words to evaluate their session. Qualitative analysis included coding the data into four distinctive themes which include 1) Unique workshop design, 2) Collaborative working and inclusivity, 3) Interactive and engaging and 4) Contextually relevant (**Figure 5**).

DISCUSSION

A Novel Approach to Bringing Biomedical Science and Audiology Together Through CMV

To our knowledge, this is the first study to evaluate the online delivery of IPL between two HCPC-approved programmes; Biomedical Science and Audiology. Both programmes need to meet the HCPC Standards of Education and Training, which require students to learn with and from other professions [5]. Students enrolled on healthcare degree programmes who partake in IPL opportunities are more likely to develop collaborative practice behaviours post-graduation in the workplace [14]. Thus, there is a growing significance in equipping healthcare professional students with skills that promote teamwork and cooperation [3, 15].

Biomedical Science is largely a non-patient facing profession, whilst Audiology professionals see patients/clients daily. Whereas both programmes include theoretical knowledge and clinical and/or practical skill components, it is

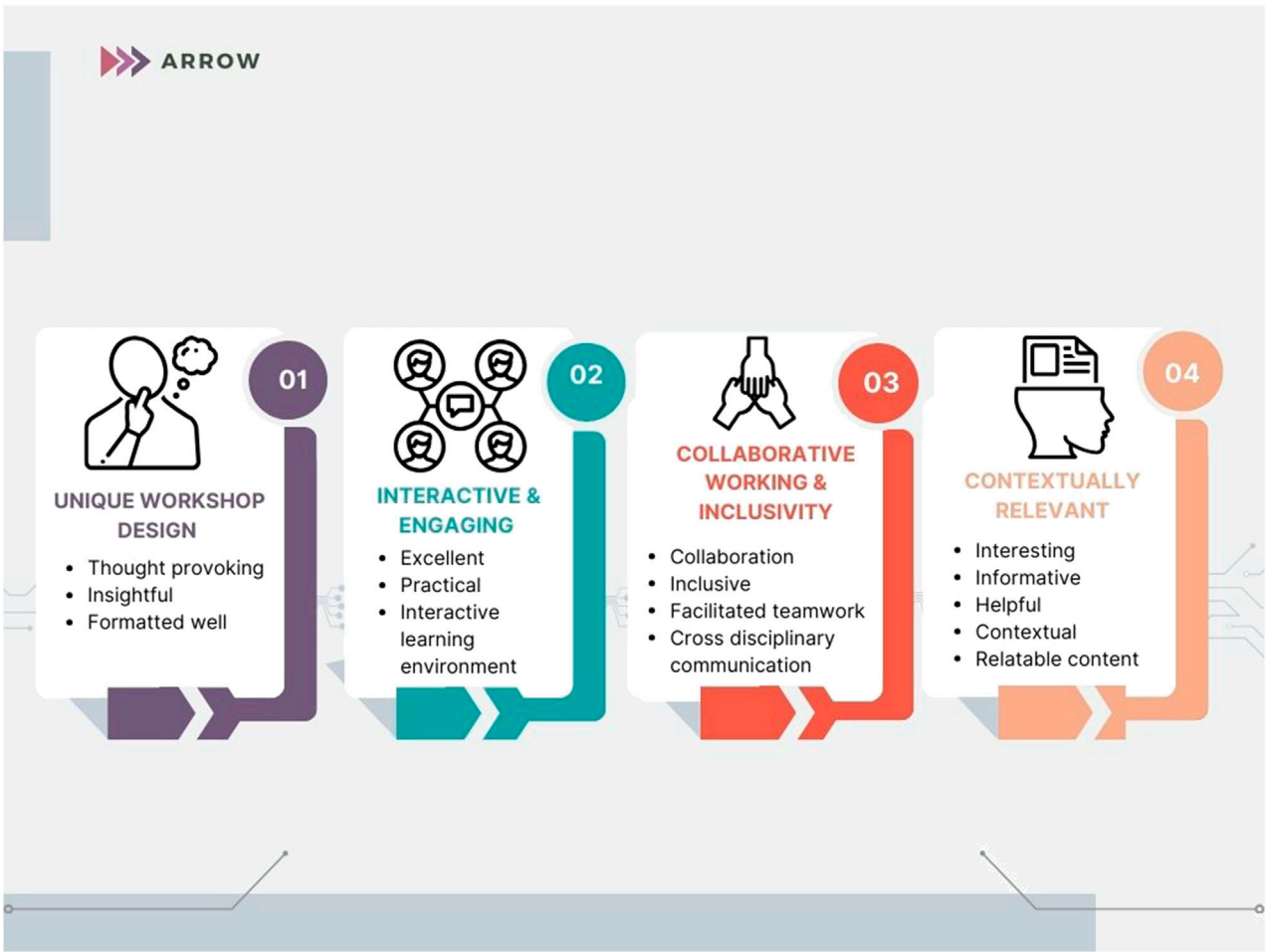

FIGURE 5 | The four common themes identified through analysis of descriptive words to evaluate the workshop.

important to provide opportunities relevant to real life contexts and to remind students that there is a patient behind each diagnosis. Therefore, the IPL workshop was designed for these two cohorts specifically to highlight the role that different healthcare professionals play in the patient journey. At face value it may seem that there is little overlap between these two professions, however, both play a key role in various conditions. CMV is one infection that can affect pregnant women and cause complications in neonates [16]. Collaboration between Biomedical Scientists and Audiologists assists in the diagnosis of conditions and improves hearing health in paediatric care. The use of a case study approach focused on CMV helps to facilitate sociocultural learning, which is deemed to be important for the delivery of effective IPL [17, 18].

Workshop Delivery

Students in this study reflected upon the content of the workshop with 84.2% reporting that the CMV congenital patient case study facilitated effective online IPL between the two professions (**Table 1**). This is further supported by the thematic analysis shown in **Figure 4**, with students stating that they felt the CMV case study was contextually relevant, educational and informative. COVID-19 has reshaped the academic landscape and transformed the delivery of higher education online [19]. This innovative workshop was facilitated by IPL through the use of Blackboard Collaborate, a virtual learning environment for 108 students across two professions. Liaw et al. explored an online IPL activity through 3D simulation to develop and promote transferable skills across a range of healthcare cohorts, including Medicine, Nursing, Pharmacy, Physiotherapy and Occupational Therapy [4].

Roles and Responsibilities

Holistic patient care is dependent upon different healthcare professionals working together with an understanding of each other's roles and remits. With the ever-changing healthcare landscape, the workforce must adapt to maintain high quality service delivery [14, 20]. Often within the healthcare setting an underappreciation of the roles of other professions can impact this [21], the results from the workshop show that 82.4% of students agreed that they need to know about the role of other

TABLE 1 | Biomedical Science and Audiology student survey responses to the online IPL workshop (n = 108). A five-point Likert scale was used to answer each statement, with 1 = strongly disagree and 5 = strongly agree ± the standard deviation (SD). A two-tailed t-test was used to determine statistical significant (*p < 0.05) between the two student cohorts.

	Audiology Mean ± SD	Biomedical science Mean ± SD	p-value	Percentage "Agreed" and "Strongly agreed"
3.1. I need to know about the role of other healthcare professionals for my future practice	4.33 ± 0.98	4.19 ± 0.90	0.61	82.4
3.2 The congenital CMV patient case study was a good format to facilitate effective online IPL between Audiology and BMS	3.87 ± 0.83	4.18 ± 0.88	0.19	84.2
3.3. Working with students and staff from other programmes improved my awareness of the role of other healthcare professionals	4.27 ± 0.59	4.14 ± 0.87	0.48	88
3.4. Completion of the activities with students from a different programme provided an alternative perspective, which may not have been considered if working with own programme alone	3.80 ± 1.01	3.63 ± 1.10	0.57	69.4
3.5. Learning with, from and about each other (from different programmes) will improve my team work skills and working relationships	4.27 ± 0.70	3.99 ± 0.99	0.20	81.5
3.6. I have a better understanding of the other students role, from the discussions during the online session	4.07 ± 0.59	3.95 ± 1.12	0.54	81.5
3.7. Doing more interprofessional learning sessions with other programmes would help me develop as a healthcare professional	4.00 ± 0.76	4.11 ± 0.94	0.63	81.5
3.8. Shared learning with other healthcare students will help me communicate better with other professionals	4.07 ± 0.70	4.13 ± 0.92	0.76	87.1
3.9. Working through the session required me to use my knowledge from across my degree	4.27 ± 0.59	4.02 ± 1.02	0.20	82.4
3.10. Task 1 allowed me to understand the commonalities in skills and attributes between Audiology and BMS professionals	4.27 ± 0.70	4.20 ± 0.96	0.77	90.7
3.11. The IPL session provided a better understanding of the registration process with the HCPC	4.33 ± 0.82	3.99 ± 1.10	0.16	81.5
3.12. I can see the importance of both professions in diagnosing a patient with congenital CMV	4.33 ± 0.49	4.37 ± 0.73	0.83	93.5
3.13. Patients will ultimately benefit if professionals work together and learn from each other	4.60 ± 0.51	4.65 ± 0.65	0.76	96.3

healthcare professionals, with 88% stating that working with students from the other programme improved their awareness of other healthcare roles and responsibilities (**Table 1**). Thematic analysis also revealed that students have an appreciation of shared duties and roles (**Figure 3**), with students also recognising the similarities in the HCPC registration pathways and continual professional development [22]. Exposing students to the roles and responsibilities of different healthcare professionals whilst at the undergraduate level provides a foundation to build clinical relationships upon entering the healthcare setting. IPL has previously been shown to improve a student's understanding of the skills and values between healthcare professions [23]. A greater appreciation of different roles can positively impact the functioning of teams and improve the standards of clinical practice and professionalism [21, 24].

Teamwork and Communication

Another successful outcome of the workshop was that 81.5% of students recognised that participating in IPE will improve their teamwork skills and working relationships (**Table 1**). Previous work involving pharmacy, medical and nursing students have shown that IPL increased their knowledge of how to work effectively within a team, whilst increasing clarity around skillsets and limits of practice within a dynamic team [24–27]. Through the workshop 87.1% of students recognised that learning with other healthcare students will help to improve their communication skills when working with other professionals (**Table 1**). This is supported by previous research which has shown that IPL helps to foster effective communication [28, 29].

Students enrolled on healthcare degree programmes who partake in IPL opportunities are more likely to develop collaborative practice behaviours post-graduation in the workplace. Thus, there is a growing significance in equipping healthcare professional students with skills that promote teamwork and cooperation [3, 15]. Collaboration between Biomedical Scientists and Audiologists may assist in the diagnosis of conditions and improve hearing health in paediatric care. To promote an understanding of the role of a Biomedical Scientist in the patient pathway and the role of Audiologists in primary care, this IPL created a platform that allowed collaborative working.

The HCPC require professionals to be reflective practitioners and demonstrate the ability to reflect upon their own practice and skills. Through this study, students self-reported an increase in key transferable skills that they gained through the IPL activity, namely, communication, subject specific knowledge and teamwork. Final year Biomedical Science students have the opportunity to demonstrate these skills through the final year project poster presentation event; this takes place after the IPL workshop. Students need to communicate their final year scientific research project to peers and academics from different disciplines through the poster presentation event. When analysing the marks awarded for the poster presentation, the Biomedical Science student cohort achieved an average mark of 65% (2022–2023), compared to

61% in the previous academic year (2021–2022). Audiology students complete an additional IPL activity with pharmacy students in the second year where they utilise interdisciplinary and team working skills they have acquired from this IPL activity. These transferable skills are also put into practice during the clinical skills development module through peer group working across cohorts. Finally, these students undertake a final year clinical placement where they work with other healthcare professionals to support patient care.

FUTURE WORK AND LIMITATIONS

Whilst participants appreciated the comfort of learning from home during the workshop, digital inequalities and working environment considerations can disadvantage some students [19]. One unforeseeable drawback of hosting this workshop online is the occurrence of technical issues during its delivery, e.g., internet connectivity [3]. Additionally, during the online workshop, some students were reluctant to turn on their cameras; reasons included managing privacy, appearance considerations and home working environment, as evidenced in other literature [30, 31]. One challenge in the delivery of IPL is imbalances in cohort size between different programmes [32]. Whilst there was an Audiology to Biomedical Science student ratio of 1:6, this did not impact the overall success of the IPL session, with both student cohorts participating and interacting with one another during the workshop. Additionally, when examining the professional landscape, we find that there exists a notable ratio of approximately 23,000 Biomedical Scientists to 2,300 Audiologists in the United Kingdom [33, 34]. This translates to a proportional representation of one audiologist for every ten Biomedical Scientists in the workforce. This observation underscores the alignment of our educational setting with the existing workforce composition, reflecting our program's adherence to the industry's standards and demands.

In the case of Biomedical Science students, the workshop occurred during their final semester, just prior to their summer examinations and subsequent graduation. Consequently, it presents a challenge to procure longitudinal data regarding the sustained impact of the IPL activity, as these students have already concluded their studies at the university. Nevertheless, it is worth noting that a significant proportion of Biomedical Science graduates have opted to pursue postgraduate studies in fields such as medicine, physician associates, dentistry as well as various other patient facing healthcare-related programs. These advanced studies necessitate a demonstrable track record of engagement within multidisciplinary teams and a proficiency in interprofessional collaboration and many applicants used this IPL activity to evidence this. Furthermore, Audiology students graduate into patient facing roles and therefore work with Ear, Nose and Throat (ENT) specialists, GPs, Speech and Language Therapists, Physiotherapists and other services. Students experience this in their clinical placements across both NHS and private sectors. This experience therefore highlights the importance of working across specialisms which helps support student training in preparation for entering the healthcare workforce.

With regards to future improvements, some students suggested that they would welcome the opportunity to engage in IPL face-to-face. For example, one student's feedback was that "*I think something like this would have worked nicely in person because it's easier to discuss things and ask each other questions in person.*" However, there are logistical and timetabling challenges that universities face with ever growing numbers of students that may impede face to face delivery on campus. Furthermore, demographic data reveals that many students work part time and online delivery better accommodates their learning needs. This is further supported by the Higher Education Policy Institute (HEPI) student academic experience survey 2023, that reports that 55% of university students are now doing paid work and 76% of students reporting that the cost-of-living crisis has negatively impacted their studies [35].

IPL is acknowledged as beneficial for fostering collaboration amongst multidisciplinary teams and, ultimately, enhancing patient care [36]. Therefore, embedding IPL activities in year 1 and year 2 in the Biomedical Science curriculum would be advantageous as students would be developing important transferable skills that are required in their placement year with many of them working in the NHS setting. Furthermore, other work has reported that peer learning facilitates the understanding of both theoretical and practical concepts whilst developing student's interpersonal and social skills [37]. Existing evidence has demonstrated peer learning to be beneficial for students belonging to marginalised groups. The majority of participants in our institution identify from minority backgrounds, thus supporting the need for further IPL opportunities.

CONCLUSION

In conclusion, this novel collaboration between Biomedical Science and Audiology effectively delivered IPL and allowed both HCPC approved programmes to learn with, from and about each other. Students felt that the CMV case study was contextually relevant, informative and they strengthened their communication and teamworking skills. Whilst traditional IPL focuses on medicine and its associated programmes, IPL opportunities should be inclusive of other healthcare related Biomedical programmes. Healthcare departments recognise the importance of collaborative working to treat and diagnose patients and undergraduate allied healthcare degrees need to provide opportunities within their curriculum to foster this.

SUMMARY TABLE

What Is Known About This Subject

- Biomedical Science and Audiology are both involved in diagnosing and managing patients with CMV.
- Both HCPC approved programmes require interprofessional learning (IPL) to be included in the curriculum.
- IPL seeks to promote knowledge exchange, skillset development and develop an appreciation of other healthcare professionals.

What This Paper Adds

- A novel contribution to healthcare education through a contextually relevant patient condition.
- An IPL opportunity between a patient facing and a non-patient facing healthcare discipline.
- Students reported a greater appreciation and understanding of other healthcare professionals involved in patient care.

CONCLUDING STATEMENT

This work represents an advance in biomedical science because it presents a novel IPL workshop with Audiology to strengthen transferable skills required in healthcare to support patient care.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving humans were approved by the Aston University Health and Life Sciences Ethics Commitee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AB conceived the study and designed the research approach. AB and RP designed the survey. AB, RP, and SH delivered the interactive workshop. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2023.11680/full#supplementary-material

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ORIGINAL RESEARCH
published: 02 October 2023
doi: 10.3389/bjbs.2023.11756

Gamification in Biomedical Science Education: The Successful Implementation of Resimion, a Scenario-Based Learning Tool

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Introduction: Scenario-based learning and gamification have many advantages in comparison to traditional didactic teaching methods, including development of many higher-level skills such as analysis and evaluation. It is hoped that these simulations provide a real-world experience in a format accessible to students. Integration of these tools into teaching excelled during the COVID-19 pandemic, an event that completely changed education and initiated the greatest advancement in digital learning to date. We discuss our experiences using Resimion, a novel scenario-based learning tool that was adapted to biomedical science, both for teaching and assessment.

Methods: Our cohort included 769 students studying BSc(Hons) Biomedical Science at the University of the West of England from 2020 to 2023. Data was obtained from assessments within four different modules, two at FHEQ level 5 and two at level 6. Students were grouped based on reasonable adjustment (RA) status, including physical issues, specific learning differences and neurodiversity, with differences between student groups and assessment types analysed by ANOVA.

Results: Data clearly demonstrate good engagement from students utilising Resimion software, representing 18,436 student interactions in total, across both assessed and non-assessed activities. RAs of any type did not alter submission rates ($p = 0.53$) or student outcome in any of the assessment types analysed. However, submission rates for Resimion assessments were notably higher than for other assessment types ($p = 0.002$). Whist outcomes were not significantly different, students with RAs did take significantly longer to complete the Haematology and Transfusion assessments ($p = 0.0012$). Specifically, neurodiverse students and those with specific learning differences used on average 81% of their allocated time, students with other RAs used 76%, whereas students without RAs used just 56% ($p \leq 0.0001$), highlighting the appropriate adjustment of extra time provided for these students. It was further observed that 1.3% of Resimion activities undertaken by students utilised the in-built inclusivity features in the software. Both students with known RAs, and those without, utilised these features, therefore also aiding students without a formal diagnosis.

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Received: *30 June 2023*
Accepted: *15 September 2023*
Published: *02 October 2023*

Citation:
May JE, Anderson E, Clark D and Hull J (2023) Gamification in Biomedical Science Education: The Successful Implementation of Resimion, a Scenario-Based Learning Tool. Br J Biomed Sci 80:11756. doi: 10.3389/bjbs.2023.11756

Conclusion: The scenario-based learning tool Resimion was successfully integrated into the teaching of biomedical science and provided an engaging platform for students, with comparable results to other traditional assessment types.

Keywords: gamification, neurodiversity, Resimon, scenario-based learning, digital education

INTRODUCTION

The concept of gamification or scenario-based learning (SBL) has been present since the early 2000s, with the term "gamification" first coined in 2008 [1]. This acts as a potential alternative to traditional pedagogical or assessment techniques, developing many higher-level skills such as analysis and evaluation. It is the hope that integration of these games will improve engagement, both inside and outside of the classroom [2, 3], allowing students to engage with their education in novel ways, through case-based learning and interactive assessment types [4]. Using SBL has already shown promise when compared to didactic teaching [5, 6]. Whilst educators are often keen to minimise didactic teaching, stimulating engagement through interactivity, it is challenging to find appropriate interactive software to develop and test skills such as critical thinking [7]. This was most obvious during the COVID-19 pandemic, an event that completely changed education. The integration of technology into teaching was rapid, however students often did not find this as engaging as traditional methods [8]. Furthermore, the evidence on the efficacy of gamification is mixed. Many authors support the notion that the higher engagement leads to better outcomes for students. However, it was argued that gamification may not be applicable to all curricula (reviewed in [9]). Mekler et al. [10] failed to find improvement in student grades with the integration of gamification. The improved student motivation and engagement needs to be coupled with factors such as autonomy, competence, and relatedness—all factors of the self-determination theory [11]. Whilst students must commit to engaging with their education, educators must commit to providing an engaging atmosphere, simulating the work environment and demonstrating the relevant skills or competencies required for their profession. In some respects, these are the underlying tenets of the Institute of Biomedical Science (IBMS) accreditation for degrees (QAA Benchmark statements) [12].

The paucity of gamification or SBL resources to educate and assess biomedical science contrasts with the depth of resources available for clinical education [13–18]. Biomedicine is a complex topic relying on diverse forms of expertise, discussing the interaction of multiple specialisms that occur within the hospital laboratories. It is often difficult for students to appreciate the specialist biomedical content, and subsequently understand how this information integrates with other specialisms. This holistic understanding, enabling integration and application of knowledge is essential, but is difficult to assess with current techniques. Gamification and SBL, and assessment via these methods, has the potential to provide learners with opportunities to be involved in the complete clinical case, gaining experience in a patient-free, risk-free game [19]. In a level 6 module at our institution teaching haematology and transfusion science, we wanted to assess the students capacity for interpretation and decision-making, rather than just knowledge recall through multiple choice questions or discrete essay questions. Traditionally, our institution has used case studies to demonstrate the integration of specialisms and allow application of knowledge. However, it can be challenging to engage students when these are paper-based. Furthermore, it is difficult to provide meaningful personalised feedback to the large cohorts we experience. This led us to integrating Resimion, a novel software designed for SBL, which had not previously been used in the biomedical/biological Science field, enabling case-study based scenarios to be developed and utilised both for teaching and assessment.

Resimion is a platform for applied learning, enabling learners to work through problem- or scenario-based activities. Utilising gamification to increase interest and deepen learning, scenarios can be run competitively with a leaderboard for anonymous peer comparisons, or individually, challenging students and providing opportunity to apply knowledge and learn from their decision-making. For example, students can be presented with background case study information for a patient and can then make informed decisions to "perform" relevant lab investigations, subsequently interpreting and analysing this data to make decisions or reach conclusions. This informal gamified learning environment can improve student motivation and encourage participation and ownership. As Resimion can be accessed via web-browser or mobile phone App it is ideally suited for use in today's increasing digital learning environment, both for applied SBL inside and outside of the classroom, and for formal assessment.

Understanding elements of game design and human motivation, gamification can provide novel techniques to engage and assess students. Engagement, education and assessment are no longer confined to classic educational environments. Whilst the integration of gamification and SBL into teaching is increasing, it is important to note that there is a broad lack of empirical evidence assessing gamification outcomes in certain groups (e.g., neurodiverse students and those with specific learning differences). It is the hope that SBL integration will lead to improved outcomes in students who typically underperform in standard assessment styles, such as those with neurodiversity or minority ethnicities. In this work, we detail the use of gamification and SBL to assess learner progress and attainment in the IBMS accredited BSc(Hons) Biomedical Science programme at the University of the West of England. Whilst we also extensively used Resimion for gamification and SBL within non-assessed activities throughout our teaching (for example, competitive leaderboard-based games in taught sessions, and non-assessed individual scenarios), this paper focuses on measuring the effective use of Resimion for assessments.

TABLE 1 | Summary of assessment types used across four modules in the BSc(Hons) Biomedical Science programme at the University of the West of England.

Assessment	Brief description
On campus, timed exam	Studies in the Biology of Disease (level 5): Students completed a 3 h unseen timed exam under controlled conditions on campus. These questions represented multiple specialisms relating to a specific case study. The case study was released 1 month before the exam without associated questions. Students were allowed to bring an annotated version of the case study into the exam with them Haematology and Transfusion Science (level 6): Students completed a 2 h unseen timed exam under controlled conditions on campus. One essay question (from a choice of 3) and one extended case study were completed. Students were allowed to bring in an A4 closed box file of notes Clinical Biochemistry (level 6): Students completed a 3 h unseen timed exam under controlled conditions on campus. There were six case studies with each lecturer providing 2 from their taught content. Students were allowed to bring in an A4 closed box file of revision notes Reasonable adjustments: For all exams, extra time was available (up to 50%) for students with reasonable adjustments. Further adjustments were available such as individual rooms, facility to type answers, dependent on individual needs This style of exam could not be completed during major COVID restrictions and was substituted with a 24 h online exam, but has been reintroduced for academic year 2022–23
Online, 24-h exam	Students accessed an exam paper online through Blackboard. Papers were available for a 24 h period, with answers limited by word count rather than by a shorter time period. This approach was used for all modules during 2019–20, 2020–21 and 2021–22 [and is still in place for some modules where assessments are not stipulated by professional bodies, for the purposes of this paper the "Blood Science" module (FHEQ level 5)] Blood Science (level 5): Students answer 2 questions from each of three sections (from a choice of 4). Word limit of 250 words per question (1500-word limit in total). Reasonable adjustments: No extensions or extra time was available for the 24 h exams
Media clip	Blood Science (level 5): Within the Blood Science (level 5) module, the coursework assignment consists of students completing a 5 min video on a blood science-based point-of-care test of their choice. Students must be visible in the clip throughout, and must include certain content, such as comparison of their test with competitors, and explaining the underlying principles of the test. Reasonable adjustments: 5 day grace period, extensions were available Clinical Biochemistry (level 6): A 5 min summary video on a specific disease commonly diagnosed through the Clinical Biochemistry biomedical specialism. Students must be visible in the clip throughout, and must include certain content, such as pathophysiology, diagnostic tests, and future research. Reasonable adjustments: 5 days grace period, extensions were available
Reflective coursework	Studies in the Biology of Disease (level 5): A reflective short answer essay similar to the Continual Professional Development available in the Biomedical Scientist journal (**Supplementary Material** USSKAT-30-2 CW2 CPD). Reasonable adjustments: 5 days grace period, however no extensions were available
Written case study	Studies in the Biology of Disease (level 5): One patient case study with 6x 250-word questions, covering each biomedical specialism (**Supplementary Material** USSKAT-30-2 CW3 MARIANA). Reasonable adjustments: 5 days grace period, however no extensions were available
Resimion MCQs and case study	Haematology and Transfusion Science (level 6): Coursework comprises three assessed tasks using Resimion. These are available for 24 h after each practical class and are based on theory and practice from each section of the module (haematological malignancies, haemostasis and transfusion). Students have 40 min once they open the assessment to complete three randomly allocated MCQs and a longer case study (with randomised elements). Reasonable adjustments: No extensions or 5 days grace period available as a timed assessment. Reasonable adjustments for extra time (up to 50%) were automatically incorporated for eligible students
Weekly Resimion quizzes	Studies in the Biology of Disease: After every lecture, a Resimion was released that assessed the knowledge in the field that related to the lecture. This could be in the form of MCQs, case studies, blood typing panels, or picture quizzes. These quizzes had a 15 min time limit; however, students could have unlimited attempts. Reasonable adjustments: There are no reasonable adjustments for this submission

Level refers to the FHEQ level defined by the QAA Qualification Framework for Higher Education.

The aim of this work was to analyse student engagement and feedback using Resimion, alongside comparing overall student outcomes from Resimion-based assessments with other assessment types. A further aim was to assess any impact of utilising Resimion on neurodivergent students and those with disabilities, by comparing engagement and assessment outcomes utilising such SBL and gamification, alongside traditional forms of assessment. It is proposed that the trends observed in our student datasets will inform pedagogical teaching methods. This work describes for the first time the implementation of Resimion in a Biomedical Science programme.

METHODS

Student Cohort

Our student cohort includes 769 individuals studying BSc(Hons) Biomedical Science during the period of September 2020 to June 2023 at the University of the West of England. Data were collected from the second-year (FHEQ level 5) modules "Blood Science" (185 students over 2 years) and "Studies in the Biology of Disease" (314 students over 2 years) covering all biomedical science disciplines, alongside the third-year (FHEQ level 6) modules "Clinical Biochemistry" (55 students) and "Haematology and

Transfusion Science" (215 students over 3 years). Only "Studies in the Biology of Disease" is classed as a core module, which students must complete, with the remainder classed as "optional" modules. Students select from several "optional" modules, therefore there may be overlap between our cohorts enrolled on each module, depending on the module selections made by students.

Use of Resimion and Assessment Types

Within this study, data was collected from Resimion-based activities utilised for both assessed and non-assessed purposes. Within the second-year "Studies in the Biology of Disease" module and third-year "Haematology and Transfusion Science" module, students were given access to interactive activities both within and outside of class, including case studies, quizzes and multiple-choice questions (MCQs), to aid their learning and provide opportunities for application of knowledge. Additionally, both of these modules used Resimion for assessment, utilising quizzes for "Studies in the Biology of Disease" and longer case studies and randomised MCQs for "Haematology and Transfusion Science."

Alongside Resimion-based assessments, we analysed other assessment types within the same modules and in two other modules undertaken by the same year group in the BSc(Hons) Biomedical Science programme. The assessment types analysed within this study varied across the four modules studied, and additionally underwent changes during our study period due to the impact and restrictions imposed during the COVID-19 pandemic. Details of all assessment types for each of the four modules are listed in **Table 1**.

The "Blood Science" and "Clinical Biochemistry" modules did not utilise Resimion for teaching or assessment, but were included in this study for comparison of student performance across other styles of assessment.

Reasonable Adjustments/Disabilities

Data regarding status of "reasonable adjustments" for individual students was provided by the University's Disability Services.

All data have been anonymised within this study, with students grouped into categories according to their disability or reasonable adjustment requirements. Students were categorised as "no RA" if they do not have disability or eligibility for additional requirements recorded on their university record. Our institution lists students as eligible for "reasonable adjustments" if they have any declared condition, disability or learning need. Often additional information is given for each RA detailing the exact adjustments needed, for example, physical adjustments, extra time, or measures to support mental health conditions. For the purposes of this study, we grouped all students as "RA" if they had reasonable adjustments recorded, whether permanent or temporary, including both physical and mental health conditions. We subsequently separately grouped students who had an RA recorded, which noted a specific learning difference (SpLD) (such as dyslexia, dyspraxia, dysgraphia) or neurodiversity (ND) [including autism spectrum conditions or attention deficit (hyperactivity) disorder], as an SpLD/ND category.

Statistical Analysis

Statistical analysis was performed in GraphPad Prism version 9. One-way ANOVA with Tukey's multiple comparisons test was used to examine differences between student groups, with $p < 0.05$ considered to be statistically significant. A two-way ANOVA was used to analyse differences in submission rates for each student cohort according to assessment type.

Ethical Approval

The data from the modules were anonymised prior to analysis. All data were collected anonymously as part of routine monitoring and evaluation of the modules. Students consented to providing feedback on Resimion through anonymous data collection using Mentimeter for routine module evaluation. This work is part of an ongoing project at UWE and has been given ethical approval by the University ethics committee (Ref No. HAS.23.06.133).

RESULTS

This study included 769 students over a 3 years period, undertaking the IBMS accredited Biomedical Science degree at the University of the West of England. The work represents the outcomes on four modules: Blood Science (FHEQ level 5), Studies in the Biology of Disease (level 5), Clinical Biochemistry (level 6), and Haematology and Transfusion (level 6). The types of assessments undertaken were wide-ranging, including a 24 h open book exam, 2 or 3 h open book on campus exams, case-study essays, a reflective essay, creation of media clips, and Resimion assessments (**Table 1**). These provide a range of assessment features that challenge students (**Table 2**), and assess a number of different skills, in addition to specialist biomedical science knowledge.

For analysis of Resimion data, the work represents 18,436 student interactions in total within Resimion software. This incorporates both assessed and non-assessed activities, including synchronous (in-class), and asynchronous (independent) interactions.

Students Interaction With Resimion Was Positive and Comparable for Neurodiverse and Neurotypical Groups

Our data demonstrate good engagement (defined here as students attempting a specific activity) from students utilising Resimion in their learning, both within the classroom and as an independent study aid. In class, students reported both enjoyment and benefits in terms of opportunity to apply the theory they had learnt. Final year students were given the opportunity to undertake asynchronous case studies through Resimion following lectures, with 74% of students utilising this opportunity. We have also observed that 1.3% of Resimion activities undertaken by students utilised the in-built inclusivity features in the software. This use of self-modified inclusivity features represents 517 instances of student interaction, benefitting students potentially not officially recognised as needing reasonable adjustments. From polling students anonymously in class, we have observed that many students suspect they are neurodiverse

TABLE 2 | Comparison of features within assessment types used across four modules in the BSc(Hons) Biomedical Science degree at the University of the West of England.

Assessment features	On campus, timed exam	Online, 24-h exam	Media clip	Reflective coursework	Written case study	Resimion MCQs and case study	Weekly Resimion quizzes
Provides instantaneous feedback						✓	✓
Provides personalised detailed feedback			✓	✓	✓	P	
Emphasises understanding	✓	✓	✓	✓	✓	✓	P
Analyses choice utilisation			P	✓	✓	✓	✓
Monitors engagement						P	✓
Assesses knowledge of biomedical science	✓	✓	✓	P	✓	✓	✓
Promotes self-evaluation				✓		✓	
Accommodation of reasonable adjustments	✓		✓			✓	
Student choice of assessment topic			✓	P			
Student self-selection of accessibility features						✓	✓
Minimises assessment offences	✓		✓	✓		✓	P
Time restrictive	✓	P	P			✓	✓
Creates an individualised experience			✓	✓		✓	✓

✓—represents positive response for that feature. P—represents partial response for that feature.

TABLE 3 | Percentages of quizzes/case studies during 2022/23 where students self-enabled inbuilt accessibility features in Resimion.

Accessibility feature	Percentage of total case studies/quizzes where feature was utilised: (%)
Background colour changes (i.e., to change contrast)	0.8
Altered panel colours or alternative colour theme selected	0.9
Text colour changes	0.12
Text-to-speech enabled	0.4
Any accessibility feature enabled	1.3

n = *39,823 case study/quiz student interactions in total across the modules "Haematology and Transfusion Science" and "Studies in the Biology of Disease."*

or have SpLDs, but lack a formal diagnosis (data not shown). Therefore, self-modified features will be invaluable to these students. The most common inclusivity features used by students were alterations to panel or colour themes (n = 358), background (n = 318), alongside enabling of the text-to-speech function (n = 159) (**Table 3**).

Feedback from students has been extremely positive regarding the use of Resimion, with many requesting increased use of this approach both within these modules, and more widely across the degree programme (**Table 4**). We also sought to gain feedback from neurodiverse students on our modules regarding their experience with using Resimion, with comments received including:

> "I thought Resimion was simple and easy to use. The time limit and negative marking was stressful in the moment of completing the case studies, but the practice Resimions made it easier. Overall, I really enjoyed the coursework and preferred it to written coursework"
>
> "Resimion also relieved coursework stress as it was quick to complete. I'd pick Resimion over a paper-based coursework"
>
> "Very helpful, because you implement knowledge based on real-life scenarios. I love more practical engagements to learning"
>
> "It didn't feel like coursework, there wasn't any stress or worry about it, as well as it actually tested other things than memory and ability to reference"

Importantly, neurodiverse and students with SpLDs or RAs did not have differing outcomes to students without RAs, in Resimion-based assessments (or any other assessment type that we analysed). However, it is of note that whilst outcomes did not differ when assessed through Resimion, how these students interacted with the software did vary at times. For example, within the Haematology and Transfusion Science module Resimion assessments, it was noted that students with RAs took significantly longer to complete the assessments (p = 0.0012). Specifically, neurodiverse students and those with SpLDs used on average 81% of their allocated time (up to 50% additional time), versus 76% for students with other RAs (excluding those students with RAs for SpLDs or neurodiversity), and 56% for students without RAs ($p \leq$ 0.0001, **Figure 1**). This difference was only for assessed

TABLE 4 | Qualitative feedback from students of their experiences of using Resimion.

Theme	Feedback
Engagement/interest/enjoyment	• Resimions are great • It did not feel like coursework, there was not any stress or worry about it, as well as it actually tested other things than memory and ability to References • Coursework is well laid out and easy to understand • I would like to have more practice resims, and extra sessions on them for every subject change • I enjoyed the coursework, however would like more insight into how the points are scored. The combination of multiple choice questions and case study, I thought, worked really well on this module
Time management	• It is really useful to have it broken up into topics and because of this I feel well prepared for the exam too! • I preferred that it was broken down into chunks, also relieves pressure if you end up messing one up • The smaller chunks were definitely preferable to a large piece, it made it a lot less stressful compared to other modules • I liked that it was over three separate cases and I think they were spaced out really well. I found the inputting of some of the final diagnosis difficult in a way that haemophilia had to be entered to unlock haemophilia A, for example, but overall enjoyed • The coursework is broken down and interactive
Assessment compared to traditional types	• Not neurodiverse but enjoyed having short, case study based CW rather than essay based • Resimion CW—is a break from long essay CW in other modules • Whatever happens, do not change the style of cw. Make it tougher if required, but do not remove it all together • Keep the cw the same. I do not mind altering the number of resims to make it more difficult. But the amount of essays this year has me dead. Heam cw is probably the best and realistic
Application of knowledge	• I really enjoyed the CW been split into three Resimions, really helped understand the lecture more. I believe it should be kept as it gives a fair chance to students to do well, understand the lab tests • The coursework is great! It does not take up a huge amount of time but really solidifies the content taught in lectures and compliments the practicals
Interactivity/practical application	• I really enjoyed the case study aspect rather than a written assignment because you engage practically with knowledge you have been given • I really enjoyed the coursework. Very interactive and allowed me to bring out all I've learnt. Great for memory training too • Very helpful, because you implement knowledge based on possible real-life scenarios. I love more practical engagements to learning

Feedback was sought regarding their experience in both non-assessed activities and assessments within the Haematology and Transfusion (FHEQ level 6) module during the 2022–23 academic year.

Resimion activities, with no significant differences observed between any cohort in terms of time taken per attempt (data not shown) or number of interactions with non-assessed activities ($p = 0.967$, **Figure 2A**). It was noted that the number of interactions for each student across the module varied widely in all student groups, ranging from minimal engagement up to 98 interactions (**Figure 2A**). Similarly, in the Studies in the Biology of Disease module, although Resimion activities were assessed, these were formatted differently, with all students having unlimited attempts to reach a pass mark (80%) within a 15 min timed quiz. Comparable results were observed in terms of time taken, with ND/SpLD students taking 6.1 min on average compared to 4.3 min for students with other RAs, and 4.9 min for students without RAs. Number of attempts students used to complete the quizzes were also comparable across the groups ($p = 0.331$, **Figure 2B**).

Students With Neurodiversity Perform Comparably to the Main Student Cohort Regardless of Assessment Type

"Learning and assessment experiences should be diverse to both reflect the variety of the subject and to increase accessibility for all" (QAA Benchmark Statements, 2023) [12].

It is important for students to experience a range of assessment types in order to fully assess skills and competencies required. However, it is also important to ensure student performance is comparable for cohorts that may struggle with certain assessment types, such as the neurodiverse, those with SpLDs and students with RAs. The assessments presented in this work represent a range of submissions across levels 5 and 6, and demonstrate that there was no difference in outcome between any of the groups assessed. The presence of specific learning differences, neurodiversity, or reasonable adjustments did not impact the student outcome of any assessment interrogated by this study ($p > 0.05$) (**Figures 3**, **4**).

The figures presented here represents the 2022/23 cohorts for the four modules described. Further analysis of the last 3 years of data for these modules, where available, has shown the same trend, with no differences between any student cohorts observed (data not shown) ($p > 0.05$). Similarly, the presence of RAs did not affect submission rates ($p = 0.53$, **Table 5**). However, there was a significant difference in submission rates across the different assessment types. It was observed that Resimion assessments had a notably higher submission rates for both MCQs/case studies and weekly quizzes (95.4% and 93.5%) when compared to other assessment types ($p = 0.002$, **Table 5**).

The Presence of Reasonable Adjustments Did Not Impact Student Outcome

The submissions presented here had a range of reasonable adjustments available to them in terms of extra time, grace

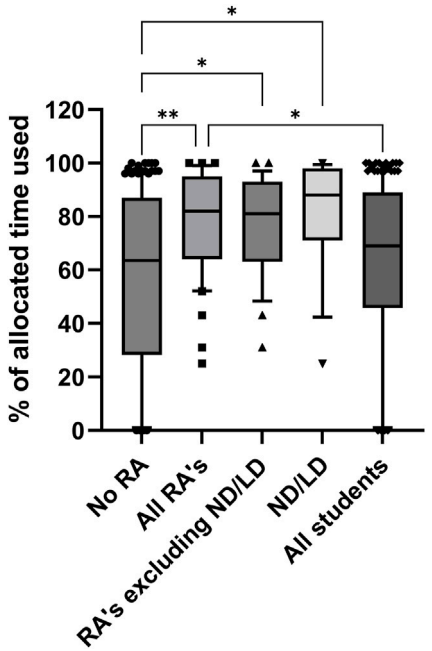

FIGURE 1 | Percentages of available time utilised by students for assessed Resimion case studies in the Haematology and Transfusion Science module. n = 210 student case study interactions in total, comprising up to 3 assessments per student during 2022–23. Some students with RAs or ND/LD had 25 or 50% extra time allocated, depending on their specific adjustments in place. Abbreviations: RA, reasonable adjustment recorded; ND/LD, student record indicates neurodiversity or diagnosis of a specific learning difference. Data plotted as 10–90th centile, with middle 50% represented by each box, and outliers shown as symbols. *$p < 0.05$, **$p < 0.01$.

periods, and extensions (**Table 1**). The available adjustments were made clear to students when the coursework was released. It is apparent from the data that no specific reasonable adjustment impacted student outcome or submission rate, regardless of RA status (**Figures 3**, **4**; **Table 5**). The one exception to this was the timed Resimion case studies for Haematology and Transfusion Science, where students did use their additional allocated time (**Figure 1**), indicating that these adjustments are appropriate and enable students to gain comparable outcomes (**Figure 4A**). Finally, grace periods and extensions for assessments do not impact submission rates within this study, with Resimion assessments demonstrating the highest submission rates, whilst not eligible for any grace periods or extensions.

SUMMARY

In summary, this work successfully demonstrates good student engagement and positive feedback associated with the integration of Resimion into biomedical science teaching and assessment. Our data shows largely comparative outcomes through a range of assessment styles, in terms of overall achievement, with a better submission rate demonstrated for assessments completed using this novel approach. It seems that providing that assessment rules are clear in advance, the outcomes of students are comparable regardless of RA status (for Resimion-based and other assessment types), with only additional time for Resimion assessments shown to be important for eligible students. It is certainly clear from our data that no group of students are benefiting from any particular assessment type. Overall, this work demonstrates successful implementation of Resimion for SBL and gamification into biomedical science education.

DISCUSSION

Benefits of Scenario-Based Learning and Gamification

There is a wealth of literature on the benefits of applied learning developing higher-level graduate skills, with "gamification" becoming an important topic in recent years [20, 21]. The integration of gamification has (predictably) provided the most success in computer science, representing 39% of the published literature. Comparatively, medicine, biology and psychology collectively account for 10% of gamification publications—a clear underperformer in the sector [22]. Our institution's use of gamification increased significantly during the COVID-19 pandemic, for both assessment and within teaching, such as a replacement of lab classes which could not run due to social distancing, and Resimion was our software of choice. As discussed by Francis, Smith and Turner (2022) [23], virtual lab simulations were used to link theory and practice, closely mimicking the skills and learning objectives achieved in wet lab practicals, whilst providing an appropriate alternative when laboratory work was impractical. Furthermore, Resimion acted as an additional interactive method to maintain student interest and engagement in online tutorials. This concurs with other published reports, where improved student academic achievement, engagement and motivation were reported in 92.9% of studies examining gamification in education [21]. The anonymity of the software and the questions posed give the learner "permission to fail" without judgement from peers, and encourages a safe environment for learning. One challenge to using online tools during COVID-19 was the issue of digital poverty, with students having reduced access to campus resources. However, both Mentimeter and Resimion are used via a standard web browser, or mobile application, enabling students to access activities anywhere, on any internet-enabled device, removing many digital poverty barriers. Use of this tool was successful and well received by students. So much so that many of the changes have been maintained since returning to on-campus teaching.

This study demonstrates use of SBL can effectively be incorporated into many teaching types (online, face-to-face, asynchronous), in addition to assessments. Studies consistently highlight the need to use a variety of interactive learning activities in effective online teaching, including gamification, to capture student interest [24, 25]. Challenges through gamification can also entice students to continue playing [26]. A significant benefit of Resimion (alongside Mentimeter and Collaborate polling) was gaining real-time assessment of students understanding, which,

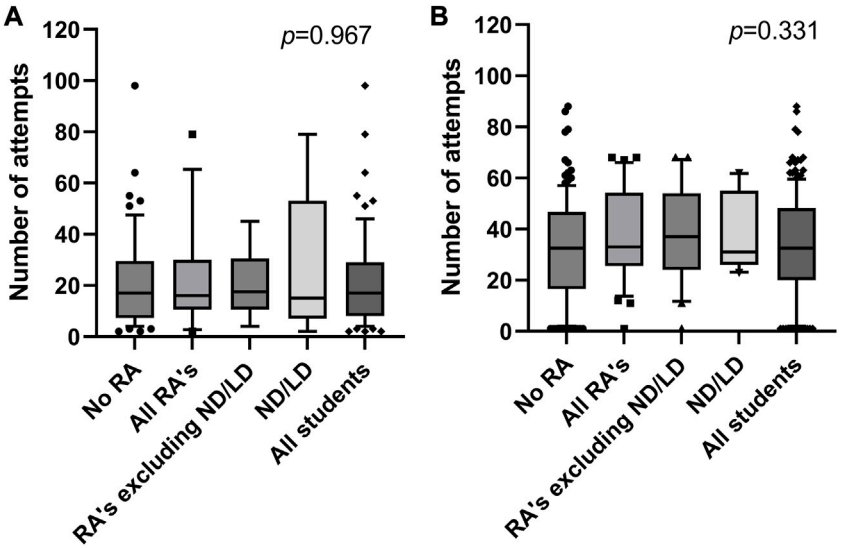

FIGURE 2 | Distribution of the number of interactions with Resimion per student over the academic year 2022–23, including both assessed and non-assessed activities. **(A)** Students enrolled on the Haematology and Transfusion Science module (n = 69), comprising 56 students with no RA, 13 students with RAs, n = 8 RA excluding ND/LD, n = 5 ND/LD students. **(B)** Students enrolled on the Studies in the Biology of Disease module (n = 163), comprising 136 students with no RA, n = 27 students with RAs, n = 15 RA excluding ND/LD, and n = 12 ND/LD students. Abbreviations: RA, reasonable adjustment recorded; ND/LD, student record indicates neurodiversity or diagnosis of a specific learning difference. Data plotted as 10–90th centile, with middle 50% represented by each box, and outliers shown as symbols.

as discussed by Neuwirth, Jovic and Mukherji (2021) [27], was challenging during COVID-19 when normal visual clues in a physical room could not be interpreted. Engagement data from Resimion was extremely useful when actual contact with students was so limited. It is widely believed in the literature that leveraging this data will provide further strategies to optimise learner engagement and outcome [28–30].

With so many changes over the last few years as a result of the COVID-19 pandemic (the rapid switch to online teaching, online exams, open-book exams, and loss of practical time) data from different years is not always comparable and it is difficult to isolate the impact of individual changes. One theme that has been consistent, however, is the positivity of students and staff toward using Resimion, with consistently good feedback from students. Use of Resimion also provides a method to support students with additional learning opportunities by providing asynchronous activities. This will become more important as we appreciate the longer-term impacts of students entering Higher Education with significant gaps in their education. A further benefit of using Resimion is the ability to monitor student engagement in real-time, providing an additional means to identify students who are struggling and need additional support.

Authentic Assessments

"In this increasingly digital world, such [transferable] skills include digital literacy; opportunities are present to exploit this and diversify how students are assessed, ensuring a range of methodologies which allow students from all backgrounds and characteristics to demonstrate their learning and development. Assessments should be authentic, with real-world application to enhance employability skills and professional development" (QAA Benchmark Statements, 2023) [12].

Competency within the biomedical laboratory relies on knowledge, technical skills and attitude to work [31]. There is a need to provide authentic assessments, allowing students to face challenges in the safe setting of education. Traditional assessment styles of essays and examinations still have their place; however, these are increasingly complemented by other assessment formats. In this study we analysed data from a range of assessment types enabling a wider range of skills to be assessed. Many of these skills are essential for the workplace, making employable and professionally-directed graduates.

This study presents, for the first time, the integration of multiple Resimion scenario-based assessments into a university undergraduate programme. Assessments were disparate in style and content, covering all the biomedical science disciplines. These scenarios and case studies simulate real-world applications enabling the opportunity to apply the knowledge and understanding that students acquire during their degree.

Allowing students choice within assessments is also important and can enable experiences to be diverse and equally accessible to all. Within the Blood Science and the Clinical Biochemistry modules we designed the coursework assignment as a 5 min video recording that had a degree of student choice. Students often target the assignment towards their own interests, and select a subject that they, or a family member, have experienced. We have observed that students are willing to read widely about a subject if they have some ownership of the area, and often have increased engagement. The coursework was also designed to enable students to develop other key employability skills such as

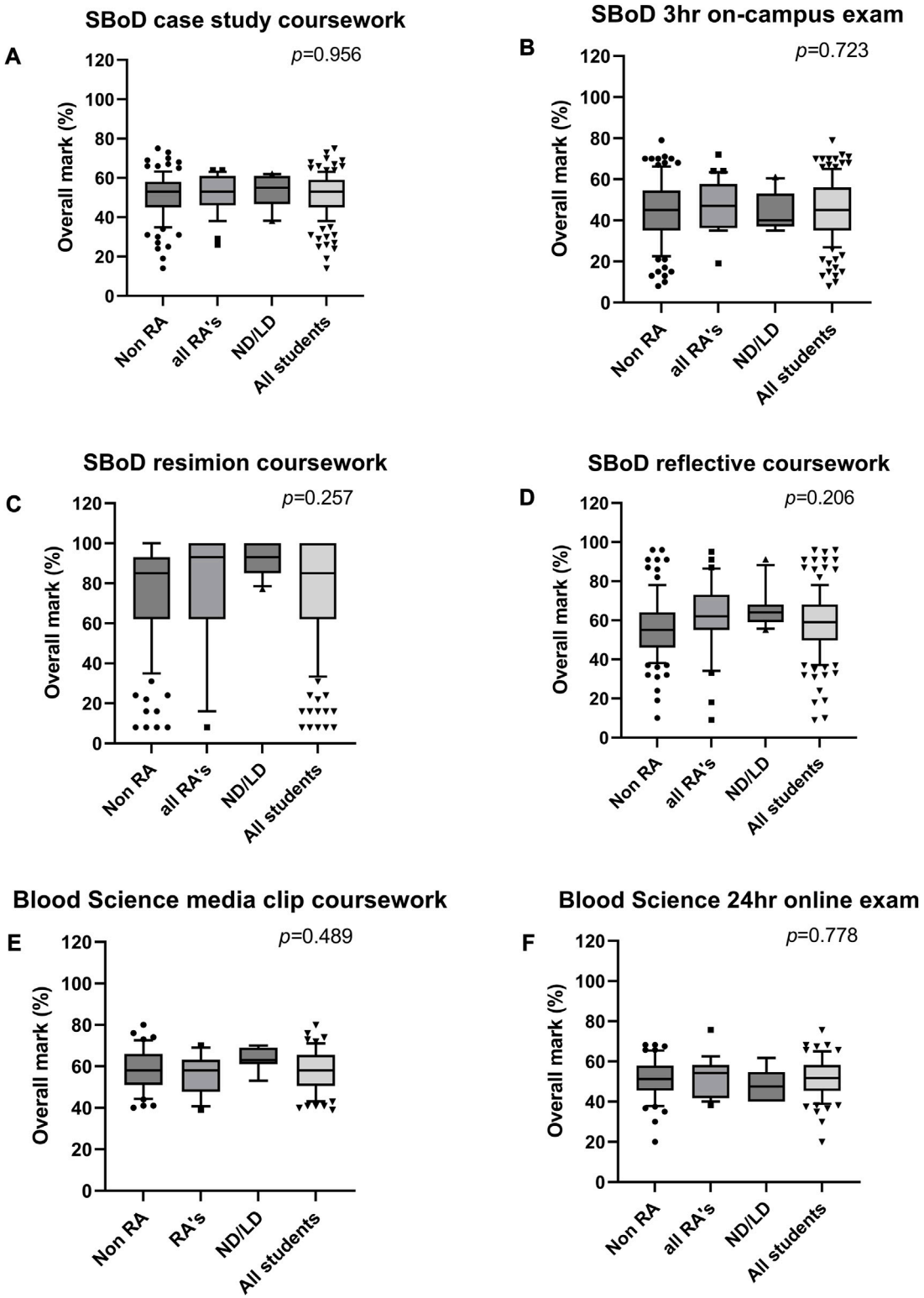

FIGURE 3 | Distribution of marks achieved by students across two level 5 modules, during the academic year 2022–23. **(A–D)** Distribution of marks within assessments in the Studies in the Biology of Disease (SBoD) module, including a paper-based case study **(A)**, a 3 h on campus exam **(B)**, quizzes undertaken in Resimion **(C)**, and a reflective piece of writing **(D)**. **(E,F)** Distribution of marks within assessments in the Blood Science module, including production of a 5 min media clip **(E)** and a 24 h online exam **(F)**. SBoD module includes 155 students total, comprising 116 without RA, 39 with RAs, of which 11 are LD/ND students. Blood science module includes 87 students total, comprising 65 without RA, 22 with RAs, of which 9 are LD/ND students. Abbreviations: RA, reasonable adjustment recorded; ND/LD, student record indicates neurodiversity or diagnosis of a specific learning difference. Data plotted as 10–90th centile, with middle 50% represented by each box, and outliers shown as symbols.

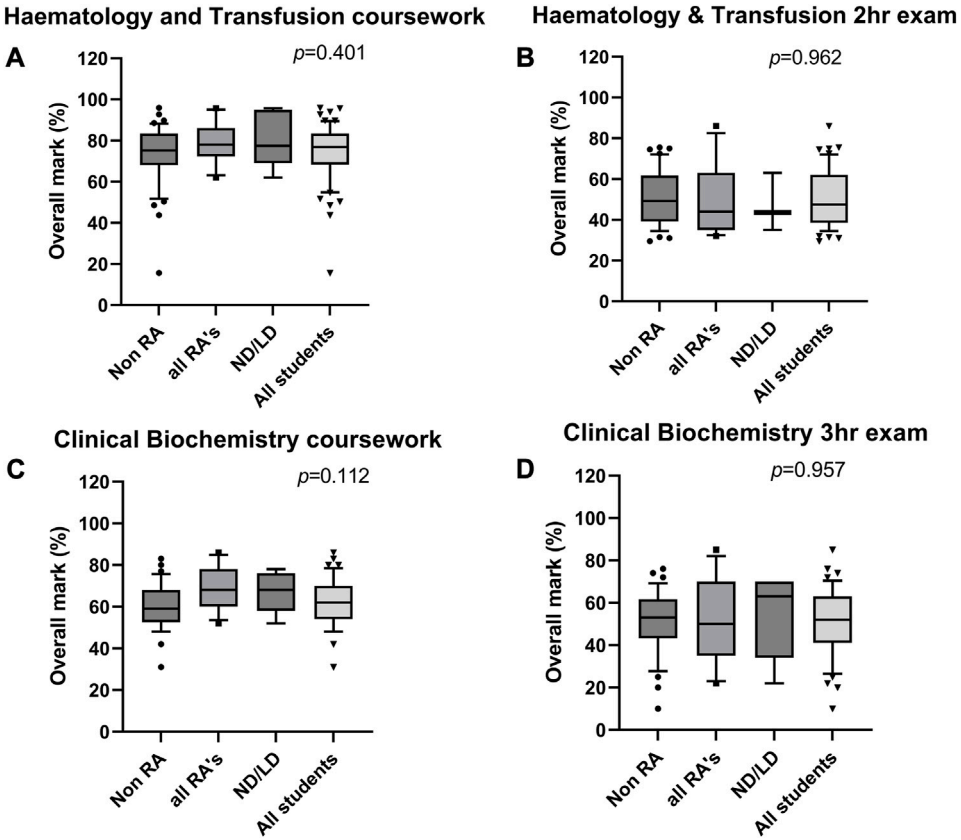

FIGURE 4 | Distribution of marks achieved by students across two level 6 modules, during the academic year 2022–23. **(A,B)** Distribution of marks within assessments in the Haematology and Transfusion Science module, comprising Resimion-based case study coursework **(A)**, and a 2 h on campus exam **(B)**. **(C,D)** Distribution of marks within assessments in the Clinical Biochemistry module, comprising production of a media clip for coursework **(C)** and a 3 h on-campus exam **(D)**. Haematology and Transfusion Science module includes 65 students total, comprising 51 without RA, 14 with RAs, of which 5 are LD/ND students. Clinical Biochemistry module includes 55 students total, comprising 42 without RA, 13 with RAs, of which 6 are LD/ND students. Abbreviations: RA, reasonable adjustment recorded; ND/LD, student record indicates neurodiversity or diagnosis of a specific learning difference. Data plotted as 10–90th centile, with middle 50% represented by each box, and outliers shown as symbols.

TABLE 5 | Percentages of students submitting assessments across several modules during the academic year 2022–23.

Assessment type	Submission rates 2022/23				
	All students	ND/LD only	RA excluding ND/LD	All RAs	Students without RAs
On campus, timed exam	Chem: 85.5% (*n* = 55)	83.3% (*n* = 6)	85.7% (*n* = 7)	84.6% (*n* = 13)	85.7% (*n* = 42)
	Haem: 87.7% (*n* = 65)	60.0% (*n* = 5)	88.9% (*n* = 9)	78.6% (*n* = 14)	90.2% (*n* = 51)
	SBOD: 83.2% (*n* = 155)	100% (*n* = 11)	75% (*n* = 28)	82.1% (*n* = 39)	83.6% (*n* = 116)
Online, 24 h exam	Blood science: 83.9% (*n* = 87)	88.9% (*n* = 9)	84.6% (*n* = 13)	81.8% (*n* = 22)	83.1% (*n* = 65)
Media clip	Blood Science: 70.1% (*n* = 87)	77.8% (*n* = 9)	84.6% (*n* = 13)	81.8% (*n* = 22)	66.2% (*n* = 65)
	Chem: 85.5% (*n* = 55)	83.3% (*n* = 6)	85.7% (*n* = 7)	84.6% (*n* = 13)	85.7% (*n* = 42)
Reflective coursework	SBOD: 83.9% (*n* = 155)	100% (*n* = 11)	85.7% (*n* = 28)	89.7% (*n* = 39)	82.0% (*n* = 116)
Written case study	SBOD: 85.8% (*n* = 155)	90.9% (*n* = 11)	89.3% (*n* = 28)	89.7% (*n* = 39)	84.5% (*n* = 116)
Resimion MCQs and case study	Haem: 95.4% (*n* = 65)	100% (*n* = 5)	88.9% (*n* = 9)	92.9% (*n* = 14)	96.1% (*n* = 51)
Weekly Resimion quizzes	SBOD: 93.5% (*n* = 155)	100% (*n* = 11)	89.3% (*n* = 28)	92.3% (*n* = 39)	94.0% (*n* = 116)

Total numbers of students in each group are shown in brackets. Chem, Clinical Biochemistry (FHEQ level 6 module). Haem, Haematology and Transfusion Science (FHEQ level 6 module). Blood Science, Blood Science (FHEQ level 5 module). SBOD, Studies in the Biology of Disease (FHEQ level 5 module). ND/LD, neurodiverse or specific learning disorders officially recorded by Disability Services. RAs, reasonable adjustments officially recorded by Disability Services.

communication, following specific instructions, and presentation skills. Many students have commented that this has been a useful experience, and they appreciate having variation from some of the other traditional forms of assessment such as essays. Whilst initially some students find the challenge daunting, afterwards they can see how the skills they have gained will be useful in the future and feel

proud of their achievements. Additionally, it gives students the chance to practice presentation skills in a safe environment, where they can have numerous attempts at recording their work. They also gain feedback on their communication skills, preparing them for an oral defence in their final year project and for future job interviews. Including these types of assessments within our study is reassuring to see that student engagement with assessments where they do not have choice are as good than those where some free choice is given. Providing students with a range of assessment types is essential to ensure that our graduates are fully equipped with the range of skills needed for successful employment.

Impacts of COVID-19

COVID-19 and the associated lockdown fundamentally changed education, but also students. There has been a notable increase in student requests for reasonable adjustments within our institution, and it seems students are struggling across the sector. This raises the challenge of providing students with accessible assessments, whilst still fully addressing the learning outcomes of the module. There have even been occasions where students request the assessment type to be altered in order to address their reasonable adjustment. This obviously raises the issue of parity across assessment types and across the student cohort. Whilst our work demonstrates that students with RAs do not perform differently in each assessment type, it is apparent from the data that students are doing better in some assessments than others. For example, results for in-person exams was much lower when compared to other assessment types, which is perhaps not surprising given that our current cohort of students did not have the opportunity to undertake previous formal exams such as A-levels during COVID-19. Average exam marks are notably lower across multiple degree programmes at our university as the return to in-person exams has left students struggling, due to lack of prior experience with formal in-person examinations. In discussion with colleagues at other institutions, this has been observed across the sector (personal communication, 2023).

Student attendance/engagement at ours, in addition to other institutions across the sector remains an issue and declined after the COVID-19 pandemic. Although we have observed improved engagement of students with interactive tools like Mentimeter and Resimion, we still have a proportion of students who fail to attend or submit any work. For example, approximately 15% of students this year failed to pass the Resimion-based coursework in Studies in Biology of Disease, even though they could have unlimited attempts to complete this. Finding ways to engage these students remains a challenge.

Whilst we do have access to significant data in terms of student numbers (769 students in total), some of the modules analysed have a greater proportion of students with reasonable adjustments. These values range from 5% to 22% across the 8 cohorts we analysed, making the data from some modules more robust than others. The percentage of students with RAs has risen over recent years, with all cohorts this academic year having at least 20% of students with recorded disabilities. This may be the result of increasing awareness and support for learning differences and neurodiversity in particular. Indeed, the Office for Students reports an increase in disabilities from 7.3% of students in 2010–11 to 13.6% of all students in 2020–21. This increase includes a large rise in mental health disorders in particular (600% increase over this period), but also increases of 29% in cognitive or learning difficulties, 56% increase of students with multiple disabilities, and 700% increase rate of students with social or communication impairments [32]. It is also possible that we have significant numbers of students who are not formally diagnosed (particularly as neurodiverse/SpLD), with other studies similarly reporting that this is likely [33–35]. Informal discussions with some of our students also indicated that they consider themselves neurodiverse but do not have a formal diagnosis.

Reasonable Adjustments

"All students should be offered learning and assessment opportunities that are equally accessible to them, using inclusive design wherever possible and by means of reasonable individual adjustments where necessary" (QAA Benchmark Statements, 2023) [12].

When integrating Resimion, one significant consideration was ensuring accessibility of Resimion for students with reasonable adjustments and specific learning needs. This is an increasingly important consideration given the rising numbers of students in Higher Education identifying as neurodivergent or having SpLDs [33]. When we initially trialled the software, students gave valuable feedback enabling additional accessibility features to be added. Subsequently, in collaboration with Resimion, we assessed the number of students utilising these self-modifiable accessibility features [36]. Some students on our modules with declared disabilities were also willing to discuss their experiences and use of these features, overall reporting positively.

We provide numerous opportunities for students to engage with Resimion before undertaking assessments (or multiple attempts in the case of "Studies in the Biology of Disease") to enable students to familiarise themselves and experiment with accessibility features. This avoids "labelling" students, as discussed by Clouder et al. (2020) [35], and enables students who are unaware of their learning preferences/needs to experiment with options, and aid individuals who have chosen not to disclose a disability. The number of students with autism spectrum disorders is proposed to be underreported in many education institutions [34]. Therefore, many students will not have disabilities officially recorded, but would still benefit from accessibility features that they can self-modify. Additionally, the assessment format itself is more accessible than a traditional written assignment, focusing on decision-making and interpretation, without penalising for grammar and spelling. This is particularly challenging for students with specific learning needs [35], and those studying in a second language. Consequently, it is reassuring that we now have sufficient data to show that in addition to students with RAs reporting positively about their experience of using Resimion as a teaching and assessment tool, our data shows that they perform comparably to students without RAs (**Figures 3**, **4**).

This work does, however, raise the question as to whether the presence of reasonable adjustments and extensions in particular, are actually good for the students. Whilst specific adjustments such as extra time and accessibility features aided students in our study, our

data also demonstrated that students do not perform differently in the absence of grace periods and extensions. If these adjustments do not have a notable impact on outcome, is there a reason for them? Indeed, we see amongst some students that access to extensions is detrimental to those who struggle with time management. Constantly applying for extensions to coursework deadlines can result in further clashes and "bunching" of assessments later in the year and during the exam period.

Limitations

Whilst our data show the positive impact of integrating Resimion into our teaching and assessment, it is important to acknowledge some of the challenges in a study such as this. In particular, the data presented is challenged by broad categories of RAs amongst our student population, e.g., "student has a mental health condition, challenge or disorder, such as depression, schizophrenia or anxiety." This definition is broad enough to include vast differences in terms of challenges and support needs. Additionally, many students are listed simply as having "multiple disabilities" which can include both physical and learning differences (but not necessarily specified), or recorded as "an impairment, health condition or learning difference not listed above." These wide-ranging categories and lack of information for some students posed challenges for us to accurately group students (and pose significant barriers for us to fully support these students in our teaching and assessment). Consequently, we grouped students with a recorded reasonable adjustment recorded in the "all RA" category, and further split students with a recorded specific learning difference, attention deficit (hyperactivity) disorder, or autism spectrum disorder within the "neurodiverse/specific learning difference" category. We did not include students with mental health conditions within this group, as there is controversy as to whether these conditions are classified as "neurodiverse," even though there is noted co-occurrence [37]. These students with mental health conditions were included in the "all RAs" category, along with all other physical and unlisted/undeclared conditions.

RECOMMENDATIONS

Every effort is made to ensure that assessment rules are clear and do not disadvantage particular groups of students. However, there needs to be a focus on evidence-based practice, especially in science education. If it is not clear that the changes we are making to submissions are benefitting students, we need to reassess their necessity.

There needs to be a diverse selection of education methods, along with assessment styles. Integration of technology into teaching is already underway and is becoming more pervasive. This is likely going to be a major advance in education, improving knowledge and skills in a form that is accessible to students regardless of neurodiversity or economic status [13]. However, the integration of technology must be tempered, as the occurrence of artificial Intelligence, such as ChatGPT, is likely going to make many assessments problematic (if not completely unusable). Programmes such as Resimion that assess knowledge and understanding simultaneously are likely to be the pathway to reduce the impact of artificial intelligence on assessment offences.

CONCLUSION

In conclusion, this study has shown that staff and students can easily adapt to using Resimion, with the latter finding that it compliments and enhances their studies. Use of Resimion as an assessment tool has shown equivalent results for students with and without eligibility for adjustments, in addition to mapping to previous assessment results using more traditional methods. In addition, Resimion-based assessments are robust in the face of increasing levels of assessment offence, and ease of access to Artificial Intelligence services such as ChatGPT.

This work represents an advance in biomedical science because it demonstrates effective integration of Resimion into the pedagogy of an undergraduate Biomedical Science degree, with comparable outcomes amongst all student groups.

SUMMARY TABLE

What Is Known About This Subject?

- Scenario-based learning and gamification has many advantages in comparison to traditional didactic teaching methods.
- Resimion is web-based and accessed from any internet-enabled device, removing many digital poverty barriers.
- Novel tools are needed to encourage engagement and ensure assessment integrity, however parity between these assessment types must be ensured.

What This Work Adds

- Students with recorded adjustments (e.g., for disabilities, learning differences) obtain comparable results across a range of assessment types, including scenario-based activities using Resimion.
- Submission rates of assessments were comparable, if not improved, using scenario-based learning for assessment.
- Resimion is a promising integration of gamification into case-based learning in Biomedical Science, and was positively received by students.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The data from the modules were anonymised prior to analysis. All data were collected anonymously as part of routine monitoring and evaluation of the modules. Students consented to providing feedback on Resimion through anonymous data collection using Mentimeter for routine module evaluation. This work is part of

an ongoing project at UWE and has been given ethical approval by the University ethics committee (Ref No. HAS.23.06.133).

AUTHOR CONTRIBUTIONS

JM performed statistical analysis and prepared some figures. DC performed data analysis. JM and JH wrote the main manuscript text. All authors contributed to the generation of data for this study, and approved the submitted version.

CONFLICT OF INTEREST

DC is employed by Resimion Ltd. as their Chief Learning Officer. His input for this study was needed to be able to access all relevant Resimion data.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ACKNOWLEDGMENTS

We are grateful to our students for providing feedback.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2023.11756/full#supplementary-material

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BJBS

ORIGINAL RESEARCH
published: 25 September 2023
doi: 10.3389/bjbs.2023.11731

Authentic Pathology Specimen Reception: A Valuable Resource for Developing Biomedical Science Student Competencies and Employability

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Background/Introduction: The pathology specimen reception is fundamental to the services provided by Biomedical Science laboratories worldwide. To ensure patient safety and that samples are of adequate quality to send for analysis, prospective Biomedical Scientists should have a robust knowledge of the processes involved and the acceptance criteria of the pathology specimen reception. This knowledge has been highlighted by employers as a current gap in Biomedical Science graduates and therefore needs to be addressed within higher education settings. To do this, this study aimed to 1) design a practical session to simulate the key processes of the pathology specimen reception and 2) to understand Biomedical Science students' opinions on these activities and the development of transferable skills required for post-graduate employment.

Methods: The practical session was designed based on industrial requirements and academic knowledge of student skill sets to ensure suitability. Qualitative information regarding participant demographics and career interests was acquired through open-answer or multiple-choice questions. Quantitative student feedback was acquired via questionnaires utilising a 5-point Likert scale (n = 77).

Results: The scenario-based practical session provided students with a positive learning experience with 98.7% of participants enjoying the session, with 87.0% stating they learned a lot by completing the session. It was also identified that participants preferred this style of learning to that of conventional higher education teaching modalities with 97.4% stating they would prefer simulated employment focussed scenarios embedded into the curriculum more often. The majority of participants also thought this session was helpful for

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Received: *23 June 2023*
Accepted: *15 September 2023*
Published: *25 September 2023*

Citation:
Hussain T, Namvar S and Jones M (2023) Authentic Pathology Specimen Reception: A Valuable Resource for Developing Biomedical Science Student Competencies and Employability. Br J Biomed Sci 80:11731. doi: 10.3389/bjbs.2023.11731

Abbreviations: BAME, Black, Asian and minority ethnic; CSR, Central Specimen Reception; EDI, Equity, Diversity, and Inclusion; HCPC, Health and Care Professions Council; HE, Higher Education; HEI, Higher Education Institute; IBMS, Institute of Biomedical Science; LIMS, Laboratory Information Management System; LOSA, Lower Super Output Areas; MLA, Medical Laboratory Assistant; NHS, National Health Service; POLAR, Participation of local areas; QAA, Quality Assurance Agency; RTP, IBMS Registration Training Portfolio; SEM, Standard Error of the Mean; SET, Standards of Education and Training; SOP, Standards of Proficiency; TUNDRA, Tracking underrepresentation by area.

the development of their key transferrable skills including teamworking, communication, and confidence. When stratified based on demographic data, there was minimal difference between cohorts and in the majority of cases, those participants from non-traditional university entry backgrounds had a more positive experience and better transferable skill development following the completion of this style of learning experience.

Conclusion: This study highlights simulation-based learning as a tool to develop core Biomedical Science knowledge, build student graduate capital, and ensure the preparedness of students for post-graduation employment.

Keywords: biomedical science education, specimen reception simulation, authentic education, graduate capital, employability

INTRODUCTION

The Pathology laboratory specimen reception, well known as Central Specimen Reception (CSR) in many Pathology laboratories, is fundamental to the analytical processes and services provided by the Pathology department. All sample handling, preparation and data entry is managed within CSR; limitations in the operation of these processes will impact the integrity of the procedures performed further down the process. Specimen reception duties are mainly carried out by medical laboratory assistants (MLA) who play an integral role in Pathology laboratory services.

With patient safety being paramount in all areas of pathology, the CSR is integral at every point of the testing pathway. All healthcare professionals have a duty of care and a legal obligation to ensure that all the steps in the sample journey from collection to the final test results are processed correctly in line with the guidelines to guarantee that all results from processed samples match the patient [1]. Samples received at CSR are first checked to ensure they meet the sample acceptance criteria. This process involves ensuring that the sample has been correctly labelled with the patient details and match those on the request form, checking the sample has been collected in the correct tube and ensuring there is a sufficient volume of sample to meet the test requirements. The sample and test request form are then labelled with a unique barcode number to allow test results to be traced back to the patient. Samples are then prepared for analysis depending on the type of test requested.

Negligence during this process can result in the incorrect reporting of results with detrimental outcomes for the patient, with pre-analytical errors during this process accounting for more than two-thirds of all reported laboratory errors [2]. This demonstrates the importance of CSR within the pathology pipeline as indicated by the Institute of Biomedical Science (IBMS) [3]. Staff who work on the CSR require high levels of accuracy and attention to detail whist maintaining appropriate records and documentation [4]. Biomedical Scientists rely on all checks and sample preparation processes being carried out correctly on CSR prior to validating and authorising test results once samples have been processed. It is therefore desired that before entering employment, prospective applicants develop experience and knowledge of the CSR and are able to begin to demonstrate they possess the appropriate technical and transferable skills required to safely practice before they enter the Biomedical Science profession [5]. This knowledge can then be potentially evidenced in combination with their professional practice during the completion of the IBMS Registration Training Portfolio (RTP) and subsequent registration with the Health and Care Professions Council (HCPC).

The IBMS and HCPC are professional bodies who set the standards of education and training (SETs) to ensure accredited Biomedical Science degrees cover the academic components required to meet the HCPC standards of proficiency (SoP) [6]. The completion of the RTP and an accredited Biomedical Science degree are compulsory requirements to become eligible for HCPC registration as a Biomedical Scientist. The IBMS RTP is commonly completed during 12 months intercalated placement opportunities within an IBMS approved training laboratory, where a student is offered a Trainee Biomedical Scientist position to complete training and demonstrate they meet the HCPC SoPs. However, it is well known that placement opportunities for Biomedical science students are limited which poses a national problem as graduates are unable to complete their training to demonstrate they meet the HCPC SoP to achieve the IBMS Certificate of Competence. This places a greater onus on Accredited Biomedical Science degree programmes to provide authentic learning experiences that accurately recapitulate elements of professional practice to help better prepare graduates for the world of work.

A recent study by Hussain and Hicks [7], assessed the employability skills of Biomedical Science graduates. Employers highlighted gaps in skills and knowledge which impact on the workforce and service delivery. A total of 93% of employers who participated in this study stated that new graduates did not meet the entry requirements for a Biomedical Scientist position and the shortfall in the skills was resulting in strains on the services provided by Pathology laboratories [7]. Specifically, they identified a deficiency in skills such as time management, professional attitudes, and lack of basic knowledge of the role of pathology in patient care and quality assurance processes. Academics at Higher education institutions (HEI's) also stated that "the shortfall in

employability skills is impacted by the difference in what is delivered in a degree and the reality of current pathology labs," and that "replicating laboratories in a university setting is very challenging." Next steps were identified to address the key issues raised in the employability study. Suggestions to bridge some of the gaps that were highlighted, included creating a virtual laboratory training platform and introducing simulation-based education to mimic pathology practice in HEI's.

Further to providing core subject knowledge, HEI's also play an important role in enhancing employability and improving graduate capital (skills/knowledge, communication, cultural knowledge, resilience and adaptability) [8]. One approach to doing this is through simulation-based learning. Simulation-based learning is an educational strategy that is widely used in nursing and medical education to achieve a wide range of learning outcomes [9, 10]. Several studies have found that simulation-based learning is an effective pedagogical method in teaching which facilitates the development of key skills aligned to the graduate capital model including interpersonal skills, teamwork, communication, problem solving and decision-making skills [11, 12]. Simulation also offers a safe environment to develop knowledge of core professional skills without risking patient safety or wellbeing [13].

Within Biomedical Science practice, one of the areas highlighted as posing a potential risk to patient safety, is if those handling pathology laboratory specimen reception are not adequately trained. It is possible to educate undergraduate Biomedical Science students about concepts such as sample acceptance criteria and quality assurance using simulation. There is a requirement to work creatively to teach the importance of pathology in patient care and the role of CSR in a simulated setting to meet the needs of employers and bridge the gap in employability skills currently observed in new Biomedical Science graduates.

The aim of this research was to highlight the impact of simulated learning in a HEI setting, on well-known HEI attainment gaps and the benefits to the Biomedical Science workforce of the future. Collaborating with employers, this study aims to design resources and educate students about the role of CSR in pathology whilst simultaneously enhancing their graduate capital through the utilisation of simulations and scenario-based learning.

METHODS

Participants

All participants were enrolled on the Biomedical Science standard or degree apprenticeship programmes at the University of Salford. A total of 223 participants were eligible to participate in the activity across the student cohorts targeted. These eligible students were the following: students at level 4 (within the main cohort) (n = 195) and level 5 (as an extracurricular activity) (n = 28) were identified to participate in this activity to ensure the development of key skills before students become eligible to apply for intercalated IBMS laboratory placements during level 5 study.

Practical Session Design

The practical session was designed to take place either within the laboratory or a flat non-laboratory space to allow for flexibility dependent on infrastructure availability. The session was designed and delivered as described in **Supplementary Figure S1** and **Figure 1**. The activity was integrated into the "Biomedical Skills" first year undergraduate laboratory practical-based module and as extracurricular activities for second year undergraduate students preparing for placements.

Students were briefed on the activities and provided with a background to CSR and the important role it plays in the Pathology laboratory. Workbooks were created to help students note down the key aspects such as sample and test request form requirements and pre-analytical variables.

A range of samples and test request forms were labelled with patient details representing a variety of scenarios. Students were divided into groups of 3–5 and presented with each of the scenarios listed in **Table 1**. Students were required to check whether the samples met the acceptance criteria. Where discrepancies were identified, they were asked to discuss their findings with the rest of the group and explain the consequences of the pre-analytical variables on test results.

Survey Design, Delivery, and Analysis

Following the completion of the simulated specimen reception activity students were provided a link to the survey (**Supplementary Table S1**) delivered via Microsoft Forms. This link was provided to only those participating students to prevent the biasing of results by non-participants. All questions

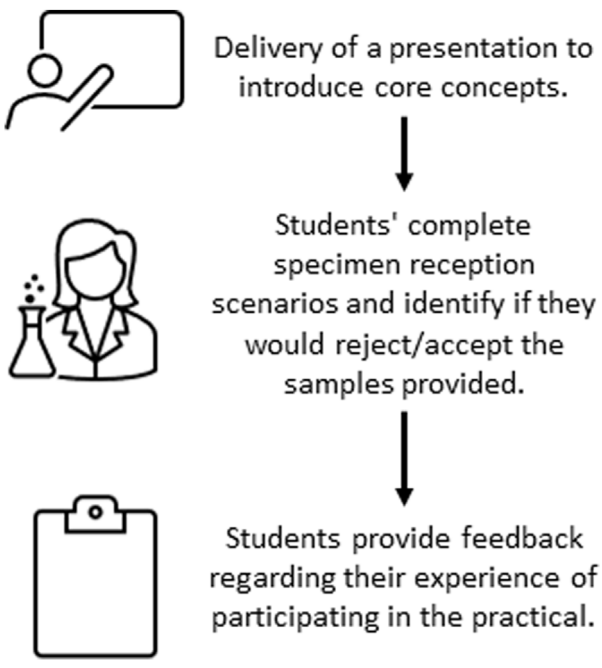

FIGURE 1 | The workflow for delivering the simulated specimen reception practical session.

TABLE 1 | The scenarios simulated during the specimen reception practical session.

Scenario 1	Acceptable full blood count and urea and electrolytes samples Reject underfilled coagulation sample
Scenario 2	Reject full blood count and coagulation samples over 24 h old
Scenario 3	Reject full blood count sample received in incorrect sample bottle
Scenario 4	Reject coagulation sample labelled with incorrect hospital number and date of birth
Scenario 5	Accept urea and electrolytes and coagulation samples
Scenario 6	Accept coagulation and urea and electrolytes samples Reject full blood count sample received in incorrect sample bottle
Scenario 7	Accept urea and electrolytes sample Reject mislabelled full blood count sample
Scenario 8	Accept urea and electrolytes sample Note missing glucose sample
Scenario 9	Reject Urea and electrolytes sample received in incorrect sample bottle
Scenario 10	Reject underfilled full blood count and glucose samples

were approved and checked for potential biases as a part of the ethical approval process.

Survey questions were split into three main categories: 1) Student background to better understand the impact of EDI characteristics, the likelihood of students participating in HE (based on the POLAR 4 scoring system [14]), student's home area representation in higher education (Based on the TUNDRA LOSA scoring system [15]) home area abundance of Higher education qualifications (Based on the Adult HE 2011 scoring system [16]), and desired future career; 2) Their experience of participating in the simulation; 3) the development of their transferable skills; 4) alignment to desired future employment and 5) the suitability of this style of activity as an alternative to traditional HE education and assessments. Survey questions were either open answer for participant background with all other questions scored using a 5-point Likert scale, with scores of 1 or 2 grouped as negative responses, 3 being a neutral response, and scores of 4 or 5 being positive responses.

Statistical Analysis

The results of all student surveys are reported as mean ± standard error of the mean. Data normality was evaluated using a Kolmogorov-Smirnov test for normality. All two group comparisons were conducted using non-parametric Mann-Whitney tests. All multiple group comparisons were conducted using a non-parametric Kruskal-Wallis test. All statistical analysis was performed using GraphPad Prism version 9.5.1 (GraphPad Software, USA). Statistical significance was set at $p \leq 0.05$.

RESULTS

Participant Demographics

A total of 114 (51.1%) of eligible students participated in the activity, with 77 (67.5% of participants) agreeing to complete the feedback form. The key demographics relating to EDI characteristics, career interest, higher education representation.

Participation are visualised in **Figure 2**. The participating cohort was predominantly female (**Figure 2A**), with 72.7% of participants identifying as female and 22.1% identifying as male. Only 1.3% identified as non-binary. The majority of participants were BAME (**Figure 2B**), with 77.9% of participants classified as BAME. When participants were grouped based on their careers of interest at the time of survey completion (**Figure 2F**), it was revealed that 62.3% were interested in persuing a Biomedical Science based career (Biomedical Scientist or MLA) with the remainder of the participants (37.7%) stating that they had no current interest in Biomedical Science based careers.

When participants were stratified based on their liklihood to participate in HE determined using the POLAR 4 scoring quintiles [14] (**Figure 2C**), found that 53.5% of the participants came from areas with a low liklihood (Quintiles 1 & 2) to participate in HE. Of the remaning respondants, 20.2% had an intermediate liklihood (Quintile 3), with a further 26.2% having a high likelihood (Quintile 4 & 5) of participating in HE. When the cohort was stratified based on their home area representation in HE based on the TUNDRA LOSA criteria [15] (**Figure 2D**), it was identified that 31.8% were lowly represented (Quintiles 1 & 2), with a further 25.8% having an intermediate representation (Quintile 3) in HE. It was revealed that 42.4% of the participants were found to be from areas that have a high representation (Quintile 4 & 5) in HE. Evaluation of the prevalence of HE qualifications in the participants area based on the Adult HE 2011 scoring system [16] (**Figure 2E**) showed that 73.2% of participants came from areas with a low prevalence of HE qualifications. The remainder of participants either had an intermediate (14.1%) or High prevalence (12.7%) of HE qualifications in their home area.

Surveys of Student Experience Following the Simulated Specimen Reception Session

Overall students had a positive experience throughout the simulated specimen reception session, as highlighted in **Figure 3**, with 76/77 (98.7%) expressing that they enjoyed participating in the session with 67/77 (87.0%) stating that they learnt a lot of new knowledge and skills from the session. Further to this, 73/77 (94.8%) of students also found the learning goals and objectives of the session to be clear. When questioned about how this session compared to traditional Higher Education taught practices (lectures, workshops, and practical sessions) and if they would like similar sessions embedded into the curriculum in the future, the majority of students provided a positive response. Of the respondents, 69/77 (89.6%) stated that this style of session was better than traditional HE sessions, with 97.4% (75/77) stating that they would like more of these sessions embedded into the Biomedical Science programme in the future. These findings highlight the student drive to participate in further simulated sessions that align to the skills required within professional practice.

Surveys of Student Graduate Capital Development Following the Simulated Specimen Reception Session

The development of key transferable skills associated with graduate employability collectively known as graduate capital

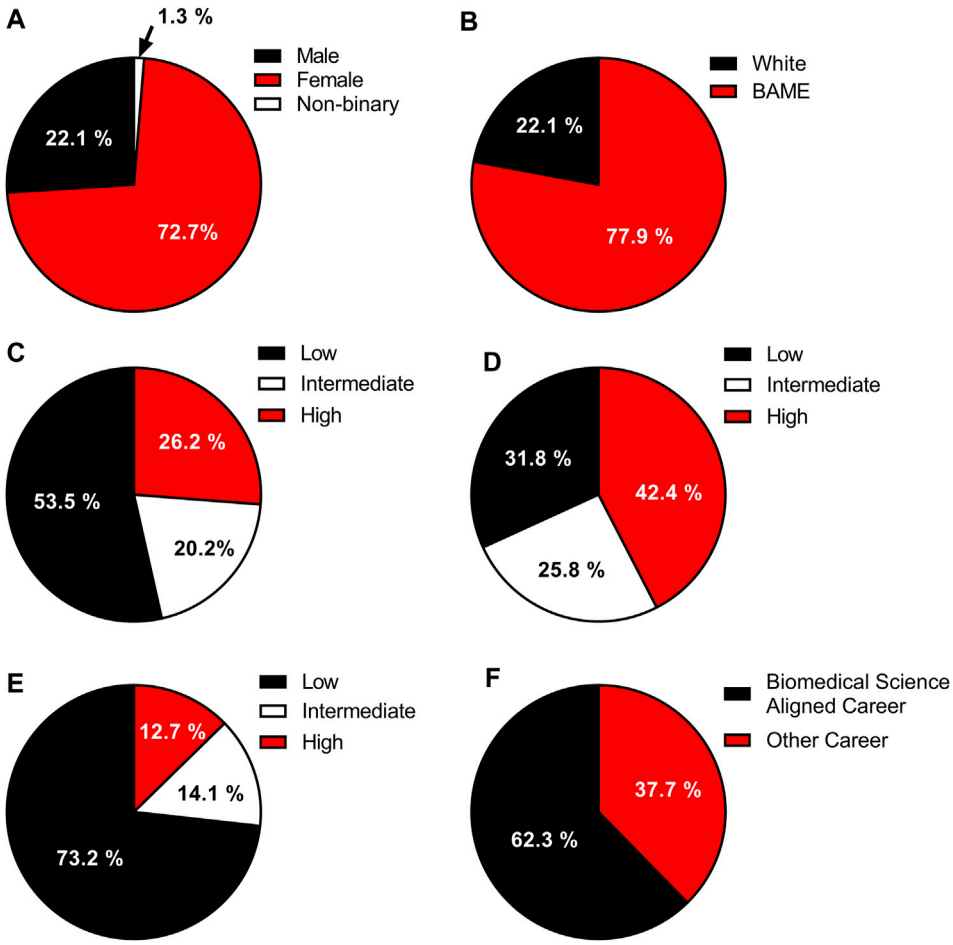

FIGURE 2 | The demographics of the participants of the specimen reception practical session. **(A)** Participant gender. **(B)** Participant ethnic status. **(C)** Survey participants POLAR 4 breakdown by quintile, where low represents quintile 1–2, intermediate quintile 3 and high indicates quintile 4–5. **(D)** Representation of participants area in Higher Education based on the TUNDRA LOSA scoring system where low represents quintile 1–2, intermediate quintile 3 and high indicates quintile 4–5. **(E)** Prevalence of Higher Education qualifications in the participants area based on the Adult HE 2011 scoring system where low represents quintile 1–2, intermediate quintile 3 and high indicates quintile 4–5. **(F)** Participants career interest at the time of survey completion. *n* for all figures = 77.

are highly desired within undergraduate programmes to facilitate a smooth transition to employment and to ensure that graduates possess the attributes desired by employers and industry. In response to questions relating to the development of their employability and transferable skills (**Figure 4**), the majority of participants stated that this session promoted the development of key transferable skills and their general employability skills with 71/77 (92.2%) stating that the simulated specimen reception session positively supported the development of their employability skills. In addition to this, 96.1% (74/77) of students also identified that the session did have a positive impact on the development of their team working skills, whilst 66/77 (85.7%) also stating that this session enhanced their communication skills. Of all student responses to the survey, 73/77 (94.8%) also stated that this session had a positive impact on the development of their confidence in handling samples and communicating with others.

Impact of Equity, Diversity, and Inclusion (EDI) Characteristics on Student Experience and Employability Skills Development

Ensuring that higher education activities are appropriate for all students irrespective of their background is an important characteristic to account for when implementing new material into the curriculum. To evaluate this the survey data presented in **Figures 3**, **4** were stratified based on key EDI parameters that are known to influence outcome in higher education including Black, Asian and minority ethnic (BAME) status (**Figure 5**), higher education participation (**Figure 6**) and student representation in higher education (**Supplementary Figure S2**).

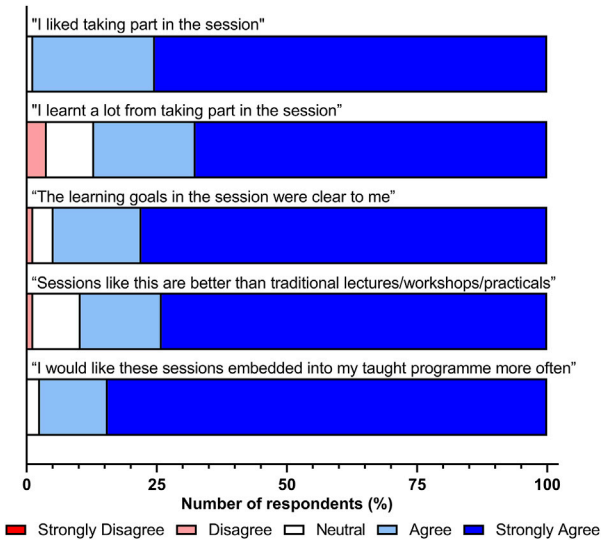

FIGURE 3 | Students' (n = 77) experience of the specimen reception simulation session.

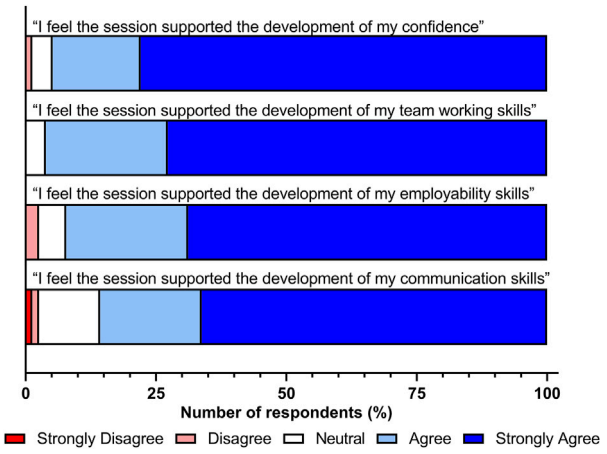

FIGURE 4 | Participant responses (n = 77) to questions relating to key transferable and employability skill development following the specimen reception simulation session.

Irrespective of BAME status student feedback on all survey questions was highly positive. When participants were grouped based on BAME status (**Figure 5**) only participant learning (**Figure 5B**) and comparisons to traditional educational practices (**Figure 5H**) were found to significantly differ between the two populations. Participants who identified as BAME had a significantly better learning experience than those from a non-BAME background (Non-BAME: 4.06 ± 1.03 (n = 17) versus BAME: 4.65 ± 0.68 (n = 60), p = 0.0057). Further to this, BAME individuals also preferred these simulation-based sessions to more traditional HE practices, when compared to non-BAME individuals (Non-BAME: 4.29 ± 0.84 (n = 17) versus BAME: 4.75 ± 0.51 (n = 60), p = 0.016).

In order to gain a better understanding on whether socioeconomics feed into the perceived benefits of specimen reception simulations, participants were stratified based on POLAR 4 scores of their declared non-term-time postcodes. For visualisation, participants were categorised as being from lower, intermediate, or higher participation. Comparison between these three populations (shown in **Figure 6**) found similar experiences and graduate capital development between two populations of students. Those participants from low participation areas reported significantly higher tendency to report improved confidence as a result of taking part in the simulated specimen reception activity (**Figure 6D**, Lower participation in HE: 4.68 ± 0.53 (n = 38) versus Higher participation in HE: 4.06 ± 1.18 (n = 16), p = 0.033). Students from lower participating areas significantly preferred this session to traditional HE taught provision than those from higher participating areas (**Figure 6H**, Lower participation in HE: 4.71 ± 0.57 (n = 38) versus Higher participation in HE: 4.13 ± 0.96 (n = 16), p = 0.044). Students from intermediate participation areas found the session of higher quality than those from lower participation areas (**Figure 6H**, Lower participation in HE: 4.63 ± 0.63 (n = 38) versus intermediate participation in HE: 5.00 ± 0.00 (n = 16), p = 0.042). All other responses to the survey were not significantly different between the three populations.

Similar findings were also observed when participants were stratified based on their area's representation within the Higher Education sector using TUNDRA LOSA criteria (**Supplementary Figure S2**). Only the participants responses relating to the quality of the session were found to significantly differ between the two cohorts. Students from higher represented areas found the session to be of a significantly higher quality to that of students of lower represented areas (**Supplementary Figure S2I**) (Lower representation in HE: 4.57 ± 0.60 (n = 21) versus Higher representation in HE: 4.86 ± 0.45 (n = 28), p = 0.036).

Student Career Aspirations

It is known that Biomedical Science degrees do not solely recruit students who will go on to work as practicing Biomedical Scientists following graduation and can lead to a variety of future career opportunities. To evaluate if the activity was suitable for students irrespective of their career of interest, comparisons were conducted between students interested in pursuing Biomedical Science aligned careers (Medical Laboratory Assistant or Biomedical Scientist) and those expressing an interest in other careers (**Supplementary Figure S3**). Overall, students had a comparable experience with the specimen reception session irrespective of their highlighted future career. The only significant difference was with the perceived session difficulty which was found to significantly differ between the two student populations (**Supplementary Figure S3K**), with those students who are seeking a Biomedical Science aligned career finding the session significantly easier than those interested in alternative career pathways (Biomedical Science aligned career: 2.24 ± 1.28 (n = 48) versus other careers: 3.00 ± 1.44 (n = 29), p = 0.034).

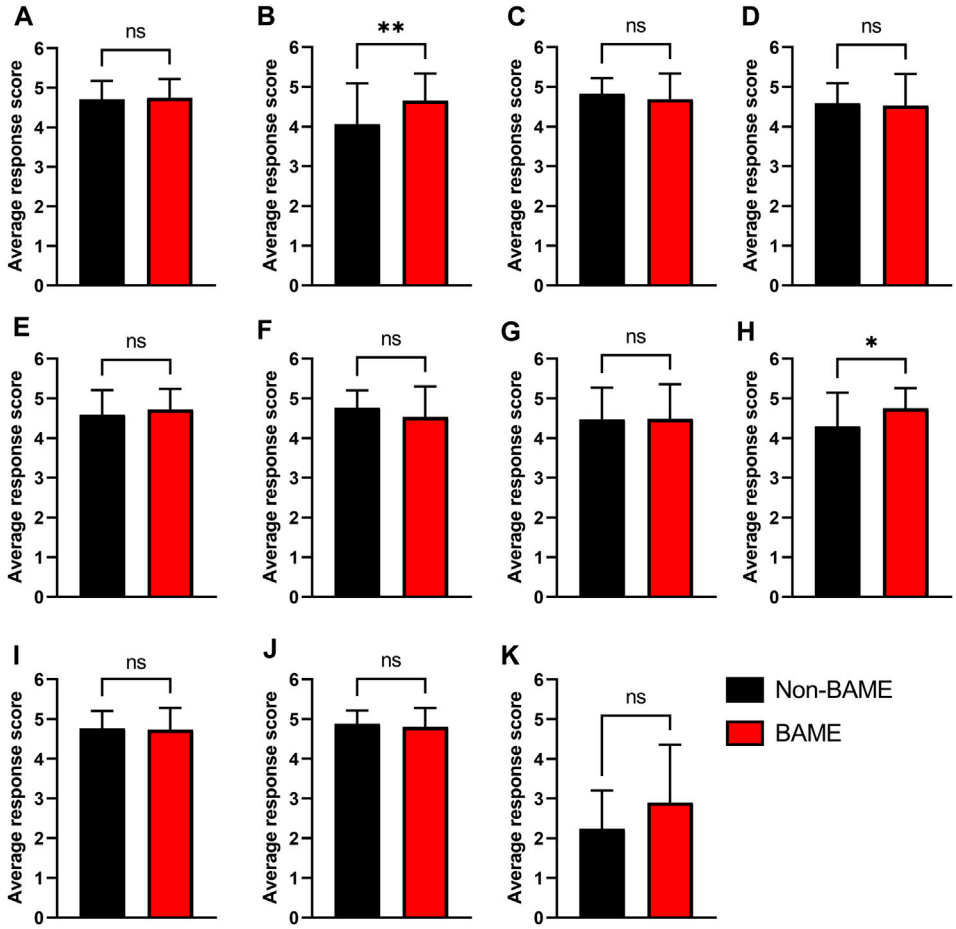

FIGURE 5 | The implications of Black, Asian and minority ethnic status on survey responses. Questions related to **(A)** Session enjoyment **(B)** Participant learning **(C)** Clarity of learning goals **(D)** Development of confidence **(E)** Development of team working ability **(F)** Development of wider employability skills **(G)** Development of communication skills **(H)** Better than traditional HE taught provision **(I)** Quality of the session **(J)** Increased embedding in the curriculum and **(K)** Session difficulty were compared between participants from a non-BAME background (Black, $n = 17$) and those from a BAME background (Red, $n = 60$). Response scores of 1 = Strongly disagree/too easy, and scores of 5 = strongly agree/too difficult. Data expressed as Mean ± Standard deviation. Statistical analysis was conducted using Mann-Whitney analysis. $^{**}p < 0.01$, $^{*}p < 0.05$, ns, not significant.

DISCUSSION

The development of knowledge aligned to core biomedical science competencies and to prepare students for the transition to employment post-graduation is one of the main goals of biomedical science degree programmes. With recent research highlighting knowledge gaps in new graduates and the future biomedical science workforce, it is essential to continue developing resources that support the development of core biomedical science competencies [7]. Our study highlights how through industry consultation and academic knowledge, HEI's can develop authentic simulated learning experiences to encourage critical thinking, problem solving and decision-making skills, promoting deeper engagement whilst applying their knowledge to professional practice, in line with the recently published Quality Assurance Agency (QAA) Subject Benchmark Statement for Biomedical Scientists [17]. Simulated learning can enhance student experience, incorporate equality and inclusive teaching for students with different learning styles and needs whilst promoting genuine employability skills development.

The pathology specimen reception simulation designed for this study, was positively received by all students who provided feedback on their experience completing the session and promoted the development of key elements of their graduate capital. Furthermore, this study found that when participants in the simulation activity were stratified based on ethnic background, likelihood to participate in HE and career interest, there was minimal disparity between survey responses. This indicates that all students participating in this activity had comparably positive experiences and highlights how simulation-based learning may have an impact on attainment disparities in HE.

It is known that within the HE sector there are attainment disparities based on factors such as gender [18], ethnicity (as highlighted by the BAME award gap [19, 20]), and socioeconomic status [21]. Whilst there is no conclusive

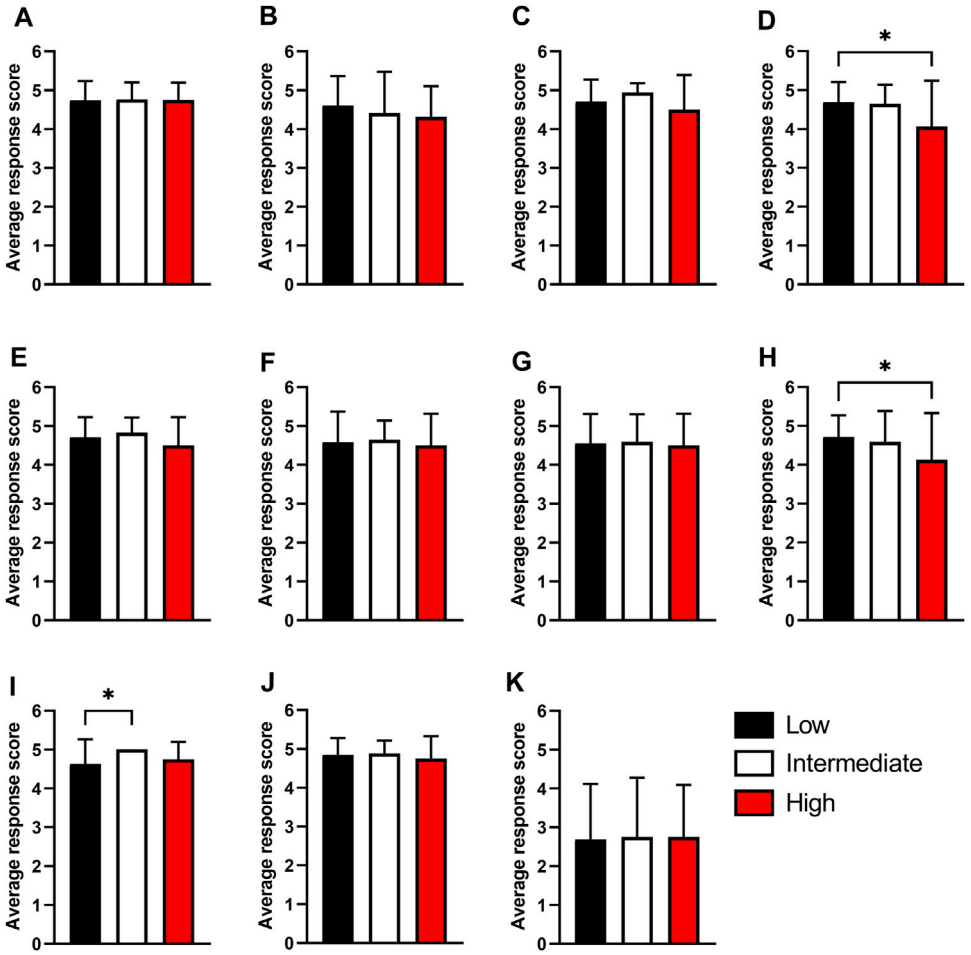

FIGURE 6 | The impact of the likelihood to participate in Higher Education on the responses to the survey questions. Questions related to **(A)** Session enjoyment **(B)** Participant learning **(C)** Clarity of learning goals **(D)** Development of confidence **(E)** Development of team working ability **(F)** Development of wider employability skills **(G)** Development of communication skills **(H)** Better than traditional HE taught provision **(I)** Quality of the session **(J)** Increased embedding in the curriculum and **(K)** Session difficulty were compared between participants with a low likelihood to participate in Higher Education (Black, $n = 38$) (POLAR 4 scores of 1 or 2), those with an intermediate likelihood (White, $n = 16$) and those with a high likelihood to participate (Red, $n = 16$) (POLAR 4 scores of 4 or 5). Response scores of 1 = Strongly disagree/too easy, and scores of 5 = strongly agree/too difficult. Data expressed as Mean ± Standard deviation. Statistical analysis was conducted using the Kruskal-Wallis test. *$p < 0.05$.

evidence for what underpins these disparities in outcomes, the need to narrow and close these attainment gaps is imperative to the future of HEI's. With simulation-based learning being more practical and problem solving focused, it may allow students who do not typically thrive in traditional HE educational practices (e.g., didactic teaching), to engage better and ultimately succeed in higher education. Our findings highlight similarities between the experiences of students irrespective of their background, and in response to some questions were more positive regarding their experience using simulation-based learning, than those from a traditionally higher attaining background. These data suggest that embedding simulation-based learning into the biomedical science curriculum may enhance attainment, as a result of improved engagement, and experience for all students, whilst promoting the development of graduate capital.

Authentic Practice in Higher Education

Authentic education offers the opportunity to gain and enhance a broader range of employability skills directly relevant to the world of work. The concept of authentic assessments was developed in the first instance by Wiggins [22] who defined authentic assessments as being realistic and should replicate the context in which competency assessments are undertaken in the workplace. Authentic education requires students to engage in simulated activities that mimic the real world and assess the students' ability to use their judgement in complex situations.

Authentic assessments are student centred where learning is demonstrated through active engagement and participation through hands-on activities. In this study, the vast majority of participants felt that the simulated session was better than traditional lectures, workshops, and practical sessions and that they would like to see more of these sessions embedded into the

taught programme. These findings are similar to those of Brannan et al. [23] which showed that nursing students preferred simulation-based education to that of lectures, due to it being a more active approach to learning. Our findings reveal that this is also the case for students studying Biomedical Science.

Once students have acquired an awareness of the principles and practice within the CSR, they can begin to evidence the application of deeper knowledge, understanding and technical capability which arguably go beyond traditional assessment modes that fall short of experiential learning [24]. Vygotsky believed that such alternative means should be sought to facilitate learning for learners who have different needs and requirements which may impact their learning [25]. An appreciation of different learning approaches is important for educators as some students learn better with experiential educational experiences such as those experienced during placements, internships, or simulated settings. The positive feedback received highlights the student demand for increased utilisation of simulated approaches in biomedical science curriculum and the desire to develop knowledge/skills which are normally not achievable outside the workplace.

One of the advantages to this type of session, and specifically relating to this simulated pathology specimen reception activity, is that it can be delivered within any flat moveable none-laboratory space. This can therefore decrease demand on laboratory infrastructure which may be limited at some HE institutions and can be readily adapted and developed as required to deliver to more advanced levels of study or to convey more advanced concepts. Furthermore, this activity is simple to adjust to constantly changing needs of the pathology sector and allows for academic creativity relating to the scenarios developed.

Scenario Based Education as a Tool for Authentic Biomedical Science Practice

Students aspiring to become a HCPC registered Biomedical Scientist must complete the IBMS RPT which involves the demonstration of knowledge and competence in numerous areas such as personal and professional development, health and safety, quality management, professional practice, and research [3]. This collection of evidence is required to indicate the HCPC SoP have been met to apply for HCPC registration [3, 6, 26].

Scenario based learning is a common pedagogical approach in healthcare courses due to its effectiveness in stimulating students' learning and enabling them to contextualise their knowledge to practice [27]. The scenarios presented to students reflected 'real life' common problems associated with samples and encouraged students to identify and explore how results of blood tests are affected and can have an impact on patient care and treatment plans. By making the task group based, it allows for discussion between groups, the development of key transferable skills and the facilitation of peer-to-peer learning [27, 28], thus enhancing student experience and learning through this style of activity.

Academic staff are utilised to facilitate discussion amongst the groups and ensure students understand the threshold concept of the session. Utilising scenario-based learning as an educational approach to stimulate learning has not only enabled the students to apply their knowledge to real life scenarios but has contributed towards the development of teamworking and communication skills between first year students, which they will continue to utilise for the remainder of their degree and beyond into employment.

Simulations in healthcare and an educational context allows students to expand their skills in a protected environment and make errors in a safe space without impacting on patient safety, while facilitating students to gain a deeper understanding of taught concepts [29].

There are benefits of merging two active-learning strategies, scenario-based learning and simulations [30]. Integration of both these pedagogical approaches provides the opportunity to strengthen knowledge and build on the development of skills. The use of scenarios enables critical thinking, encourages engagement, and allows room for reflection while students can take an active approach in the development of their own skills. The utilisation and creation of simulated learning experiences facilitates the replication of conditions in healthcare systems and clinical practice which enables learners to practice in a safe space encouraging the application of theoretical knowledge to professional practice [31].

Simulation Based Education as a Tool to Prepare Students for Employment

Placements provide students with the opportunity to develop their scientific skills and apply their academic and theoretical knowledge to practice. These opportunities are hugely beneficial for students as it allows them to consolidate their learning and helps them to gain a better appreciation of the subject area while developing their employability skills [32]. However, placements are usually unpaid which puts those from traditionally underrepresented backgrounds at an increased disadvantage when considering the financial implications for travelling and the general costs of living preventing these students gaining professional experience [33]. This in turn causes students to postpone applying for placements in the hope that they will be able to apply for paid trainee positions following graduation. These trainee positions are also highly competitive and are often offered to internal candidates already employed by an NHS Trust as MLAs who were in the same position following graduation, waiting for the opportunity to complete their training and the IBMS RTP. Subsequently, the lack of work experience and exposure to the Pathology laboratories results in a workforce shortage of trained and skilled Biomedical Scientists.

The lack of placement opportunities and the increasing pressures on HEIs to address the issue of graduate employability [34, 35] has encouraged academics to think of innovative ways to teach aspects of healthcare professions that are difficult to teach without physically being present in a healthcare or laboratory setting. The challenges of facilitating placements in Pathology laboratories for an ever-increasing student population is rising year on year as the NHS experiences staff shortages, increasing workload and burnout. Employers stated that they would be willing to provide more placements to students if some aspects of the registration

portfolio were completed at university as this would reduce the workload and pressure on training officers [7].

There was a consensus across employers and HEIs that completing the knowledge requirements of the RTP specifically relating to Personal Responsibility and Development, Equality and Diversity, Communication, Patient Records and Data Handling and Professional Relationships could be facilitated at university. There was also an agreement that evidence for meeting the knowledge requirements in the Professional Knowledge, Health and Safety and Research and Development modules could also be completed as part of the portfolio in the university [7]. Allowing exposure to key clinical laboratory practices early on in education, may generate interest in students pursuing biomedical science as a career and may transfer to the workforce despite the current challenges associated with the staffing and workload pressures in the NHS. Facilitating students to encounter multiple scenarios in a simulated pathology specimen reception setting enabled students to practice problem solving and critical thinking skills as a team. This session was also utilised as an opportunity for students to gather the first piece of evidence for the portfolio and promote the idea of gathering further evidence for the IBMS RPT whilst at university.

Our study reports that simulated specimen reception boosts confidence, team working, employability and communication skills for most students. These data support the importance of simulated learning and how it contributes to experiential learning and the application of knowledge in the world of work. Students can engage with meaningful learning through a cognitive experience as they gain knowledge enabling them to connect and relate situations to the real world which enhances their understanding during the process. These concepts allow students to develop their understanding of the knowledge requirements for the sector in a playful manner but also begin supporting students' university-to-work transition early on within their academic journey to be continually scaffolded throughout the remainder of their degree.

Future Directions

We have highlighted areas within our simulation which can allow students to continue the use of acquired knowledge from this study through the integration of further elements of the CSR. This simulation can be further expanded by bringing in data entry and test requesting onto a Pathology Laboratory Information Management System (LIMS) which is another extremely important aspect of CSR and is integral to the workflow of the pathology laboratory. By developing the simulation to bring in data entry to teach students the importance of maintaining accurate records and patient demographics, this provides an opportunity to apply their existing knowledge and build on this with new concepts, moving students to a higher level of engagement.

Collaboration with other teams to teach interdisciplinary working through role play can also facilitate peer-to-peer learning while encouraging professionals from different disciplines to work together and share different skills [36–38]. Research demonstrates a gap in academic practice where new graduates in the healthcare workforce are insufficiently equipped to participate in clinical work and patient care. These gaps are also reflected in critical thinking, communication, managing time and responsibilities and multidisciplinary team working [39] as well as clinical reasoning skills [39]. Partnership with phlebotomists, nurses and physicians can help to reinforce the importance of clear communication between multidisciplinary teams while developing professional relationships and effective team working skills. This will also help clear up any misconceptions of roles and responsibilities enabling students to appreciate and value how other roles also contribute and have an impact on providing high quality patient care as a result of a collective process between different teams. This is also a HCPC requirement which students must meet by demonstrating their ability to sustain working relationships in the context of the role of a biomedical scientist to achieve the best results for service users.

Limitations/Challenges

Whilst this study did not directly address the potential attainment implications of the addition of simulation-based activities into the Biomedical Science curriculum due to ethical approval implications. Future studies will seek to explore student knowledge of the specimen reception and sample acceptance criteria before the commencement of the session and determine if this was improved following the completion of the activity.

The activity selected was primarily focused on the Biomedical Science specialisms of haematology and biochemistry, due to the professional knowledge of the study designers. We acknowledge that there are significantly more specialisms associated with professional Biomedical Science practice and would look to expand the concept of this study further as a part of its future development. For example, we would seek to include samples from other Biomedical Science specialisms to ensure that students develop well-rounded specimen reception knowledge.

Though there is strong evidence to advocate the benefit of authentic learning experiences and assessments in HEI, there are challenges associated with simulation-based learning. Developing authentic experiences for a large number of students is time consuming. This may dissuade academic staff from developing novel simulated approaches to Biomedical Science education without additional support or allocated development time. Further to this, when designing these kinds of simulated activity, the learning objectives and task must be identified and appropriately aligned to the wider programme curriculum and other biomedical science specialisms. The threshold concept of the session must be appropriate for the level of study whilst ensuring that employability skills are also effectively embedded into the session to allow for successful scaffolding student learning and establishing a base for lifelong future learning.

CONCLUSION

This work represents an advance in biomedical science as it highlights simulation-based learning as a tool to develop core knowledge, build graduate capital, and prepare students for employment.

SUMMARY TABLE

What is Known About the Subject?

- The pathology specimen reception is an integral area of Biomedical Science practice commonly overlooked within education.
- Practicing as a Biomedical Scientist and the IBMS RTP aligns to key components of the graduate capital model.
- QAA (2023) Biomedical Science Benchmark statement seeks to develop stronger links to the development of employment skills.

What This Paper Adds

- A novel simulation based practical that can be easily integrated into biomedical science curricula.
- Simulation based education was positively received by Biomedical Science students.
- Highlights the student demand for simulation-based learning to be further integrated into biomedical science education.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because of the ethical approval criteria associated with this study. Requests to access the datasets should be directed to TH, t.hussain21@salford.ac.uk or MJ, m.a.jones9@salford.ac.uk.

ETHICS STATEMENT

The studies involving humans were approved by Ethics committee at the University of Salford under the Ethics code: 6414. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

TH and MJ conceptualized the simulated activity. TH designed all scenarios. SN completed all ethical approval documentation. TH, SN, and MJ delivered the simulated specimen reception practical sessions. TH and MJ designed and gathered student feedback for analysis. MJ analysed the results of the survey. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ACKNOWLEDGMENTS

We would like to thank the Walter Bodmer teaching laboratory technical team at the University of Salford for their support preparing for the practical session.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2023.11731/full#supplementary-material

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BIOMEDICAL SCIENCE IN BRIEF
published: 04 September 2023
doi: 10.3389/bjbs.2023.11654

Beyond the Advanced Therapies Skills Training Network: An Instrumental Case Study of Life Sciences Skills Development for Biomedical Science Graduates in Scotland

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Biomedical sciences graduates are employed in a variety of different settings and form a significant part of the Life Sciences sector workforce in Scotland. Their degrees should equip them with the skills and knowledge to not only enter the workplace, but be adaptable in an environment that will inevitably change over the course of their careers. Industry and student feedback continue to identify perceived skills gaps, necessitating regular government-backed upskilling initiatives together with industry concerns about graduate readiness. For more than a decade, this Scottish Modern University has worked in partnership with industry and Scottish Government agencies to provide upskilling courses and incorporate relevant skills into the biomedical sciences curriculum, from problem solving and reflection to more applied, practical skills. Using the recent Advanced Therapies Skills Training Network collaboration as an instrumental case study this paper describes current best practice which has significantly impacted teaching and workplace training, ensuring biomedical sciences graduates have the knowledge and skills required for employment within the Life Science sector. Limits to the current life science skills model in Scotland are also identified (availability of placements, ad-hoc and inefficient collaborative structures, incompatible provider strategies) and recommendations made to ensure that biomedical sciences degrees continue to be part of a more sustainable, scalable solution to the skills gap. Recommendations include: better industry acknowledgement of accreditation, and more coherent, authentic and strategic collaboration which should improve skills advice and training, through a supported alliance between Industry and University Life Science Skills Committees and the establishment of regional training Centres of Excellence that would provide a focus for pooled resources and a simulated industry experience.

Keywords: skills, training model, evaluation, employability, life science

OPEN ACCESS

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Received: *06 June 2023*
Accepted: *25 August 2023*
Published: *04 September 2023*

Citation:
Garden CLP (2023) Beyond the Advanced Therapies Skills Training Network: An Instrumental Case Study of Life Sciences Skills Development for Biomedical Science Graduates in Scotland. Br J Biomed Sci 80:11654. doi: 10.3389/bjbs.2023.11654

INTRODUCTION

In Scotland, Life Sciences is a strategically important growth sector worth just under £3.4bn supporting over 38,000 Full Time Equivalent jobs, with the Pharmaceutical sector making up around half [1]. There were 3,500 jobs posted in the sector in 2022, with one third sourced from new graduates [2, 3]. Scotland also has the highest number of higher education students enrolled in Science, Technology, Engineering and Mathematics (STEM) subjects relative to population size, compared the rest of the United Kingdom (UK; [1]. In 2019/20 11 Scottish Higher Education (HE) providers produced 745 biomedical science graduates, rising to 940 in 2021/22 [4]. These providers comprise different types of universities, from those with a traditional research focus through to modern, applied institutions. Biomedical Science degrees act as a gateway to a diverse range of career pathways influenced by the type of accreditation as well as the focus of the provider. Graduates possess a set of core skills that remain in demand in differing contexts and applications that change frequently [5]. For example, critical thinking, innovation and digital skills continue to be in demand in the rapidly changing life science industry, together with more applied knowledge and skills such as clinical chemistry (biomarkers), cytopathology/cellular pathology (microscopy and cell culture), microbiology and immunology, and techniques such as molecular genetics, electrophoresis, flow cytometry, and serial data collection and analysis [5].

The Association of the British Pharmaceutical Industry (ABPI) has worked for nearly 20 years to identify and find solutions to the skills gap they face [6]. This led to the Royal Society of Biology (RSB) accreditation scheme and more recently, a number of commitments to supporting apprenticeships as a solution to skills shortages in the sector [5, 7]. However, there are a number of challenges associated with apprenticeships, including recent decreased applicant demand compared to HE, and decreasing employer demand [7]. Given that there are no *graduate*-level apprenticeships in Life or Biomedical Sciences in Scotland (apprenticeships are available up to SCQF level 7), a significant barrier to sector growth, in Scotland, Biomedical science graduates are already an important part of the life sciences skills landscape [2]. These graduates need to have the appropriate skills to enter the sector to sustain growth. However, undergraduate students in HE are expressing dissatisfaction regarding their skills training [8, 9], and so current best practice is to blend the two approaches by incorporating more industry-appropriate skills into the undergraduate curriculum, supported by industry experience opportunities and accreditation, occasionally enhanced by curricular input from upskilling initiatives.

This paper will present an instrumental case study [10] of the experience of developing and delivering a recent Advanced Therapies Skills Training Network (ATSTN) upskilling course. This case was chosen to illuminate a particular issue, the present limitations of the life sciences skills training model in Scotland. The aim is to showcase current best practices in pedagogical approaches which have significantly impacted teaching and workplace training ensuring biomedical sciences graduates have the knowledge and skills required for employment within the life science sector. The limitations of the current model will be explored, giving recommendations for sustainable future development including an examination of the three available accreditation frameworks in the UK from the point of view of life sciences skills to support this aim.

THE CURRENT LIFE SCIENCE SKILLS MODEL IN SCOTLAND

There are a mixture of providers of Life Science Skills training in Scotland, including colleges, universities and industry, reflected in the make-up of the recent ATSTN consortium [11]. The SFC funds qualifications in relevant subjects at colleges (who also support apprenticeship), together with university degrees for Scottish students, and have recently instigated a coherence and sustainability review of tertiary education and research with the aim of driving more strategic collaboration amongst providers [12]. Each university is committed to an outcome agreement as a result of this funding, and performance is measured through UK-wide graduate outcomes and student satisfaction surveys (there is no Teaching Excellence Framework in Scotland as Education is a devolved matter [13]). In addition, universities also participate in the Research Excellence Framework as a measure of their research activity. Although all universities undertake teaching, the balance of research-led and applied teaching activity differs according to the strategic priorities of each institution and so due to differing priorities some are better placed to contribute to sector growth through addressing skills shortages than others. Indeed, graduates from any biology or biomedical science(s) degree are able to enter a variety of professions [5], and a few Scottish universities offer an industry-focussed undergraduate curriculum, whereas others specialise in training biomedical scientists to seek registration with the Health and Care Professions Council (HCPC) to work under the protected title of Biomedical Scientist, or prepare graduates to enter the research route. Regardless of the supply of new college and university graduates, employers continue to rely on on-boarding and in-work skills training, and regularly report issues to do with graduate readiness [2]. These are addressed through upskilling initiatives sporadically funded by various government agencies and delivered through industry-academia partnerships.

For more than a decade this Scottish Modern University has worked with partners in industry to provide solutions to these challenges by incorporating life sciences skills development into the undergraduate biomedical sciences degree. Industry-led or informed teaching activities rely on significant partnership working between industry, either directly or via various associations, and universities because the academic staff base is predominantly trained via the research route with limited experience of working in industry. To meet this need, we established an Employer Liaison group a decade ago, now called the Industry Advisory group, to inform our life science curricula, and invested in industry-experienced academic colleagues. In 2015 £2.7m Scottish Funding Council (SFC) -funded Graduate Employability Project supported the development and implementation of a skills

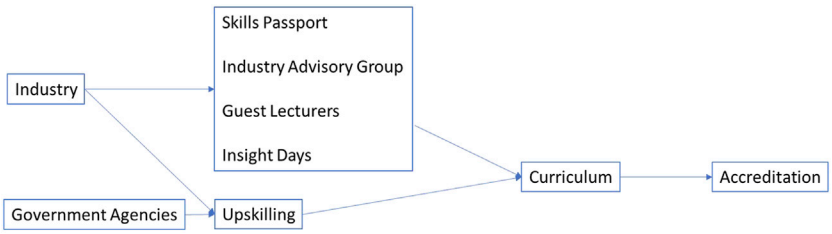

FIGURE 1 | Current best practice for incorporating life sciences skills into the Scottish undergraduate curriculum as developed at a Scottish Modern University. The model describes institution-level partnerships between industry, government agencies and the university which are used to support the development and implementation of a skills passport, industry advisory group, guest lectures, insight days and upskilling which influence the curriculum as evidenced by accreditation.

passport [8, 9]. Shortly after, our Biological Sciences undergraduate suite of degrees (including biomedical sciences) were among the first in Scotland to achieve RSB accreditation in recognition of this approach, with the accreditation being renewed recently. Since then we have been regularly awarded small amounts of funding (totalling £90,000) to provide collaborative upskilling courses with industry such as laboratory skills and quality assurance. We incorporate aspects of these into our taught degree curricula, including guest lectures and industry insight days, ensuring that these courses have an impact beyond the participants, influencing the education of hundreds of students (**Figure 1**). These courses are funded by, and delivered on behalf of government agencies, most recently we were the only Scottish University partner in the Cell and Gene Therapy Catapult -funded ATSTN consortium.

Most partnership working currently takes place at an institutional level, although a national industry guidance board to assist outreach has been suggested to assist with cooperation [2]. There is an active Industry Leadership Group and Scottish Cross Party Life Sciences Group in Scotland with some university representation, the Scottish Universities Life Sciences Alliance (SULSA) being the main conduit to academia for the purposes of skills collaboration [2, 14–16].

THE ADVANCED THERAPIES SKILLS TRAINING NETWORK CASE

The ATSTN in Scotland brought together industry with SFC funded entities including one Scottish Modern University as the sole university partner [11]. The £664k consortium was funded by Innovate UK and the Department for Business, Energy and Industrial Strategy via the Cell and Gene Therapy Catapult to provide upskilling to meet the needs of the accelerated growth of this part of the Life Science sector [2]. UK employee headcount in cell and gene therapy and/or vaccine manufacturing more than doubled in the period from 2019 to 2021, and is forecast to double again by 2026 [2].

Our 5 days intensive courses were designed in partnership with an industry partner, and incorporated over a decade of experience delivering upskilling courses and industry-relevant skills within the undergraduate degree in order to meet the aims of the project (**Table 2**). We quickly identified basic laboratory skills (including pipetting), cell culture, and an awareness of medicines regulation (including Good Laboratory Practice, GLP), governance and standards as the core curriculum for the courses, as these skills gaps are regularly reported by industry and were already being addressed to some extent in our undergraduate curriculum [2, 9]. We added some knowledge-based content on advanced therapies to provide context and sought to provide as much industry-authentic hands-on practical experience as possible. The courses were delivered 9am–5pm to encourage "at-work" professional behaviours and attitudes and were accompanied by a set of workbooks and Standard Operating Procedures. Throughout the course, opportunities to develop numeracy, network and to undertake personal development/ careers planning were embedded. Each week-long course incorporated 1 day of lab experience in industry undertaking molecular biology and immunoassay, gaining a practical understanding of GLP. Three days of practical experience at the university included cell culture, core laboratory skills, immunoassay and microscopy. The course culminated in 1 day of medicines regulation, governance and standards theory delivered by industry partners and the award of a certificate of completion.

The project was jointly developed before the impact of the COVID-19 was felt across the Higher Education and Life Sciences sectors. The pandemic necessarily constrained its delivery, delaying the first course until January 2022. Recruitment to the first course was limited to current students at this institution due to health and safety requirements at time. Participant numbers were limited to 24 (four groups of six participants) per course to ensure that labs and teaching spaces were COVID-19 compliant and the first cohort comprised current postgraduate or final year undergraduate students at the university because of the difficulty in releasing employed participants during a high demand period in 2022, and the buoyant employment market for recent graduates. In total, three courses were delivered in 2022 to 68 students from eleven universities and a local college, with recruitment supported by SULSA. Course tutors comprised fourteen members of staff working with our industry partner and eight academics who had either previously worked in industry or had recent experience in collaborative industry-relevant curriculum development. Tutor biographies were included in the participant handbook, and participants benefited from networking with tutors, hearing a number of different career paths involving the Life Sciences

TABLE 1 | Course evaluation including modified Careers Readiness Survey questions.

Question	Question type	Number of responses
What is your biggest learning point from the course?	Open ended	37
What action will you take as a result of the course?	Open ended	31
At the end of the course I feel	Sliding scale: strongly disagree- strongly agree	37
More Confident in the lab		
I understand more about how the Life Sciences Industry works		
I understand what roles might suit me in the Life Sciences Industry		
More able to apply for jobs in the Life Sciences Industry		
I have a clear plan of what to do next to achieve my career goals		
Tell us about your career plans	Sliding scale: strongly disagree- strongly agree	56
I have not decided what career I want to follow after my degree		
I have a career in mind but need to research it		
I have a career in mind but need some experience		
I feel ready to apply for a job		
I already have a job or further study ready		
I am interested in working in the Life Sciences Industry		

TABLE 2 | The ENU ATSTN Course met needs as described in the 2021 UK Cell and Gene Therapy Skills Demand Survey Report [2].

Need [2]	Precursor at ENU	Realisation	Legacy
Short training courses; Training programmes to "seed the market" with skills	Previous upskilling courses in laboratory skills and Quality Assurance and Regulatory Affairs; industry-relevant curriculum	3 × 1 week ATSTN courses	Incorporate content and learnings into curricula
Transparent schemes to get people into industry	industry-relevant curriculum, RSB accreditation (undergraduate)	Included 1x industry lab day and 1x industry theory day Certificate provided	Incorporate content and learnings into curricula
Increased number of free courses on Online Training Platform	SFC funded undergraduate degrees	Face to face course free at point of delivery to participants	Incorporate content and learnings into undergraduate (SFC funded) curricula
Identify and recognise transferable skills	Skills passport [9], RSB accreditation	Partnership approach to development, certificate	Continued RSB accreditation, dissemination of course content and outcomes, contribute to sector discussion on Graduate Readiness
Attracting people with potential	SFC funded undergraduate degrees	Recruitment of 65 students from 10 Scottish Universities	Incorporate content and learnings into undergraduate (SFC funded) curricula
Attracting people to work in Manufacturing and Quality roles and in Good Manufacturing Practice environments	Legacy content from Quality Assurance and Regulatory Affairs upskilling, relevant guest lecturer workshop in existing 4th year module	Inclusion of Quality content and case studies and networking with relevant role holders in course	Continuation of delivery of theory day after end of ATSTN course in addition to previous guest lecturer content
Creating an industry guidance board to assist outreach; Need to work as a community to share talent	Existing institutional Industry Advisory Group	SULSA Liaison for project	Institutional partnerships with industry; SULSA Skills committee for member university collaborations
Industry experience or relevant transferable skills	Industry-relevant curriculum, Skills passport [4], RSB accreditation	Included 1x industry lab day and 1x industry theory day	Institutional partnerships with industry; SULSA Skills committee for member university collaborations

Industry. Participants were encouraged to continue to network after the course via LinkedIn.

COURSE EVALUATION

The short courses achieved positive results in an evaluation administered via Mentimeter on the final day of the course (**Table 1**), with participants reporting an increased interest in working in industry and improved confidence in their practical skills as a result of the course. This was especially poignant given the context of delivering these courses during the COVID pandemic. The combination of laboratory skills training and industry partnership delivery and insights appeared to work well for the courses with "lab work," "people/networking" and "industry insights" ranking as the top three items participants enjoyed most about the week. Indeed, the biggest learning point from the course was "working in a regulated lab/industry standards," "lab skills/confidence" and "careers insights."

TABLE 3 | Life science industry-relevant skills accreditation for biomedical science or pharmaceutical sciences degrees.

Industry requirement	Requirement source	Accreditation framework (s)	Barriers and limitations	Solution
Core subject knowledge, e.g., physiology, cell and molecular biology, pharmacology, etc.	QAA Subject Benchmark [18, 23]	IBMS [20]; RSB [19]; APS [21]	N/A Universities are experienced in knowledge transmission	
Core professional skills, e.g., reflection, numeracy, critical, analytical, research, group work, etc.	QAA Subject Benchmark [5, 18, 23]	IBMS [20]; RSB [19]; APS [21]	Student skills and knowledge on entry	Integrated academic Skills support
Entrepreneurship	QAA Subject Benchmark [1, 16, 21](1)	RSB: an understanding of the interdisciplinary nature of enterprise [19]	Student skills and knowledge on entry	Integrated support from University Centres for Entrepreneurship
Digital Skills	[3, 23]		Student skills and knowledge on entry	Integrated academic Skills support
Laboratory skills	[23]	IBMS [20]; RSB [19]; APS [21]	Limited teaching lab space, growing student numbers. Access to applied knowledge, spaces and equipment	Blended approach using online simulations, VR and video: guest lecturers, pooled resources at Centre of Excellence for Skills and Training, Simulated Placements
Safe Working Practices, e.g., risk assessment	QAA Subject Benchmark [18]	IBMS [20]; APS [21]	N/A Universities are experienced in safe laboratory practice	
Applied Knowledge: Medicines Regulation, e.g., GxP; Governance and Standards	[3]	IBMS mentions GLP, compliance, governance and audit [20]; RSB mentions GLP and regulatory issues [19]; APS [21]	Academic skills and knowledge	Guest lecturers, central coordinated Centre of Excellence for Skills and Training, Simulated Placements
Placement/Industry Experience	QAA Subject Benchmark [18]	IBMS [20]; RSB mentions contextualised learning [19]; APS [21]	Industry capacity [7]	Industry Advisory Groups, Simulated Placements

Participants answered all questions positively from a modified careers readiness survey included in the evaluation [17], indicating a positive impact of the course on the participant's careers readiness. Many participants planned to continue their journey towards a career in the Life Sciences industry after the course through further research, training or job applications. This initiative met the following needs as described in the 2021 UK Cell and Gene Therapy Skills Demand Survey Report (**Table 2**, [2]).

Our students already benefit from the Skills Passport [9], which includes the introduction of GLP type activities early in their course and an emphasis on laboratory skills. However, the ATSTN courses provided valuable lab experience, having had reduced face-to face lab teaching during the pandemic (lab-based honours projects continued as usual), and reached participants beyond the university, leading to employment for some. As a legacy to the project, we are continuing to offer the industry lab and theory days to our students, and plan to add a clean room experience and networking opportunity with another industrial partner.

The strength of project was the continuation and deepening of collaborative partnerships between industry and academia in the design and delivery of the courses. This led to the establishment of the SULSA Skills Committee which continues to support collaboration on the skills agenda between member universities. However, despite the option to use pooled resource to work across companies being a theme across multiple respondents to the 2021 UK Cell and Gene Therapy Skills Demand Survey Report [2], which led to the ATSTN project, there are no plans to continue to fund collaboration between Scottish industry and academic partners in a sustained and coordinated way. This will severely limit the potential legacy of the project.

DISCUSSION

The ATSTN courses we led were a great success for participants, who received both industry experience and relevant skills training in line with the project aims (**Table 2**). Furthermore, the collaborating institutions also continue to benefit from the legacy of sustained curriculum development and partnership delivery (university partner) and employment of successful candidates (industry partners). One project aim was to establish an industry quality trademark to know "good" programmes. Although not established during the project, accreditation frameworks for degrees that incorporate aspects of this content already exist (**Table 3**). The requirement for grants to support social mobility through Equality, Diversion & Inclusion was also beyond the scope of our part of the project, however, Scottish universities continue to meet this aim via their SFC outcome agreements.

Accreditation

There remains an ongoing requirement to embed skills in undergraduate degrees to continue to improve graduate readiness, expanding the work we already undertake beyond our institution. To an extent, accreditation serves this purpose by setting skills and knowledge requirements for accredited degrees. We chose RSB accreditation because of the breadth of our provision and the explicit industry focus of the accreditation framework, which matched our own [5].

The Quality Assurance Agency (QAA) has published benchmark statements necessary for undergraduate Biomedical Science(s) programmes [18] and there exist three accreditation schemes in the UK for courses relevant to the life science industry. Most universities choose one or more aligned to their strategic aims and the needs of the degree. Each is different because of the professions they serve: the Royal Society of Biology (RSB) has the broadest and most flexible framework which aims to, among other things: "enhance competitiveness for students in a global jobs market; provide industry with an assurance of the level of employability skills and subject relevant bioscience skills provided by a programme; maintain and improve the UK's position as a premier location to develop the life scientists of the future" [19]. By contrast, the Institute of Biomedical Science (IBMS) accreditation aims to "meet the Health and Care Professions Council (HCPC) standards of proficiency for biomedical scientists" by ensuring that a degree course covers the academic components of these standards, with a further certificate of competence required to demonstrate an individual's full adherence with them [20]. The new Academy of Pharmaceutical Sciences (APS) Curriculum framework has been established to promote good practice in the training and development of pharmaceutical scientists and supports two of the APS strategic themes: "establishing and promoting the reputation of pharmaceutical sciences and scientists and promoting careers" [21]. However, this scheme seeks to accredit *pharmaceutical* sciences degrees with a minimum of 65% pharmaceutical content, which may be limiting for some university offers.

The core industry requirements (synthesised from [22–24] are mapped against each accreditation framework below (**Table 3**). This shows that the three schemes, although they each have a different emphasis, do fulfil most of these requirements, except for Digital Literacy, which was not mentioned explicitly in any of them. Unfortunately, despite the RSB scheme running for over 8 years now, and IBMS accreditation reaching back decades, industry still identified a requirement for a "quality trademark to know good programmes" offering core skills training in a recent survey [2]. Therefore, accreditation alone is unlikely to meet this need without better industry awareness of the underpinning frameworks and buy in for partnership delivery. We implement an enhanced accredited curriculum via a dedicated Professional Practice module and the Skills Passport [9]. In order to future-proof student learning in a rapidly changing landscape we prioritised student-focussed reflection, core skills such as problem solving and laboratory skills, and flexibility over competency-based assessment [5, 8]. However, there is an ongoing requirement for collaboration to continue to meet employer needs and core curriculum changes which we manage through our Industry Advisory Group and guest lecturers. A more sustainable solution with impact beyond this institution may be found by supplementing accreditation through future partnership work to develop a competency framework linked to core skills, knowledge and behaviours, via a regional coordinated Skills and Training Centres of Excellence, delivered through simulated placements assessed by industry.

Industry Experience and Relevant Skills

A 1 week upskilling course cannot meet all the needs of students and demands of a growing industry [5], serving only as an introduction to relevant specialist skills and experience for a limited number of participants. The 1 day industry lab experience was prized by all involved, but was no substitute for a longer, more immersive industry placement that would have consolidated and strengthened industry-relevant skills and behaviours, something that is desirable but generally lacking in degrees [7]. Unfortunately, life science placements and internships are expensive and do not meet demand, with 697 provided in total in 2022 across the UK, almost double 2009 levels [25], fewer than the number of Biomedical Sciences graduates Scotland alone produce in a year. These workplace experiences are also vulnerable to economic impacts, affecting reliability and sustainability: "When you build a skills system that relies heavily on employers being able to offer jobs or placements, then what happens at the point where employer capability to do that reduces, say in a recession, when you have more young people wanting to take those opportunities?" [7].

Given that industry placements and upskilling initiatives reach limited numbers of individuals, an alternative must be sought. Indeed, the Quality Assurance Agency states the following in its Benchmark Statement: "2.17 Courses should work with relevant stakeholders to incorporate work-based or work-like learning where possible. Enhancing student employability is a fundamental outcome for Biomedical Science and/or Biomedical Sciences courses. Therefore, engagement with the relevant employment sectors should be extensive. The courses should have a clear strategy for students to have the opportunity to develop employment-focused skills and engage with employers. Students may engage with employers through paid and/or unpaid placements of various durations during which students will be fully immersed in the workplace and experience the day-to-day routine of employment" [18]. A centralised work-like training offer may be one solution to this persistent issue.

Centralised Life Sciences Skills and Training

Life sciences research and innovation has received sustained funding and contributes to the success of the sector in Scotland, the subject of a number of recent reports [1, 3, 24, 26]. Close links and partnership working between the private sector, NHS Scotland and University research have been central to the strength and growth of the sector [1], and there is a similar, unmet, requirement for coordinated partnerships and activities to grow skills training that would reach more people to meet demand in Scotland [24].

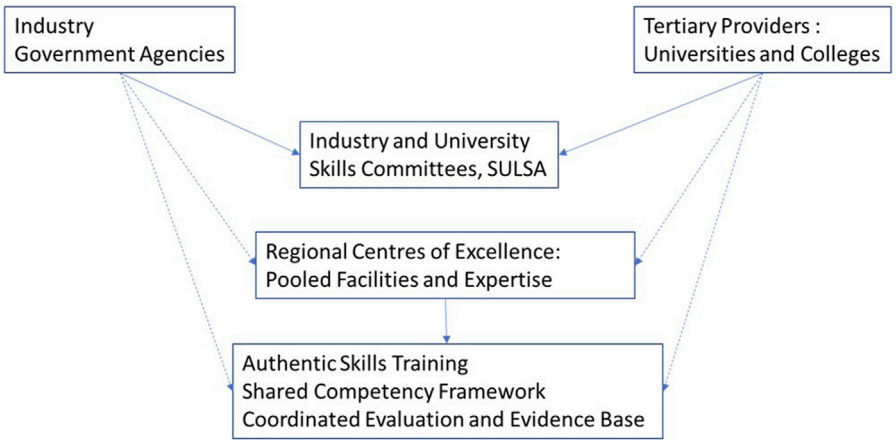

FIGURE 2 | Regional Centres of Excellence would bring together stakeholders in Scotland in a strategic, efficient and sustainable way to properly support partnerships and realise the potential to meet workforce requirements. Skills committees (solid arrows) are now in place, with SULSA playing a strategic role in bringing together stakeholders. In the future, Regional Centres of Excellence could act as a focal point for pooling facilities and expertise, leading to a more impactful skills offer through shared training, curriculum and evaluation (dotted arrows).

The ATSTN initiative went some way to deliver its upskilling aims, although growing demand will not be met without sustainably scaling up life sciences skills training in Scotland [2]. Indeed, not much has changed in over a decade with regards to the training approach, a mixture of upskilling and degree content [22]. Scaling up training will require radically changing the model away from limited institution-level partnerships towards more centralised, strategic pooling amongst key stakeholders. This would allow many universities to work together with colleges, industry and government agencies to incorporate industry-informed skills training and experiences into their degrees whilst contributing their research, learning and teaching expertise. Given the complicated stakeholder landscape in Scotland, sustained and strategic collaboration between colleges and universities, industry and government agencies to inform and develop curriculum is difficult. Indeed, the option to use pooled resource to work across companies was a theme across multiple respondents to the 2021 UK Cell and Gene Therapy Skills Demand Survey [2]. These partnerships can be difficult for individual universities to resource, with industry struggling to meet demand from multiple sources. Although a national skills committee for industry has been established for some time, its university equivalent has only recently been put in place, supported by SULSA. These now require support for strategic collaboration to unleash the potential for more efficient, transformative partnership working. Furthermore, mirroring the National Horizons Centre in England, regional Life Science Skills and Training Centres of Excellence in Scotland would be required in order to maintain competitiveness north of the border. This would also support collaboration between the various SFC-funded providers, including universities, meeting a recent SFC strategic requirement for sector collaboration and consolidation [12].

This requirement for supported collaboration is doubly important because life sciences is different to the professions such as law, teaching, nursing and medicine, and the arts where teaching and practice are integrated. Most academics responsible for developing and teaching life science courses have a research or clinical background and lack recent industry skills and experience required to design and deliver applied/industry-relevant content. Therefore, if teaching is to be relevant to cutting edge applications with up to date, context-dependent materials, sustained partnership working with industry is required. Collaboration via regional Life Science Skills and Training Centres of Excellence offering full access to industry experience and relevant skills training, together with the implementation of a relevant competency-based curriculum/accreditation framework for degrees would be a fruitful area for future development that would meet market demand for skills and support growth of the sector.

Regional Centres of Excellence would bring together stakeholders in Scotland in a strategic, efficient and sustainable way to properly support partnerships and realise the potential to meet workforce requirements. This would also continue to improve harmonisation and access to meet skills demand, and the need to work as a community to share talent [24]. Regional Centres of Excellence could provide an environment where placements could take place in an authentic space co-designed with industry partners, using skills training competencies and equipment developed in partnership, assessed by industry trainers and acknowledged in university degree structures (**Figure 2**). Innovations such as blended learning and virtual reality could be incorporated to maximise the benefit of the practical training and experience, contextualised by industry-relevant scenarios. Cell and gene therapy is only one application for life science skills training provided by university degrees. There is high export-growth potential in: Precision medicine; Regenerative medicine and tissue repair; Preclinical drug development; Clinical trials and preclinical services; Biopharmaceutical safety testing; Specialist and high value

manufacturing and Regulatory support applications [1], so the option to vary the context should be borne in mind as the context for core skills training with some flexibility around specialist laboratory skills is likely to continue to change. This "simulated placement experience" is a recommended area for future work.

RECOMMENDATIONS AND FUTURE DIRECTIONS

The ATSTN project serves as an instrumental case study demonstrating the mutual benefits to biomedical science graduates and the Life Science Industry of continued collaboration between academia and industry to develop and embed relevant skills training into their curriculum. To date there has been no initiative to scale up this type of life sciences skills provision in a sustainable way to support the strategic growth of the sector in Scotland. This is due to a number of barriers, as outlined above. A summary of recommendations that would mitigate these barriers and support growth in industry-relevant life science skills training is found below:

1. Support and strengthen collaboration between national Industry and University Skills Committees.
2. Establish regional Life Science Skills and Training Centres of Excellence to coordinate academia-industry collaborative life science skills provision and host an authentic industry designed environment.
3. Develop, implement and evaluate an authentic Simulated Placement offer based on industry-relevant competencies and behaviours assessed by industry partners to be delivered at the central space.
4. Encourage industry engagement with and recognition of accreditation as a means to identify high quality courses.

These recommendations require sustained investment, and would be designed to be flexible and applicable to the emerging specialties in the sector. This investment would also incentivise universities to take part where competing strategic priorities currently temper engagement. Partnership working between academia and industry will remain a high priority with universities contributing research and teaching expertise for curriculum/model development to ensure effective and evidence-based interventions, whilst industry contribute context-dependent expertise and materials. Building in evaluation of outcomes would ensure that the value of any intervention is measured and disseminated for long term impact.

LIMITATIONS

The paper focuses on a single Scottish University and upskilling course as an instrumental case study [10]. By definition, this is a case chosen to illuminate a particular issue, here the issue is the present limitations of the life sciences skills training model in Scotland. It is appreciated that other Scottish and UK providers are also working in this space, and they will likely recognise the challenges outlined.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

CONFLICT OF INTEREST

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ACKNOWLEDGMENTS

The author wishes to thank the following individuals for their contribution to the design and implementation of the ATSTN course and the Skills Passport: John Cook, Samantha Campbell Casey, Janis MacCallum, Amy Dillon, Gemma Hunter, Nathan Barnett, George Chambers Samantha Donnellan, Sharron Vass, Catharina Alam, Giacomo Russo. The Cell and Gene Therapy Catapult are also thanked for funding the described upskilling initiative. The study was not funded as part of the initiative.

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ORIGINAL RESEARCH
published: 21 August 2023
doi: 10.3389/bjbs.2023.11561

Non-Laboratory Project-Based Learning for Final Year Bioscience Students: Lessons From COVID-19

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Background: Provision of "dry-lab" final year honours projects, based outside the laboratory, have been proposed as a viable alternative to traditional "wet-lab" projects in bioscience subjects, but their value has not been widely evaluated to date. In 2020–21, the COVID-19 pandemic meant all students in the School of Biomedical Sciences at Ulster University (UU) undertook dry-lab projects, due to campus lockdown. Therefore, this provided an ideal opportunity to evaluate the provision of dry-lab projects in a large student cohort.

Methods: A pilot group of final year students (n = 4) studying Biomedical Science at UU were interviewed to evaluate their experience of conducting a dry-lab project. This evaluation and the themes that emerged were subsequently used to inform the co-creation of a survey to appraise student experience of dry-lab research project learning across the final year student cohort in School of Biomedical Sciences (n = 140). Quantitative and qualitative data was collected and analysed for trends and themes.

Results: The results of this project identified four main themes related to dry-lab projects; expectations, skills & employability, quality of experience and choice. Student expectations about dry-lab projects were not dramatically changed, although initial negative opinions of some individuals were over-turned. Most students recognised that they had developed many useful employability skills through dry-lab projects, although lack of practical laboratory experience was still perceived as a drawback. Student experience was influenced by personal circumstances but students reporting poor project experience had significantly lower levels of communication with supervisor ($p < 0.05$). Most students agreed that choice of dry- and wet-lab projects would be valuable for future cohorts.

Conclusion: This report concludes that dry-lab project provision can be a suitable and equitable alternative for wet-lab projects. Dry-lab projects can be valuable for learning new skills and may be an attractive option for some students and supervisors who prefer to work outside the laboratory setting. A choice of both dry-lab and wet-lab projects is highly recommended as it provides more choice for students to tailor their final year experience to their individual circumstances, strengths and future career aspirations.

Keywords: COVID-19, honours project, wet-lab, dry-lab, bioscience

OPEN ACCESS

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Received: *10 May 2023*
Accepted: *21 July 2023*
Published: *21 August 2023*

Citation:
McKenna DJ (2023) Non-Laboratory Project-Based Learning for Final Year Bioscience Students: Lessons From COVID-19. Br J Biomed Sci 80:11561. doi: 10.3389/bjbs.2023.11561

INTRODUCTION

In UK higher education, the final year honours project is a highly valued component of the university degree, representing a "gold-standard" stamp of academic excellence that provides students with important research skillsets for employment after graduation [1]. In Science, Technology, Engineering and Maths (STEM) subject areas, it is typical that project-based learning in the final year of a science degree is a laboratory-based experience (colloquially known as "wet-lab"). However, this traditional arrangement has been challenged in recent years, with many universities producing evidence to illustrate that students can benefit equally from "dry-lab" science projects based outside the laboratory [2, 3].

This is a welcome development which helps overturn the stereotypical view of the scientist [4]. Scientists in the workplace will spend much of their time writing, interpreting data, communicating science and working at computers, in addition to laboratory bench work. Since employability and workforce readiness are integrated concepts in many University science degrees, it is therefore appropriate that students have the option to develop these extra non-laboratory skills by providing a more diverse range of projects at final year, including dry-lab projects. Such projects could be data-analysis, computational projects, systematic reviews, meta-analyses or tailored presentations [5]. However, there is an understandable reluctance by educators to change from "tried-and-tested" laboratory-based approaches that have worked successfully in the past, not least because there is evidence that science students do not consider dry-lab projects to be as worthwhile as wet-lab experiences [6]. The challenge for our School of Biomedical Sciences at UU, similar to departments in other institutes, is to change preconceptions and expectations about dry-lab projects amongst both students and educators.

It is important this challenge is addressed, because various academic, economic and pedagogic factors mean that project-based learning practices must undergo significant revision to create a sustainable, inclusive model of final year research project provision for future cohorts of students. For example, as student numbers increase in UK higher education, there is increasing financial pressure on universities to provide relevant wet-lab projects in suitably equipped environments [7]. Hence, as student numbers increase, dry-lab projects are a more financially viable option and have the extra benefit of being more environmentally friendly. Moreover, providing a dry-lab project workflow will allow students to work through project activities in a virtual environment in their own time without the need for a supervisor in attendance and without having to access to laboratories facilities at scheduled times. Employed properly, the dry-lab project can therefore be more efficient in terms of organisation, time-commitment and availability of those involved [8]. Furthermore, increased student recruitment to distance-learning courses means that provision of dry-lab projects will need to become more common. Indeed, the importance of the "remote laboratory" in STEM-related education has been identified as a key resource in promoting internationalization, as well as access to education for traditionally underrepresented groups [9]. This will also be attractive to students who find wet-lab project provision problematic because of circumstances that make it difficult for them to attend laboratories in person. Dry-lab projects may well be a more attractive option for students in this position and would address inclusivity and accessibility issues in the process [10]. Importantly, this also has value beyond Biomedical Sciences, since many other science disciplines are facing similar pressures, so case studies of successful dry-lab projects will be very important for inspiring and motivating colleagues to develop their own projects [3].

For change to happen, however, evaluation is needed to demonstrate the value of this type of project. This is very achievable, since dry-lab research projects in science is not a new idea [7]. Indeed, there are many examples of free and commercial resources that are available to educators to help virtual teaching [11]. However, there is still a need to robustly evidence that such approaches are fit-for-purpose, both in terms of pedagogy and value to stakeholders. At UU, the disruption caused by the COVID-19 pandemic in 2020 ended up providing an ideal opportunity to do this, since all students in the School of Biomedical Sciences in the academic year 2020–21 undertook dry-lab projects as laboratory access was prohibited. Therefore, this review describes a project that was developed to evaluate alternative options to traditional laboratory-based projects.

METHODS

Participants

A pilot group of four final year students studying BSc (Hons) Biomedical Science were randomly assigned to complete a dry-lab research project under the supervision of principal investigator (PI). The students and PI collaborated to apply their personal experience of this type of project-based learning to the co-development of a survey which would subsequently evaluate the student experience of dry-lab research project learning across the entire final year cohort in School of Biomedical Sciences. The pilot group took part in focus groups and the themes identified were embedded into the survey design exploring the student experience of dry-lab project-based learning. The survey was released to all final year students in the School of Biomedical Sciences, who were all undertaking some form of dry-lab research project. The data collected from this survey (n = 140 respondents) provided important quantitative and qualitative baseline data from the year group for further evaluation.

Ethics

Ethical implications for the project were also considered carefully and approval granted by Centre for Higher Education Research and Practice (CHERP) at UU (Ref:CHERP-20-001). Students in the pilot group were provided with a Participant Information sheet about the project, explaining (i) how their feedback may be used and (ii) that their decision to partake (or not) will have no impact on the support they receive during their project. For the wider survey of the entire final year student cohort, students were again under no obligation to complete the questionnaire. Completion of questionnaire implied consent, but no student

was penalised for opting out. All responses were anonymised and responses collected were held confidentially by the primary researcher under password protected access.

Evaluation Design and Justification

Evaluation for this project was based upon scrutiny of the quantitative and qualitative data collected via the tools and approaches below. Throughout, the project aimed to align with guidance provided through the UU's Strategy for Learning and Teaching Enhancement (SLaTE) [12].

Peer-led focus groups were held to evaluate and discuss project direction. This type of collaborative learning was deemed appropriate for students to become actively involved in shaping education experience for their peers [13]. Indeed student-staff partnerships are an increasingly important part of Higher Education, offering much scope for innovative pedagogic practice [14]. The student input is integral to changes in curriculum, and this type of partnership helps the case for students as agents of change [15]. Importantly, in terms of manging power imbalance and possible bias, students were made aware that these focus groups were not linked to the assessment of their work. Instead, they understood that they were invited to collaborate in co-developing the nature of the survey for the wider cohort of students, by recommending questions/themes that would provide information they would like to know.

Semi-structured interviews were employed as a qualitative research method which can explore deeper opinions about a given topic [16]. In this project, semi-structured interviews were conducted with the sub-group of four students. To avoid possibility of power bias, these were conducted by a colleague of the PI. There are drawbacks to semi-structured interviews, since they are time-consuming and it is difficult to canvas large numbers, so there may not be sufficient data to inform meaningful analysis [17]. Nevertheless, they were very suitable for this project as one element of a mixed methods data collection, from which themes could be extracted and explored further in a larger cohort via a bespoke survey.

Student surveys are a long-accepted method for collecting feedback from students on education experience. However, they must be properly designed and conducted to ensure useful data is collected [18]. That is why it was important that the finalised set of survey questions for this project was informed by the focus-groups mentioned above and by informal discussions with colleagues. Survey responses provided information on how students felt about the project-based learning, skills accrued, support they received and how they feel they met learning outcomes, in order to provide a rich source of qualitative and quantitative data to robustly evaluate student experience of dry-lab projects.

Data Collection and Analysis Procedures

Data collection was managed using REDCap electronic data capture tools hosted at UU. REDCap (Research Electronic Data Capture) is a secure, web-based software platform designed to support data capture for research studies [19]. It provides 1) an intuitive interface for validated data capture; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for data integration and interoperability with external sources.

Results were a 'mixed methods' combination of qualitative and quantitative data, gathered from the methodologies listed above. Together these combine to inform a grounded theory approach to the project [20]. Rather than being entirely linear, this allowed for some flexibility, adapting approaches in response to both the data collected and surrounding discussions. Quantitative data was provided through the 'scored' questions on the bespoke survey issued to students (i.e., where a rating is selected against a question). This data was presented to allow comparisons of answers from linked questions where appropriate. This helped visualise any changes in responses which might have occurred by the experience of undertaking a dry-lab project. Statistical significance was assessed by paired *t*-test with data considered significant where $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. Qualitative data was collected from the focus group, semi-structured interview and from open questions on the bespoke survey. This data was reviewed and analysed for thematic content by a six-step process [21, 22]. The grounded theory approach helped evaluate how the findings can be used to potentially inform further data analysis in future. The final structure of the reporting was informed by guidance about aligning outcomes with objectives [23].

Reflective Practice

The collection and analysis of data was informed throughout this project by collegial discussions with colleagues, including course directors, final year project module coordinators and other colleagues. To capture the formative ideas that arose from these discussions, and the journey of the primary researcher through the process, a reflective journal of notes was kept throughout the process [24]. This captured evolving perceptions, project progress, key decisions and personal reflections on the transformative experience of doing the project and learning new research approaches (particularly analysis of qualitative data). This reflection in turn influenced the critical thinking within the discussion below.

RESULTS AND DISCUSSION

Pilot Group Results

The pilot group of students ($n = 4$) in this project were placed in the subject area of genetic medicine, therefore bioinformatic analysis was adopted as the basis for a dry-lab project, since it aligns with wider advances in cancer research and analyses of health-related patient data [25, 26]. A project was therefore designed which would substitute traditional wet-lab activities with computer-based ones, while remaining focused on the area of genetic medicine.

The value of this approach was then evaluated through focus groups and semi-structured interviews, which would be used to inform and co-develop the survey for canvassing the experience of the wider student cohort. This idea of student as partner or

TABLE 1 | Summary of responses collected from focus groups and semi-structured interview(s) with Pilot student group, including identification of key themes.

Area of discussion	Summary of responses	Theme identified
Defining dry-lab science projects (prior knowledge, experience & expectations)	• Didn't know what to expect in general • Had heard term "dry-lab," did not know what it meant • Won't get the same skill as in wet lab • Not the skills needed for job • No chance to develop new techniques • Wet lab experience can help understand the work better (learning by doing) • Wouldn't be in the lab, all computer based • Might be disadvantaged to other years, may not get the same experience in comparison to wet lab • More flexibility (time and travel)	Expectations
Expertise Gained (skills, transferable knowledge)	• learned more skills (bioinformatics, online and computer skills) than were not expected • Been looking at job applications and they are asking for IT skills • As they are new and transferable skills, I believe I have more to put on the table in a job • Employers are looking for bioinformatic skills	Skills & Employability
Advantages & Disadvantages	• Surprised on how different the experience was compared to expectation • A lot less stressful than expected • Things ran smoother than expected, got results easier without much waiting • Some challenges in communications as it relied on emailing back and forth rather than being beside someone to point things out • Been enjoyable, flexible • No standing around • It worked a lot better than expected	Student Experience
Recommendations	• would be happy doing dry lab again • Yes if the supervisor is like is good at responding to emails and communication; no if the supervisor is not a good communicator • Depends on supervisor • Depends on flexibility for individual student	Choice

'producer' encourages collaborative relations between student and academic to generate knowledge [27]. The analysis of this information revealed four main themes, which are summarised and itemised in **Table 1** below.

These reveal that students really did not know what to expect about a dry-lab project, principally because they had little exposure to, or awareness of, what it might constitute. One student statement summed up the apprehension in the pilot group about studying outside a laboratory;

> "Prior to starting my project, I was sceptical as to how a dry lab project would be carried out and if it would be just as beneficial as doing a wet lab-based project."

In terms of skills, there was a fear that lack of laboratory skills would be a drawback, although once the project progressed, students became more aware of the variety of skills being accrued, including digital skills which employers might particularly value, as articulated by one student;

> "Throughout my project I have learnt so many new skills that I did not expect to learn while doing a dry lab project. I believe I have a good understanding of bioinformatics and also really have improved my IT skills, this is so beneficial when applying for jobs as I have found these skills to be very important to employers."

Student experience naturally included some negative and positive aspects, although there was a general acceptance in this small group that there was increased flexibility and less stress than expected;

> "A benefit of this being a 'dry-lab' project was the flexibility around planning time for this project, studying for other modules and my part-time job."

Perhaps most tellingly, there was a general consensus that preconceptions about dry-lab projects had been somewhat overturned, with acknowledgement that it would be acceptable choice in future;

> "I used to think I was a very hands on learner and would not be able to learn anything from a computer screen rather than real life however this year has definitely changed my opinion of online learning and wet lab projects."
>
> "I do not feel disadvantaged using this experience versus a 'wet-lab' final year project experience. I would definitely recommend a 'dry-lab' based project to others."

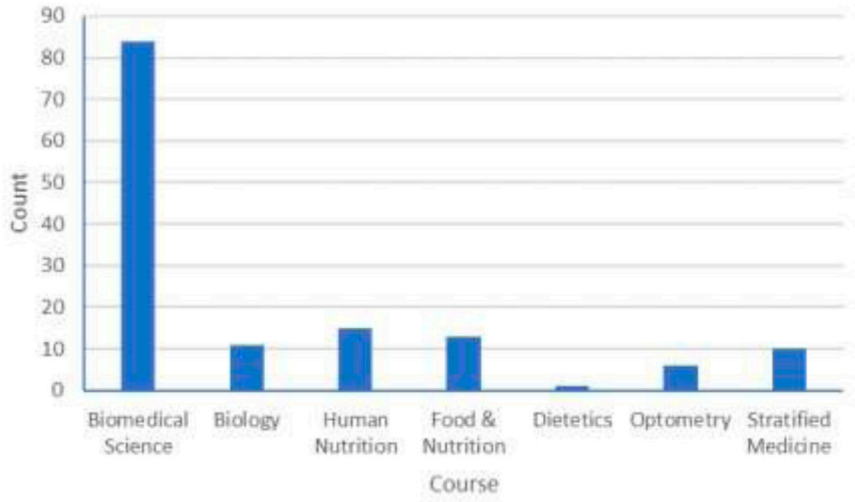

FIGURE 1 | Number of respondents from each of the seven courses in School of Biomedical Sciences. [Data: (No. of responses, % of survey respondents): Biomedical Science (84, 60.0%), Biology (11, 7.9%), Human Nutrition (15, 10.7%), Food & Nutrition (13, 9.3%), Dietetics (1, 0.7%), Optometry (6, 4.3%), Stratified Medicine (10, 7.1%)].

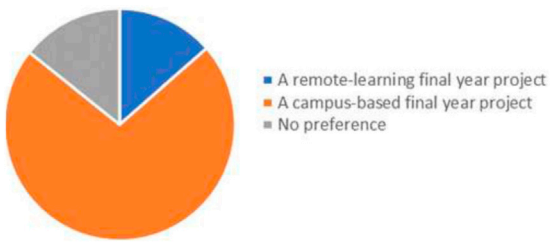

FIGURE 2 | Comparison of student preference for remote-learning (dry-lab) or campus-based (wet-lab) final year project. [Data: A remote-learning final year project (19, 13.6%), A campus-based final year project (101, 72.1%), No preference (20, 14.3%)].

However, it was pointed out that the role of the supervisor, especially in communicating effectively throughout, would be paramount in ensuring a good overall experience. The themes identified in **Table 1** were then discussed further with the pilot group of students to co-develop the survey design for further exploration and validation. The focus was on asking questions which would determine if the experiences and opinions of the pilot group were matched across the entire cohort of final year students. As a result, the final survey was designed to incorporate four sections, each aligned with a different theme as shown in **Table 1**. The survey was released to all final year students and the data collected is presented and discussed below.

Overall Student Survey Results

The survey results were collected and analysed for both overall trends and thematic content. A total of 283 final year students from 7 different courses were contacted on 3 occasions over a 3-week period following completion of their projects in May 2021. 140 responses (49.5%) were received, primarily from the Biomedical Science course, which was not unexpected as it consists of 3 separate cohorts and has about four times as many students as each of the other courses (**Figure 1**).

The data collected from the other questions in the survey were analysed and have been presented below against the four themes identified in **Table 1** for ease of understanding and discussion.

Expectations

It was not surprising to learn that a substantial number of students preferred to do a wet-lab one when they were asked to reflect on their preconceptions about dry-lab projects at the start of the year (**Figure 2**). This confirmed data from elsewhere which found similar attitudes among students [6, 28]. Although this question depended on students recalling how they felt several months before survey was completed, it is still likely to be a true reflection of the apprehension about dry-lab projects which was also apparent in the pilot group of students. This is linked to a lack of knowledge about what constitutes a dry-lab project, which is understandable since exposure to this type of project is limited in undergraduate degrees [3]. The more pertinent question was whether the experience of undertaking a dry-lab project would change that preconception.

To explore this further, the students were asked if they were satisfied that doing a remote-learning project was a suitable replacement for doing a campus-based project, but were also challenged to consider if their opinion had changed from initial expectations by the end of the project. **Figure 3** shows a comparison between the answers before their individual project began and after it was completed.

Again, this question depended on students recalling how they felt at the start of the project so we must be cautious about the interpretation of this data. The graph only shows overall numbers and does not compare how individual students voted before and

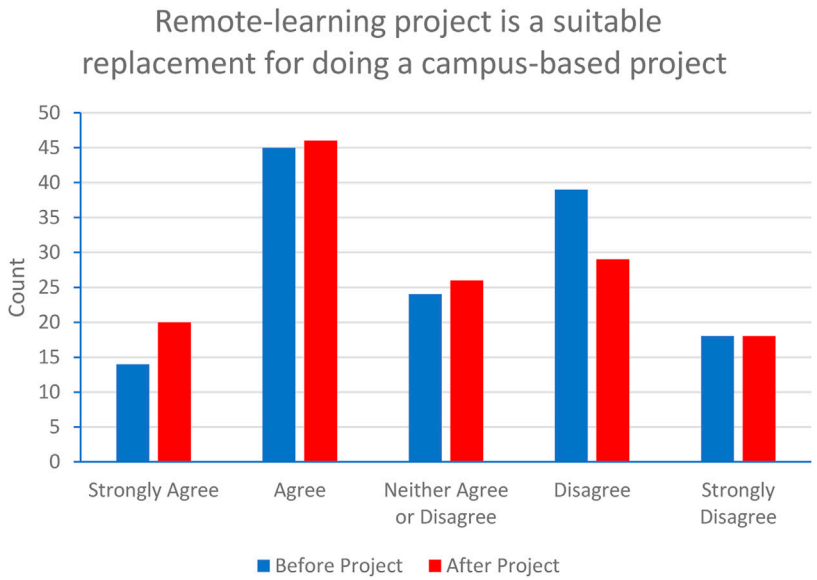

FIGURE 3 | Student opinion, before and after project completion, on whether a remote-based project was suitable replacement for campus-based project.

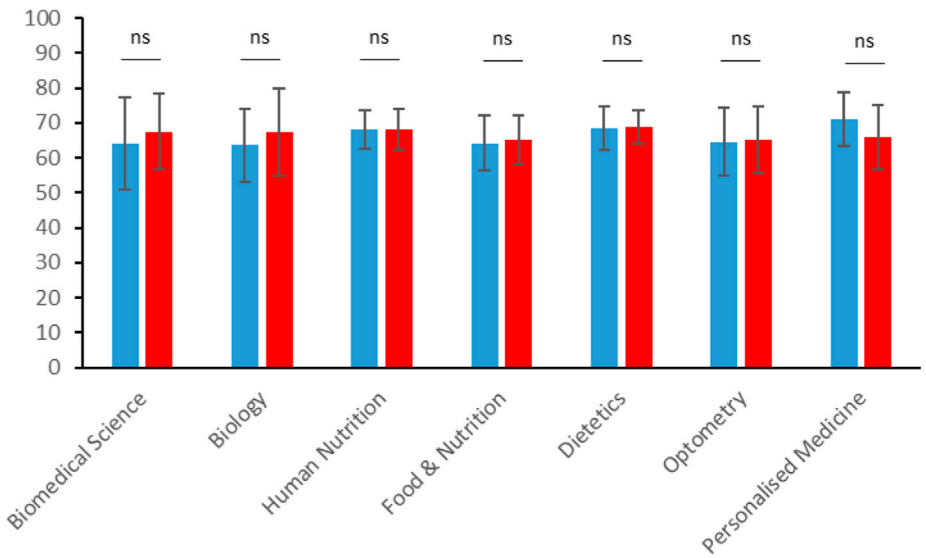

FIGURE 4 | Average scores for dry-lab projects in 2020–21 (red bars) were not significantly different from average scores for wet-lab projects provided in 2019–20 (blue bars) in any of the courses (Data shown is Mean ± SD. Student's t-test; ns, non-significant).

after project completion. However, more nuanced information can be found in the analysis of the qualitative data about how expectations were challenged and, in some cases, overturned. The reflective quotes from one student illustrates how the experience of dry-lab projects changed their opinion;

> "Before starting the investigative project, I was concerned about it being a dry lab experiment. I wanted to get the best grade possible and was not sure this was going to be possible without being in a lab doing the experimental work myself as well as having the supervisor present."
>
> "Now that I have completed my project I would recommend a dry lab project to everyone after understanding all the skills I have gained this past academic year that I would not have been able to gain while doing a wet lab experiment."

Importantly, the dry-lab project provision did not significantly impact on the average marks for each of the 7 courses across the

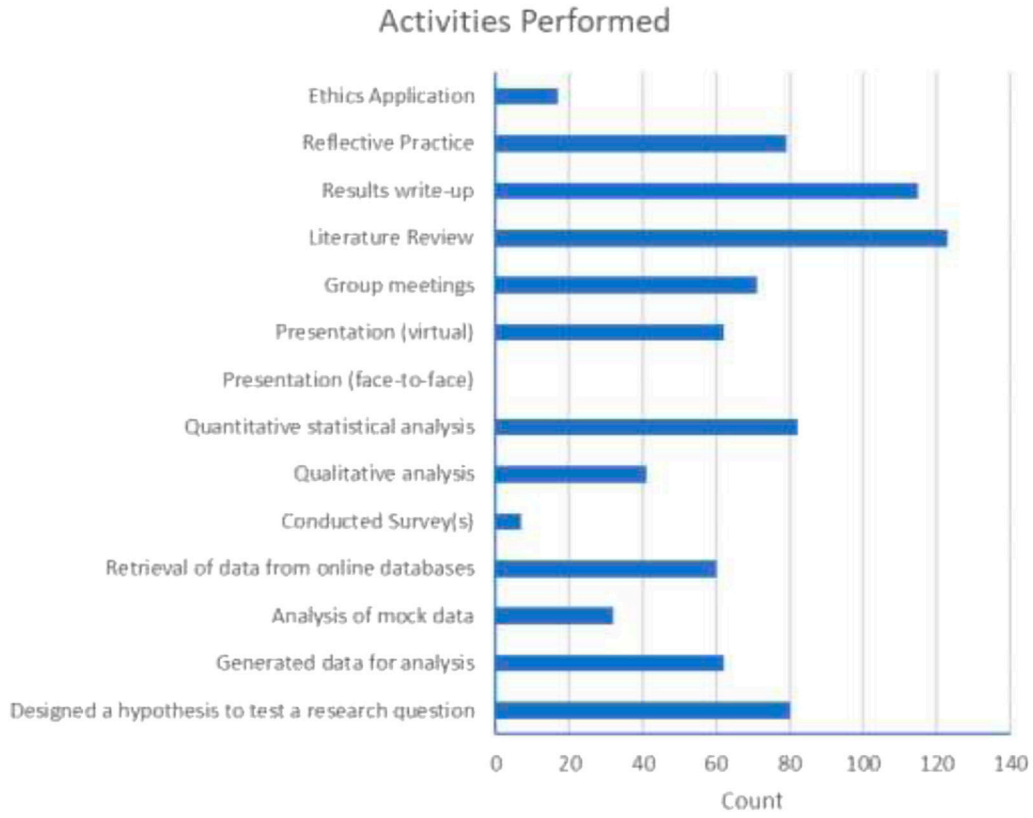

FIGURE 5 | Activities identified by students as having been undertaken in their dry-lab projects.

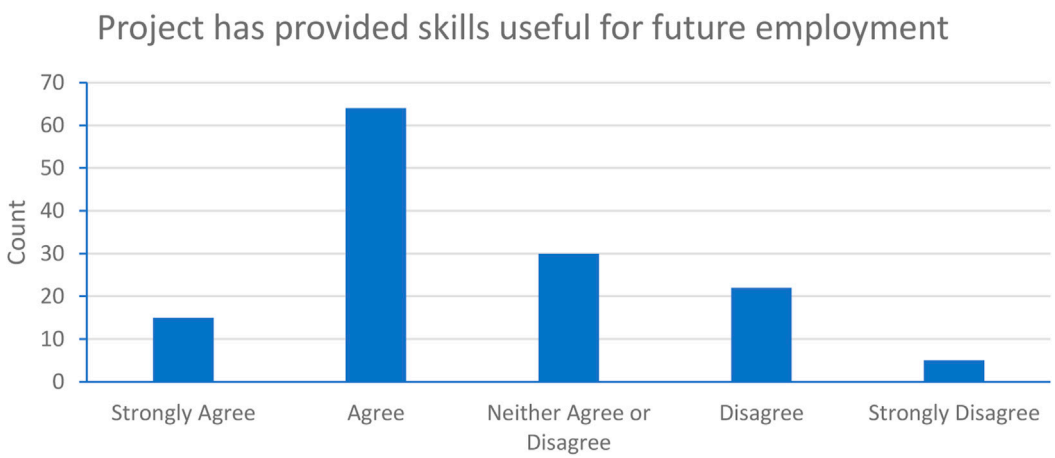

FIGURE 6 | Student opinion on whether dry-lab projects would be useful for employability. The majority of students either strongly agreed (15, 11.0%) or agreed (64, 47.1%) that this was the case. [Other Data: Neither Agree or disagree (30, 22.1%), Disagree (22, 16.2%), Strongly disagree (5, 3.7%)].

School (**Figure 4**). This demonstrates that the learning outcomes for the final year project modules can be met by dry-lab project provision and that students do not experience a grading advantage or disadvantage from this type of project. This is important if a choice of dry- and wet-lab projects are to be offered together in future, so one option is not seen as academically "easier."

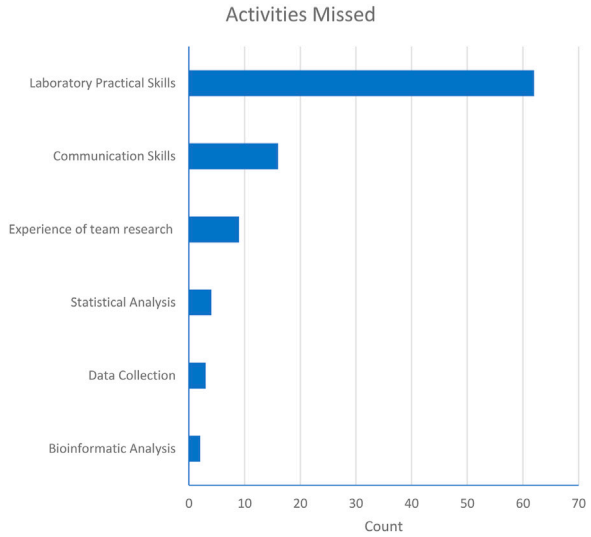

FIGURE 7 | Activities not experienced by students during dry-lab projects indicating clearly that lack of practical laboratory experiences was undoubtedly recognised as a deficit.

Skills and Employability

The pilot group of students felt it was important that the survey gave their peers the opportunity to identify and confirm what activities they performed during their project, so that they could appreciate the scientific skills they were accruing. As **Figure 5** below shows, students undertook a wide range of different methodologies, analyses and presentation approaches across the various dry-lab projects. This emphasises that laboratory activities constitute only one element of science projects, so dry-lab projects can effectively provide experiences in many other important science skills.

This type of data is valuable because it allows educators to demonstrate to students that these are skills that employers in the Life Sciences sector (and beyond) value in graduates and prospective employees [29]. Encouragingly, the majority of students (58.1%) did recognise that their dry-lab project experience had provided them with skills that will be useful in future employment (**Figure 6**).

This is important for students to realise and to be able to articulate in future job applications and interviews, since work-based projects in the Life Sciences sector will involve a blend of hands-on practical skills with digital literacy and computational acumen [30]. In a typical bioscience degree, most students will already have significant wet-lab practical skills from modules completed in Year 1 and Year 2 of their degree, while a significant proportion of them will also have gained working laboratory experience in their placement year. What they may not have gained is exposure to the non-laboratory skills which are equally important in science-related jobs. Dry-lab projects therefore offer the chance for students to complement their laboratory experimental skills with digital experimental skills [31]. In this cohort of respondents, there did appear to be general acknowledgement of this fact.

However, dry-lab projects simply cannot substitute every aspect of the wet-lab experience, so it was not surprising to find that students clearly recognised they had missed out on exposure to laboratory skills at Level 6 (**Figure 7**).

It therefore seems sensible that the optimal final year project would have a blended approach, allowing students to get both hands-on laboratory exposure and digital familiarity so they can build a broad base of demonstrable skillsets. Key to this is variety and choice of project, which is discussed further below.

Experience

The student experience of dry-lab projects was captured in terms of elements which students identified as being advantages or disadvantages (**Figures 8A, B**). Of course, the wider context of the pandemic is an important factor to consider in reviewing this data, but it should still provide some insight into the aspects of dry-lab project provision which students found beneficial or not.

Interestingly, elements which some students considered appealing were considered drawbacks by other students, illustrated by the two contrasting quotes below.

> **Positive:** "We had flexibility of working times, additional time available by not having to travel to campus and plenty of support."
>
> **Negative:** "Some students may find it useful to work from home but personally I felt at a huge disadvantage. I struggle to work from home and concentrate."

This again emphasises the diversity which exists within the student cohort in terms of personalities, preferences, responsibilities and requirements. It therefore follows that improved variety and choice of final year projects will be welcomed by students who want a project which best fits their personal circumstances.

However, one key aspect (not explicitly shown in **Figure 8** above) which shaped the experience of the dry-lab project was linked to the relationship between student and supervisor. Whilst this has always been the case for any research project [32], it appears to be even more essential when the communication is primarily through virtual means, as it has been for the past year. **Figure 9** below shows the data collected for contact frequency and type of contact between student and supervisor. "Meet" indicated synchronous meetings, typically by virtual tools such as Zoom. "Communicate" mostly referred to asynchronous contact, such as email.

Regardless of the type of contact, the frequency of communication was very important in making sure students felt supported and guided through their project. This is even more important in dry-lab projects, since students on-campus will usually have interactions in person with other laboratory members and researchers besides their supervisor. In home-based dry-lab projects, they are more reliant on supervisor alone, with even the normal interactions with fellow students more limited than usual. It follows that student who had less overall communication with supervisors were the ones who reported a poor or very poor experience (**Figure 10**).

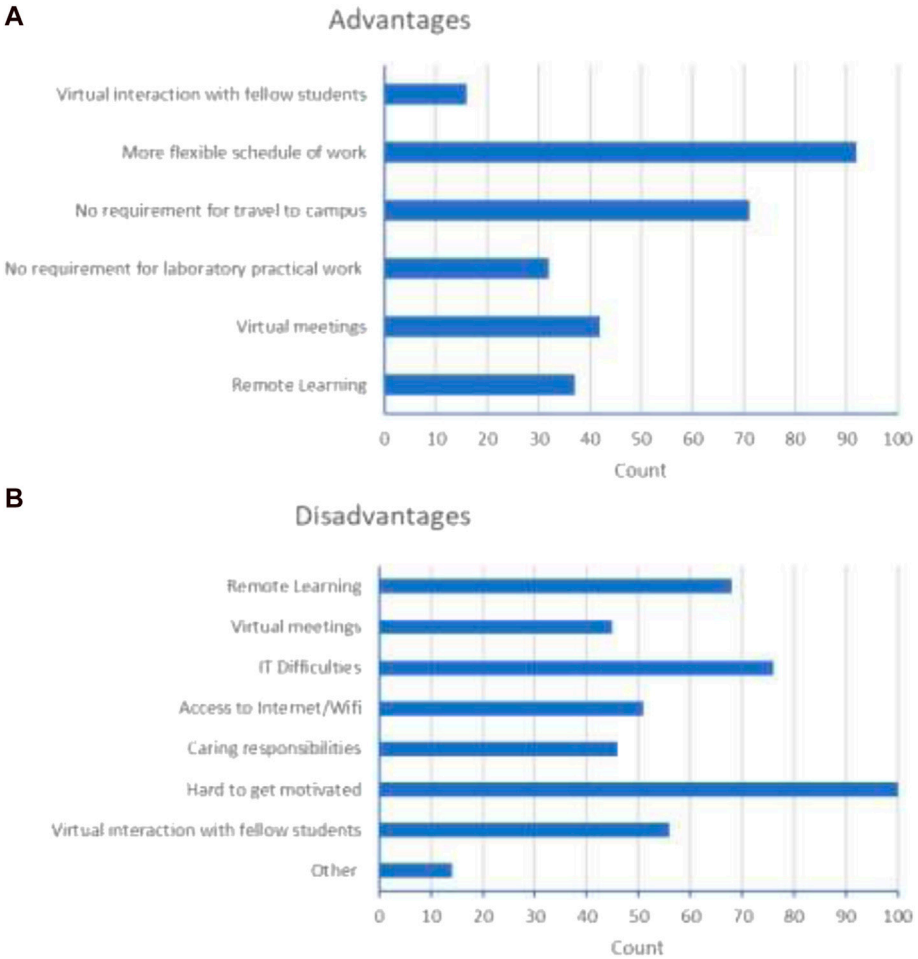

FIGURE 8 | Elements of the dry-lab project experience which students considered to be **(A)** advantages and **(B)** disadvantages.

The importance of supervisor interaction was captured succinctly by one student, who commented;

> "Having a fantastic supervisor [meant] it was easy to keep organised with the workload ahead and what was involved in each part. However, I have known individuals who were not so lucky and their supervisor rarely contacted them and so they struggled. I believe this year your supervisor had a significant impact on your grade as you had very little interactions with other members of staff or students to talk through the project and how to approach it."

Choice

Despite the range of experiences that students recorded, and the various pros and cons identified in the process, the vast majority of students did think final year students in School of Biomedical Sciences should have a choice of wet-lab and dry-lab projects (**Figure 11**).

It is important to listen to this type of feedback from students. Offering an expanded range of final year project types affords students more choice to address gaps in their skillsets, thereby empowering them to improve themselves in accordance with the Student Learning Principles model outline in the current Learning & Teaching Strategy at UU [12]. Moreover, this type of project may be particularly attractive to students who may have personal circumstances which make attending wet-lab sessions difficult [33, 34]. As a School and course team, we are committed to supporting student wellbeing, which includes making recommended adjustments for students who may be experiencing difficulty with their allocated research projects for various personal reasons. In previous years, completion of wet-lab projects has been difficult for these students, due to circumstances with prevent them attending the laboratory sessions in person. A dry-lab project may well be a more attractive option for students in this position, rather than having to make ad-hoc adjustments to a wet-lab project to fit their needs [7]. This is illustrated nicely in this survey by one student, for whom dry-lab provision has been a very welcome development;

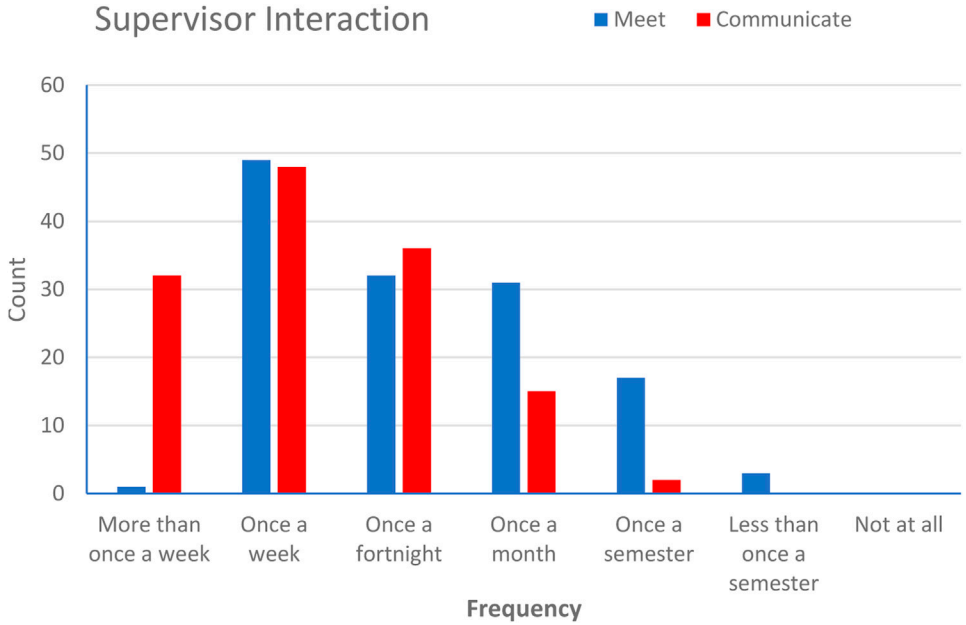

FIGURE 9 | Frequency of supervisor interaction with student via meeting (live virtual, synchronous) or communication (phone, email, asynchronous).

> "I am autistic and while I did feel isolated this year due to remote learning, it was also much more comfortable being able to manage my own schedule with breaks to desensitize (an option that was not really possible during lectures and lab sessions for my entire course). Having a choice between a labwork-based project and a data analysis-based project is a great opportunity for the university to improve accessibility for neurodivergent students through accommodating and supporting them in a situation that suits their strengths and need."

The quantitative data above is also supported by qualitative data, gathered from open-ended questions in the survey where students were given the opportunity to provide any other comments. A representative selection of these comments, both positive and negative, are shown in **Table 2** below, again aligned against the four themes identified.

Mirroring the data collected on student experience, the importance of the supervisor in the project was further evidenced by a word frequency analysis of these qualitative comments, as visualised in a word cloud (**Figure 12**).

Notably, the words "supervisor" and "supervisors" appear prominently, reflecting the frequency with which students mentioned how their supervision had contributed to either a positive or negative learning experience. However, it cannot be said for sure that this range is unique to the dry-lab project experience, since we do not have a similar set of data collected for student doing mostly wet-lab projects. Indeed, it is likely that the same variety in experience and a similar emphasis on good student-supervisor interaction would be reported for any cohort of final year students undertaking research projects. Other studies have similarly found that students associate research-focused staff with being less interested in teaching and in spending a reduced amount of time with their students [35]. This may create a tension between staff and student expectations, so it is important that supervisors understand their role may be different from that associated with traditional wet-lab projects. The data presented here reflects findings from other studies that show the challenge for improving student experience lies both in the provision of choice, allowing students to select projects that suit them [28], and in ensuring there is sufficient quality communication between supervisor and student throughout the project [36].

Impact of Project for Academic Colleagues

The study aimed to demonstrate how colleagues could potentially address challenges that currently exist in the traditional model of final year science project provision. The impact upon colleagues at UU and in other academic institutes is likely to be improved by demonstrating the benefits in terms of finance, widening participation and workload.

For example, as student numbers increase in UK higher education, there is increasing economic pressure associated with providing relevant wet-lab projects in suitably-equipped environments [7]. This problem is exemplified at UU where the average number of students allocated to a final year project supervisor in Biomedical Sciences per year has risen from two to seven in the last decade. Although supervisors get a small stipend of money to purchase consumables for the practical delivery of these projects, this is largely insufficient and is normally supplemented by other financial resources. However, this approach is increasingly unsustainable as student numbers increase, so dry-lab projects are clearly more

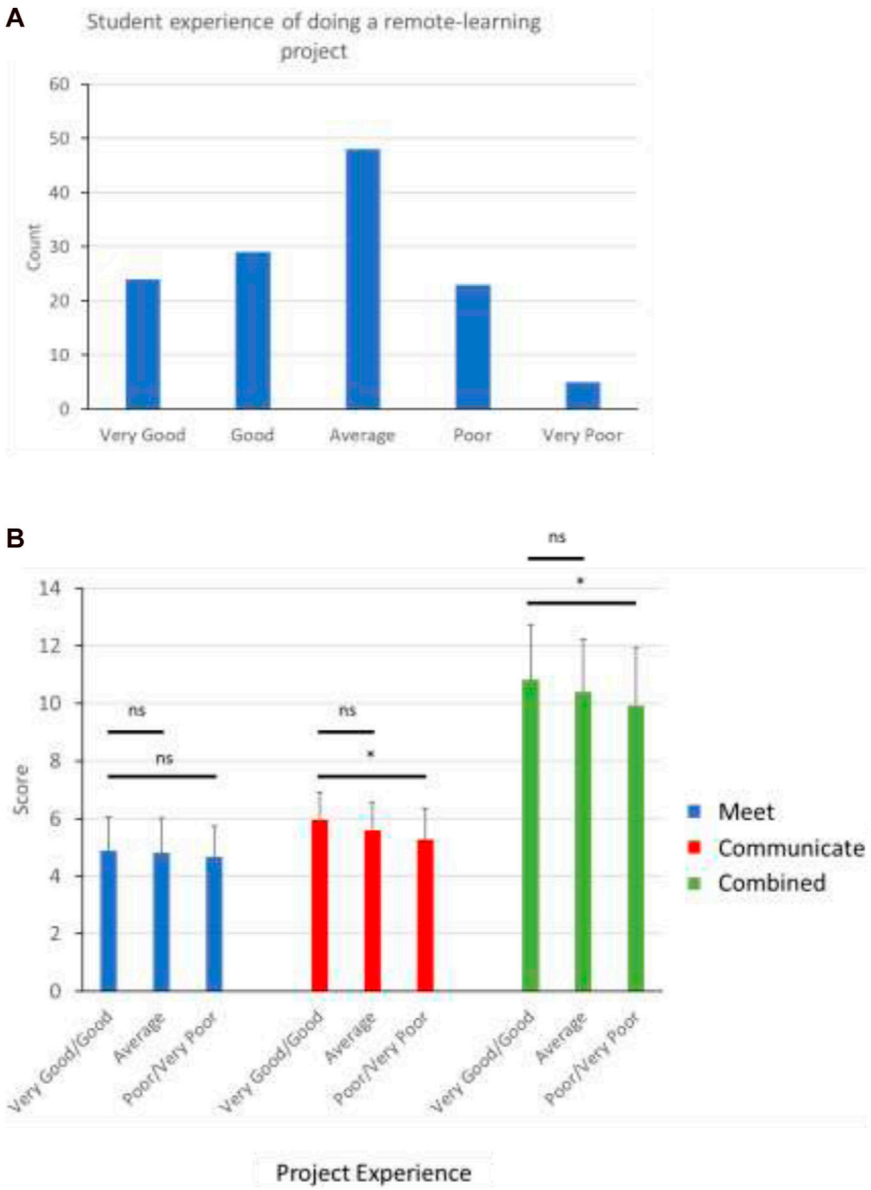

FIGURE 10 | (A) Overall experience of student respondents undertaking dry-lab project provision in School of Biomedical Sciences 2020–2021 **(B)** Students who reported a very good or good experience had a significantly higher level of communication with supervisor than those reporting a poor or very poor experience. [Data shown is Mean ± SD. Scores based on student reporting of average interaction with supervisor during project; 7 = More than once a week, 6 = Once a week, 5 = Once a fortnight, 4 = Once a month, 3 = Once a semester, 2 = Less than once a semester, 1 = Not at all (Student's t-test *p*-values; $*p < 0.05$, ns = non-significant)].

financially viable, especially as student numbers are only likely to increase further in coming years.

Furthermore, increased student recruitment to our distance-learning courses in Biomedical Science at UU means that provision of dry-lab projects will become more commonplace. This is important for UU's widening participation civic agenda because the importance of the "remote laboratory" in STEM-related education has been identified as a key resource in promoting internationalization, as well as access to education for traditionally underrepresented groups [9]. Therefore, the onus is on the School to explore innovative ways of online research project provision which can be delivered remotely and still meet the learning objectives of our courses.

Finally, in terms of workload and efficiency, it is increasingly difficult for supervisors to manage bigger numbers of students working in the laboratory, both in terms of space and time. Providing a dry-lab project workflow will allow students to work through project activities in a virtual environment in their own time without the need for a supervisor in attendance and without having to access to laboratories at scheduled times. In effect, this frees up both supervisor and student from a limiting timetable where face-to-face meetings are dependent on access to

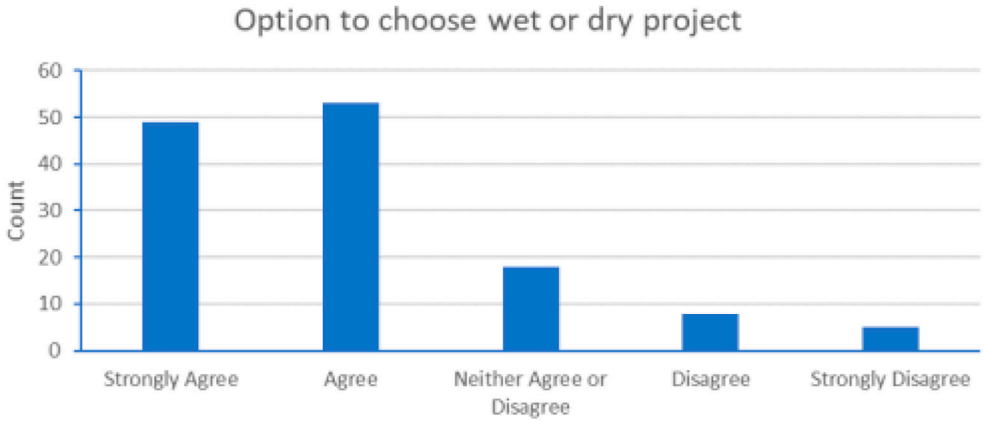

FIGURE 11 | Students strongly agreed (49, 36.8%) or agreed (53, 39.8%) that a choice of wet- or dry-lab project should be made available for students in School of Biomedical Sciences. [Other Data: Neither Agree or disagree (18, 13.5%), Disagree (8, 6.0%), Strongly disagree (5, 3.8%)].

TABLE 2 | Selected comments from the student feedback section of the survey.

Theme	Good comment	Critical comment
Expectations	"Although I had reservations at first I thoroughly enjoyed conducting my research project." "Although wary at first I found researching and retrieving data as easy at home"	"Remote learning is a poor replacement, more should have been done by the university to make it safe for students to be on campus" "I thought it would be a disaster"
Skills & Employability	"It allowed me to develop computer based skills that I otherwise would have lacked" "The remote learning project has actually allowed me to strengthen and deepen my statistical and critical analysis skills"	"Remote learning has prevented students from gaining vital practical skills to make them employable" "I would be completely unqualified to go and work in a lab environment now" "My remote learning project gave me no opportunity to gain new skills"
Student Experience	"Overall, due to the weekly communication between myself and my supervisor it really helped to resolve any problems I was having" "I enjoyed my online project and worked well with my supervisor as they were good at communicating with me." "I believe a good motivated supervisor is key to working virtually."	"Connection issues did make these meetings difficult on occasion" "It was difficult to get in contact with my supervisor and they rarely replied to emails." "I needed and use facilities on campus as my own facilities for WiFi/ technology are not very good" "I struggled a lot to get motivated"
Choice	"I think a few things could be improved- but it should definitely be an option post COVID" "The opportunity for multiple types of data analysis needs to be offered for the student to have any benefit." "I would encourage the practice of remote learning to become common place in the future education in Ulster University."	"Remote-learning was okay. But it could never replace the social on-campus learning" "Unsatisfied with the delivery of final year projects during the pandemic and if given the choice I would not have chosen [sic] to go through this again." "If dry projects are offered in the future supervisors need to be well equipped and willing to work around those students."
Overall	"Overall it was a very enjoyable experience."	"The remote learning experience was an awfully challenging experience in my opinion"

laboratory facilities. Instead, a combination of synchronous IT communication and online tutorials can be used to meet, brainstorm, set tasks and review performance. Employed properly, the dry-lab project can therefore be more efficient in terms of organisation, time-commitment and availability of those involved [8].

However, we also know that increasing workloads and pressures within academia mean that many lecturers do not have the time or freedom to implement new learning techniques in the classroom [37]. Without the time to reflect on and enhance teaching practice, adoption of new approaches will always remain a challenge unless they clearly demonstrate how it will reduce workload. Therefore, dissemination of this case study may help to persuade educators how a dry-lab project can actually solve many issues at once.

Limitations

However, it is important to consider potential limitations to the work which could be addressed in future evaluations of this type. The small number of participants in the pilot group may have

FIGURE 12 | Word cloud generated form the text included in the comments provided by students in the open-ended feedback question of the survey, clearly indicating importance of supervisor(s).

meant some important themes were not considered. A larger pilot group, ideally spread across several different projects, would have been more holistic and would help avoid bias that may come with one practitioner. Ideally, it would be best to randomly allocate students to wet- or dry-lab projects and compare their experiences. One study made students take both wet- and dry-lab experimentation and compared their experiences, which helped students develop more appreciation of scientific practice [3]. However, even this approach acknowledged some hard-to-control variables, such as personal circumstances and supervisor input. It also removes the idea of choice from students, which runs contrary to the wishes of students as shown in the data above. Nevertheless, more projects like this are required to robustly compare the wet- and dry-lab experience for students.

The survey carried out here was necessarily student-centred, but it would have been advantageous to do a staff-focused survey as well to canvas their experience of delivering a dry-lab project. It may well be that the same problems experienced by students in the mode of learning would be manifested in staff. Notably, some staff have also provided anecdotal evidence of difficulties with motivation, engagement and technology, so these are not student-specific issues. Indeed, it is worth noting that during the COVID-19 pandemic, staff were probably more likely to have caring responsibilities (e.g., home-schooling) than students, on top of dealing with a dramatically changed role in teaching and research as work moved off-campus. Staff wellbeing is also important to consider as a factor which may have contributed to the staff-student interactions which have been highlighted above as so important to the overall student experience of dry-lab projects. Capturing the staff experience of this entire process would provide a useful comparator for the student results reported here. Unsurprisingly, others have also seen the pandemic as a possible catalyst for change and have engaged with staff across various universities to put aside their preconceived ideas on research projects and work collaboratively to share ideas and create outputs [38–40]. This has led to a suite of open-access resources being made available to help staff develop, manage and deliver non-traditional projects. The need for this is clear as the authors conclude; *"We cannot return to our old ways – the worlds of work and education have changed forever."* Interestingly, the results from this project corroborates evidence from a previous survey, collected from Level 5 and 6 students across 16 Universities in the UK, which concluded there was a need for the sector to re-think its provision of undergraduate projects, and the range of projects offered, in order to address student needs and career aspirations [29].

FIGURE 13 | Recommendations for enhancing final year project provision.

Looking to the future, it would be interesting to follow this cohort of students to track their employability statistics and the types of job they progress to. This might tell us if the lack of practical laboratory skills is a barrier to gaining employment in the Life Sciences sector. Alternatively, it may transpire that the gain in digital skills may well prove to be an advantage which employers valued even more highly following the experiences of the COVID-19 pandemic. A follow-up survey of these student respondents in this project in one or 2 years could be very illuminating.

RECOMMENDATIONS

The ideas, opinions and themes discussed above can be summarised in the following recommendations, based on the appropriate acronym 'STEM' (**Figure 13**).

Selection

Providing choice in the types of project available is key to empowering students to choose a final year project that suits them best. It is highly recommended that bioscience courses offer a variety of dry-lab and wet-lab projects as this provides more choice for students to play a proactive role in tailoring their final year experience to suit their individual circumstances, strengths and future career aspirations. Ideally, projects should be a hybrid design, allowing students to gather both wet- and dry-lab skills [3].

Training

Training and continual learning is essential for staff to develop the necessary skillsets required to deliver dry-lab projects effectively. Course teams are encouraged to nominate a coordinator who can monitor and disseminate the ever-growing number of resources that can be used to facilitate dry-lab project provision. These include digital tools, case studies, 'off-the-shelf' projects, design-your-own-project toolkits and open-access datasets. However, many colleagues are not aware of these and require direction on where to find them and how to use them. Training should be facilitated alongside these resources to inspire and encourage staff to innovate in terms of providing new types of projects. This training can then be paid forward to students undertaking the project. In our School this coordinator role is being assumed by a local Active Learning Champion.

Employers

Regular engagement with prospective employers is important to identify the skills that they value in graduates. Course teams should utilise employer advisory board (EAB) partnerships and other industry networks to keep abreast of new skills required in the fast-changing Life Sciences sector and beyond. This information can inform the design of new projects, including those which foster dry-lab scientific skills for the world of work [39]. Indeed, some employers may even be willing to provide placement-type opportunities for student to complete final year projects in the workplace. Crucially, it needs to be articulated clearly to students which skills they will get an opportunity to develop, both to aid in their choice of project, but also so they can evidence these skills when they progress to job-seeking.

Mentorship

Engaged supervisors are critical to a good project experience for students. Therefore, supervisors offering dry-lab projects must be aware of the need for regular communication aligned with this type of project. At the very least, it is recommended that this should include a good balance of synchronous and asynchronous interaction, with a clearly outlined schedule to guide progress. Moreover, the expectations of both student and supervisor must be established and agreed upon at the start of the project, so that there is clear understanding of the mentorship relationship and the responsibilities on both sides [36]. This is especially important for dry-lab projects where students are working remotely. This training already exists at UU for PhD supervisors, so this could easily be adapted for undergraduate project mentors.

CONCLUSION

A combination of educational, financial and societal driving factors means that final year project-based learning practices in the School of Biomedical Science course need a significant change if we are to create a sustainable model of final year research project provision for future cohorts of students. In this project, evidence is presented to demonstrate that dry-lab projects can deliver an equitable, feasible alternative to wet-lab projects for students. Increased adoption of dry-lab projects can address the various pressures involved with project provision to an increasingly diverse undergraduate population in ways that can empower both staff and students alike. However, staff who are not familiar with dry-lab projects need to be motivated and supported to embed this practice routinely. In future, providing a choice of both dry-lab and wet-lab projects is highly recommended as it provides more choice for students to tailor their final year project experience to their individual circumstances, skill requirements and future career aspirations.

SUMMARY TABLE

What is Known About This Subject?

- Non-laboratory based research projects in Biomedical Science courses are becoming increasingly commonplace in higher education.
- There is some evidence that students can benefit equally from these "dry-lab" science projects compared to traditional "wet-lab" projects.
- However, further evaluation is required to change preconceptions and expectations about dry-lab projects amongst both students and educators.

What This Paper Adds

- This research carried out an evaluation of dry-lab project provision for students in the School of Biomedical Sciences at Ulster University.
- This research provides evidence that dry-lab project provision can be a suitable and equitable alternative for wet-lab projects.
- However, supervisors need relevant training to ensure dry-lab project provision is appropriately designed, delivered and supported.

CONCLUDING STATEMENT

This work represents an advance in biomedical science because non-laboratory based research projects are increasingly commonplace, so this study demonstrates their value and provides recommendations for their implementation.

DATA AVAILABILITY STATEMENT

The data presented in this article are not readily available per ethics approval. Further enquiries should be directed to the author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Centre for Higher Education Research and Practice (CHERP) at Ulster University (Ref:CHERP-20-001). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

DM designed and performed the study as part fulfilment for Master in Education (MEd) degree. Final manuscript was drafted, and revised by DM.

CONFLICT OF INTEREST

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ACKNOWLEDGMENTS

Thanks to Amanda Platt, and Sarah Floyd in CHERP at UU for their constant guidance and valued suggestions over the duration of the project, which helped me approach the topic with clarity and focus. In School of Biomedical Sciences at UU, thanks to Maria Mulhern for help in using RedCAP for the survey and to Cynthia Stafford for helping to interview students. To the students who comprised the pilot group in this survey (Richard, Amy, Yasmin, Alexandra) and to all students who gave of their time to complete survey, my thanks and my best wishes for the future. Be excellent to each other.

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ORIGINAL RESEARCH
published: 08 August 2023
doi: 10.3389/bjbs.2023.11584

An Innovative Workshop Embedding Pathology Service Users into the Undergraduate Biomedical Science Curriculum

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The integration of pathology service users into the biomedical science curriculum has been driven by the refinement of the Health and Care Professions Council (HCPC) Standards of Proficiency. This study aimed to design and implement a novel and innovative service user event with a reflective assessment to enhance students' knowledge and understanding of the impact of pathology laboratory results on the patient pathway. The 4-h workshop consisted of a series of service users. Patients discussed how pathology services had contributed to their diagnosis and treatment, while service providers—a Microbiology Consultant, a director of primary care, and the patient referral optimisation officer—discussed their roles and their interactions with pathology services. Post-event, students completed a 750-word reflective assessment, highlighting challenges experienced by service users and providing suggestions for improving the delivery of pathology services. In total, 57.5% of respondents (57/99) completed a post-reflection survey, which included open- and closed-ended questions. Quantitative analysis of the survey data revealed that over 87.7% of respondents had increased knowledge and understanding of the revised HCPC standards. Following the assessment, students reported a significant increase in their confidence with respect to reflective writing ($p < 0.001$), with over 90% of respondents agreeing that the reflective assessment had increased their knowledge and understanding of the limitations that may negatively impact service users and patient care. Moreover, respondents highlighted how advancements in point-of-care testing (POCT) and improvements in communication can improve patient experiences. Thematic analysis revealed that respondents agreed that embedding patients into the curriculum reinforced the importance of there being a patient behind every sample. Respondents reported that reflecting upon service user experiences enabled them to identify improvements to the delivery of pathology services while recognising the essential role that Biomedical Scientists play in the patient pathway. This successful workshop has created a platform encompassing a range of pathology service users in the undergraduate curriculum. We recommend that other accredited biomedical science programmes adopt and embed this innovative workshop and reflective assessment into their programmes to help them meet these standards relating to service users while fostering important transferable skills in their students.

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Received: *16 May 2023*
Accepted: *18 July 2023*
Published: *08 August 2023*

Citation:
Bashir A, Wilkins K and Pallett R (2023) An Innovative Workshop Embedding Pathology Service Users into the Undergraduate Biomedical Science Curriculum. Br J Biomed Sci 80:11584. doi: 10.3389/bjbs.2023.11584

Keywords: patient care, biomedical science, higher education, reflective writing, service users

INTRODUCTION

To ensure the delivery of high-quality patient care and pathology services, it is imperative to have a thorough understanding of the needs of patients. The integration of service users into the biomedical science curriculum has been driven by the refinement of the Health and Care Professions Council (HCPC) Standards of Education and Training (SETs), which explicitly state that "service users and carers must be involved in the programme (SET 3.7)" and "the learning outcomes must ensure that learners meet the Standards of Proficiency for the relevant part of the register (SET 4.1)" [1, 2]. The HCPC Biomedical Scientist Standards of Proficiency (SOPs) have underscored the importance of incorporating patients' perspectives and listening to patients' voices to enhance the delivery of pathology services and patient care [3]. While the HCPC's definition of "service user" refers to individuals who utilise or are impacted by the services of HCPC professionals, it has historically been challenging to define pathology "service users," as pathology laboratories were typically located at the periphery of hospitals with limited interaction with the ultimate service user [1–3].

Since 2014, the HCPC has required all programmes approved by the regulatory body to involve "Service users and carers" in the programme [2]. However, the revised HCPC Standards of Proficiency of September 2023 have emphasised the "central role of the service user" and the requirement for "registrants to understand the importance of valid consent and effective communication in providing good care." In addition, registrants should be "promoting public health and preventing service users' ill-health" and understand "the importance of valid consent and effective communication in providing good care" [3]. The timing of these revisions coincides with a shift in public knowledge, where patients now have a better understanding and a greater appreciation of the role of laboratory medicine in the diagnosis and treatment of disease [4].

The COVID-19 pandemic served as a catalyst for raising public awareness and recognition of the critical role played by Biomedical Scientists (BMS) in the United Kingdom in the processing and testing of COVID-19 samples [4]. Before the pandemic, patients were primarily familiar with the role of medical professionals such as doctors and nurses in providing healthcare services, whereas the pandemic drew attention to the vital role of laboratory workers who operate behind the scenes in testing and diagnosing diseases [5, 6].

The evolution of point-of-care testing (POCT) in the last decade has brought about significant changes to the role of Biomedical Scientists as diagnostic testing has become more accessible across healthcare pathways. Many commercial POCT manufacturers recognise the value of close working relationships with BMS and have established collaborative working and development groups [7]. However, the COVID-19 pandemic has dramatically changed the role and responsibilities of BMS, thereby necessitating a corresponding adaptation in the training of future biomedical science students [8]. A BMS processes hundreds of patient samples on a typical workday, which can lead to a lack of appreciation for the fact that each sample represents an individual patient. Thus, it is imperative for biomedical science students to be conscious of the importance of test results for patients. It is important to recognise that medical professionals, such as doctors and nurses, who order laboratory tests are considered service users for pathology laboratories; however, the primary beneficiaries are ultimately the patients themselves.

The involvement of patients in medical education has become a standard practice among educators [9, 10]. The General Medical Council (GMC) has long recognised the value of patient involvement and requires educators to incorporate a variety of patient-centred sessions into the undergraduate curriculum [11]. However, there is still much to be learned about how to systematically integrate patient involvement into other allied healthcare courses. Studies have demonstrated that both patients and practitioners benefit from a patient-centred curriculum [12]. Patients take on the role of educators, teaching students about patient-centred care and the importance of patient autonomy, and helping to make education increasingly engaging and transformative [12]. As BMSs rarely interact directly with patients on a daily basis, the involvement of patients in the curriculum reinforces the importance of the patient being behind every sample.

Medical educators and patients have joined forces in promoting patient-centeredness; however, BMS service users have yet to be fully integrated into the biomedical science curriculum in the same way. Reflecting upon the experience of patients can assist learning and professional development; this reflective writing is considered a core element in medical education that promotes critical thinking, better communication, and empathy skills [13, 14]. Therefore, the aim of this study was to embed patients and BMS service users into the undergraduate biomedical science curriculum through a "service user event" with a reflective assessment to enhance students' knowledge and understanding of the impact of pathology laboratory results on the NHS service and ultimately the patient.

MATERIALS AND METHODS

The steps involved in the creation of the novel, innovative service user event are detailed in **Figure 1** and can be adopted by other higher education institutes that require the incorporation of service users into their curriculum.

Service User Event

A service user event workshop was created and facilitated by academics from the School of Biosciences, Aston University, United Kingdom, for final-year biomedical science students. The event is part of the 30-credit final-year "Professional Development for Biomedical Scientists" module. The workshop was scheduled for 4 hours, and the following pathology service users were invited as guest speakers: a patient with beta-thalassaemia major, a patient

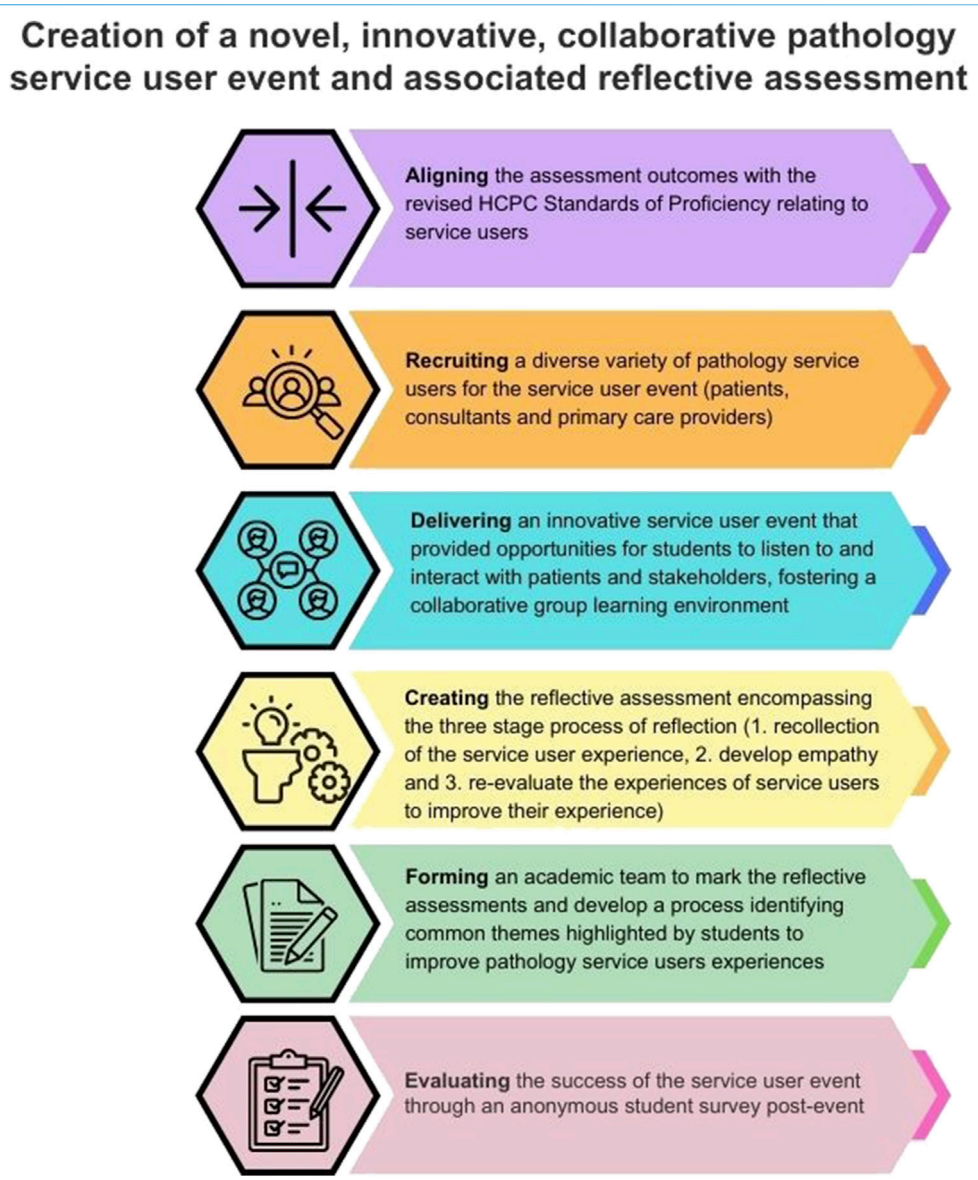

FIGURE 1 | The six-step process involved in creating an event to involve pathology service users in the undergraduate biomedical science curriculum.

diagnosed with a giant cell tumour, a Microbiology Consultant, a director of a primary care provider, and a patient referral optimisation officer. Both patients and service users provided consent to participate in the workshop. The patients discussed how pathology services have contributed to their diagnosis and treatment, while service providers discussed their roles and their interactions with pathology services. All speakers highlighted issues that have affected the delivery of an optimal service. This was followed by an interactive class discussion, which was directed by the assessment brief.

Service User Reflection Assessment

Following the event, all students were required to complete a 750-word reflective piece, with this assessment contributing to 33% of the overall module mark (**Supplementary Table S2**: Assessment Brief). This assessment required students to reflect on the voices of the different service users and how taking action to address problematic areas in healthcare can enhance the delivery of biomedical science and improve patient care. Students were directed to specifically comment on several areas, such as 1) past and current challenges to the delivery of pathology services; 2) advancements in point-of-care testing (POCT) and its increased use in the diagnosis and monitoring of disease; 3) the changing role of Biomedical Scientists and diagnostic laboratories in healthcare; 4) the increased awareness of the profession following COVID-19; and 5) empowering patients to understand and access their results.

To support students in writing a reflective piece, they were provided with a range of resources, which included a workshop that gave them

TABLE 1 | Survey questions asked following the service user event and reflective assessment and the relevant revised HCPC Standards of Proficiency.

Question: "Following the service user event and reflection assessment I now have increased knowledge and understanding of . . . "	Relevant revised HCPC Standards of Proficiency
Public health and prevention of service users' ill-health	SOP 15.1 understand the role of their profession in health promotion, health education and preventing ill-health SOP 15.2: understand how social, economic and environmental factors (wider determinants of health) can influence a person's health and well-being) SOP 15.3: empower and enable individuals (including service users and colleagues) to play a part in managing their own health
The role of equality, diversity, and inclusion, with specific importance placed on ensuring practice is inclusive for all service-users	SOP 5: recognise the impact of culture, equality and diversity on practice and practise in a non-discriminatory and inclusive manner SOP 5.1: respond appropriately to the needs of all different groups and individuals in practice, recognising this can be affected by difference of any kind including, but not limited to, protected characteristics, intersectional experiences and cultural differences SOP 5.3: recognise the potential impact of their own values, beliefs and personal biases (which may be unconscious) on practice and take personal action to ensure all service users and carers are treated appropriately with respect and dignity
The central role of the service-user, including the importance of valid consent and effective communication in providing good care	SOP 7.1: use effective and appropriate verbal and non-verbal skills to communicate with service users, carers, colleagues and others SOP 7.5: modify their own means of communication to address the individual communication needs and preferences of service users and carers, and remove any barriers to communication where possible SOP 7.8: understand the need to provide service users or people acting on their behalf with the information necessary in accessible formats to enable them to make informed decisions
The importance of leadership at all levels of practice	SOP 8.6: understand the qualities, behaviours and benefits of leadership SOP 8.7: recognise that leadership is a skill all professionals can demonstrate SOP 8.8: identify their own leadership qualities, behaviours, and approaches, taking into account the importance of equality, diversity and inclusion SOP 8.9: demonstrate leadership behaviours appropriate to their practice
The need to be able to use information, communication and digital technologies appropriate to practice	SOP 6.5: recognise that the concepts of confidentiality and informed consent extend to all mediums, including illustrative clinical records, such as photography, video and audio recordings and digital platforms SOP 7.7: use information, communication and digital technologies appropriate to their practice SOP 9.3: use digital record-keeping tools where required SOP 13.1: be able to change their practice as needed to take account of new developments, technologies and changing contexts

an opportunity to approach reflective writing and links to the marking scheme. Students were also given a generic example of a reflection and were asked to work in mixed groups to mark the reflective piece and provide feedback according to the assessment marking scheme. In addition to this, students were directed to additional reading that covered the importance of reflective writing for practitioners and how to write in-depth reflections. Students were also allowed to attend an additional drop-in session to ask any questions they had regarding the assessment (**Supplementary Table S3**: Marking Rubric).

Collecting Student Feedback and Analysing the Results

Final year biomedical science students' experiences of the service user event were collected following submission of the reflective assessment through an eight-item online questionnaire [15] (**Supplementary Data Sheet S1**). Ethical approval was granted by the Health and Life Sciences Ethical Committee (Project #1494). Students were invited to participate in the study by email and were provided with a link to the online survey via the virtual learning environment. Online consent was required before accessing the questions. Students completed questions asking whether, after the submission of their reflection, they had an increased understanding of:

(1) The impact of pathology results on service users and effective communication in providing patient care.
(2) An understanding of the changing role of the Biomedical Scientist in the patient pathway.
(3) The value of embedding patients in the biomedical science curriculum to improve the delivery of healthcare.
(4) The value of continuous reflective practice and its role in asking difficult questions and finding meaningful answers.

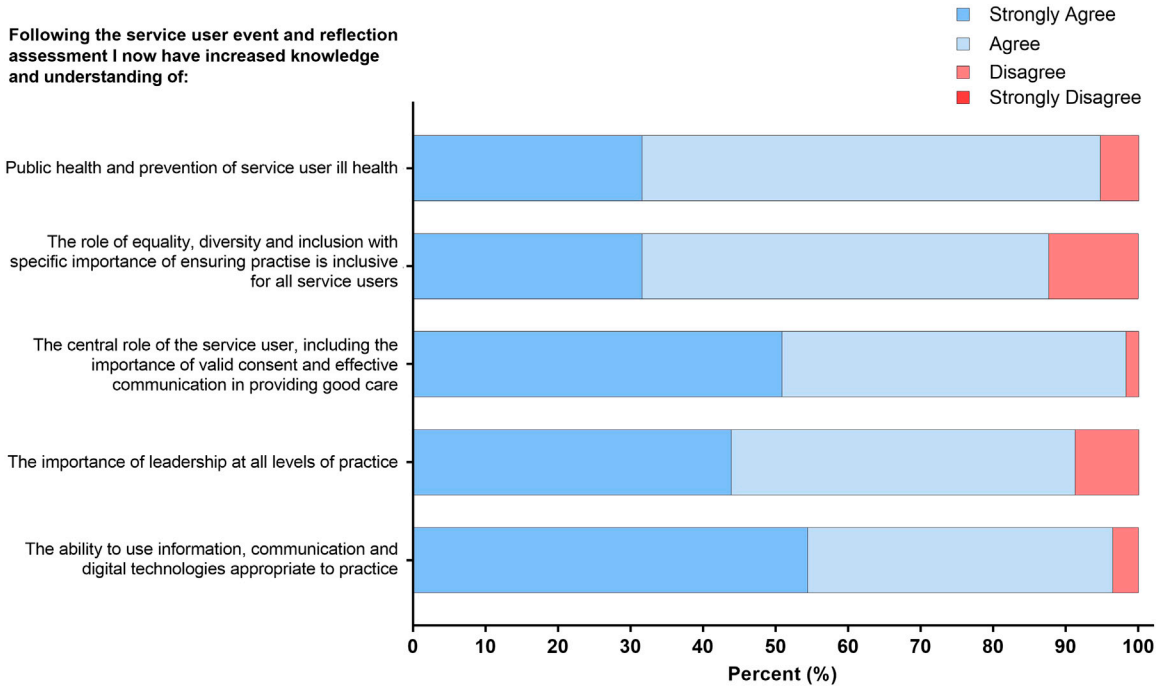

FIGURE 2 | Student responses to statements relating to increased understanding and knowledge of HCPC standards following the service user event. The response to the four-point Likert scale for each statement is shown as a percentage.

The questions reflected the revised 2023 HCPC Standards of Proficiency, which address embedding service users within the biomedical science curriculum (**Table 1**). A mixed methodology approach was adopted, which included open- and closed-ended questions. The results were analysed both quantitatively and qualitatively. To compare the responses of biomedical science students pre- and post-completion of the reflective assessment, a Chi-squared test was used to determine statistical significance ($p < 0.05$). Free-text responses were analysed using thematic analysis [16, 17]. The researchers read the data for familiarity, generated codes to form initial themes, and checked for plausibility. The process was repeated by all three members of the team, and the final themes were collectively agreed upon to produce the thematic analysis.

RESULTS

A total of 99 students were enrolled onto the module, and all attended the service user workshop, 57 of whom completed the post-event online survey. To better understand the demographics of the student cohort, they were asked if they had worked in the NHS in the last 3 years. A total of 20 (35.1%) respondents stated that they had worked in the NHS, with 9% of respondents having completed their Institute of Biomedical Science (IBMS) registration portfolio as a Trainee Biomedical Scientist during their placement year. Other roles included: Medical Laboratory Assistant, Administration and Clerical Staff, Domestic Assistant, Dental Receptionist, Vaccination Support Officer, and Clinical Trial Support Officer.

Incorporation of Revised HCPC Standards of Proficiency

Following the service user event, students were asked to reflect on whether their knowledge and understanding of the some of the revised 2023 HCPC Standards of Proficiency for all 15 HCPC registered professions had improved. Of the respondents, an overwhelming percentage either "strongly agreed" or "agreed" that the session increased their knowledge and understanding of; "*public health and prevention of service users' ill-health*" (94.8%); "*the role of equality, diversity, and inclusion, with specific importance placed on ensuring practice is inclusive for all service-users*" (87.7%); *"the central role of the service-user, including the importance of valid consent and effective communication in providing good care"* (98.3%); *"the importance of leadership at all levels of practice"* (91.3%) and *"the need to be able to use information, communication and digital technologies appropriate to practice"* (96.5%) (**Figure 2**).

Reflective Writing Can Emphasise the Central Role of Service Users Within the NHS

Students wrote a 750-word reflection following the service user event. Post-assessment, over 93% of respondents either "strongly

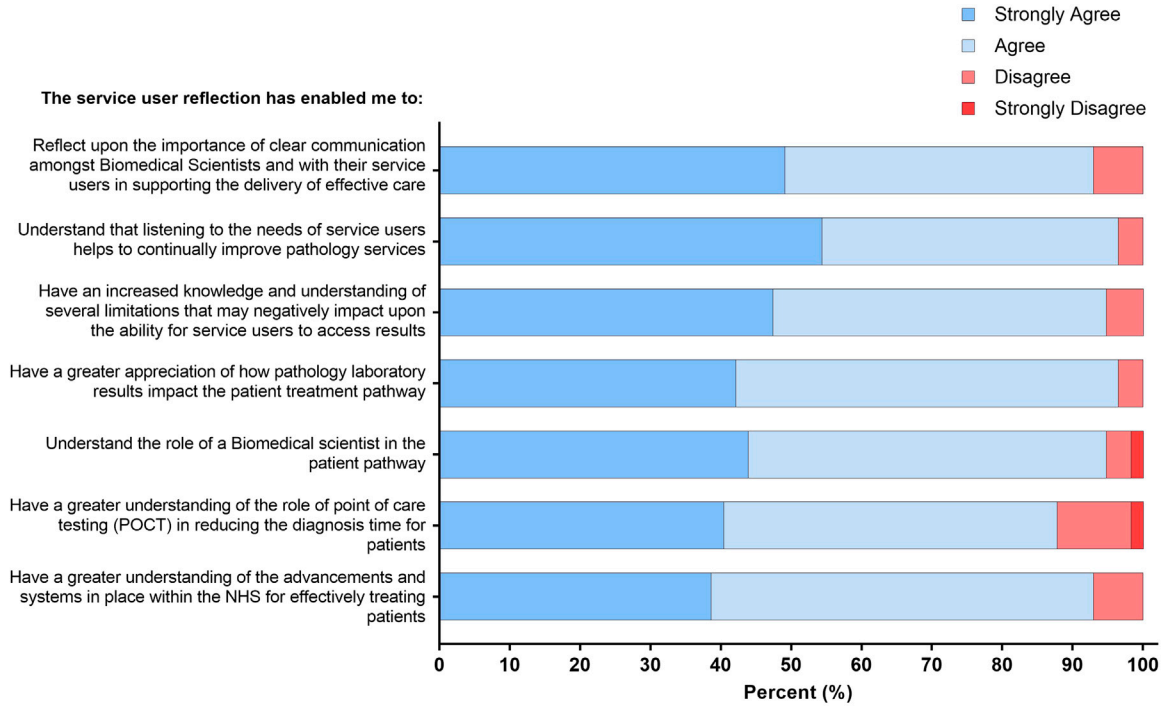

FIGURE 3 | Student responses to statements relating to increased service user awareness and POCT advancements within the NHS pathology laboratories. The response to the four-point Likert scale for each statement is shown as a percentage.

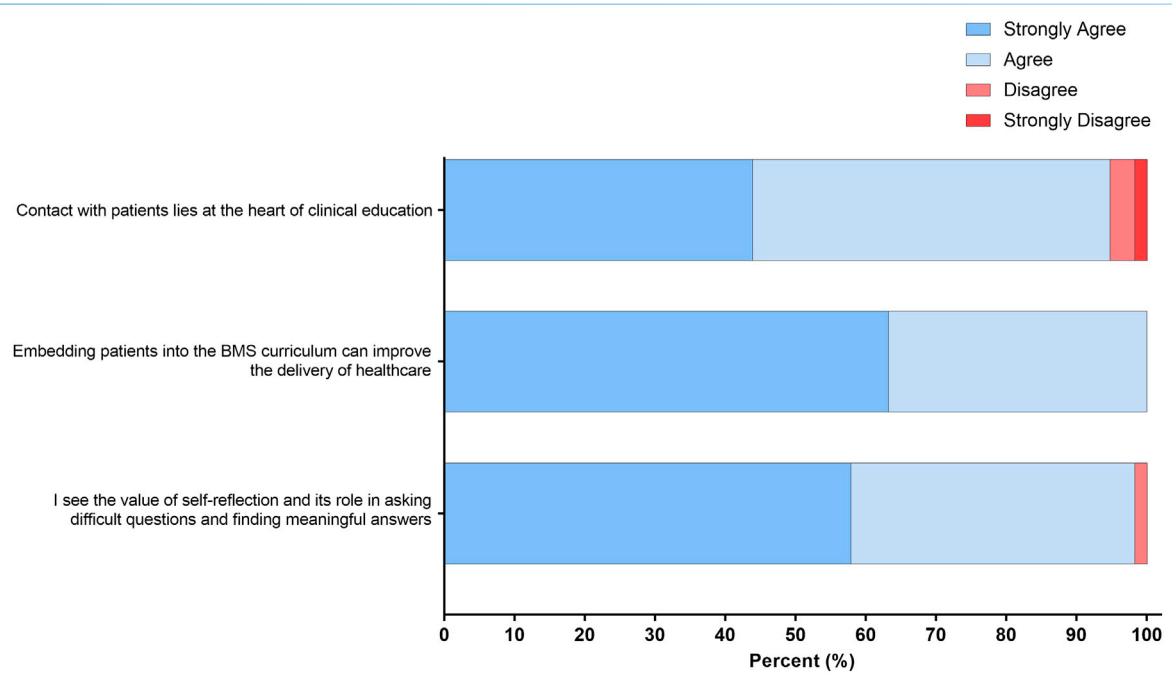

FIGURE 4 | Student responses to statements related to the value of self-reflection and embedding patients into the biomedical science curriculum. The response to the four-point Likert scale for each statement is shown as a percentage.

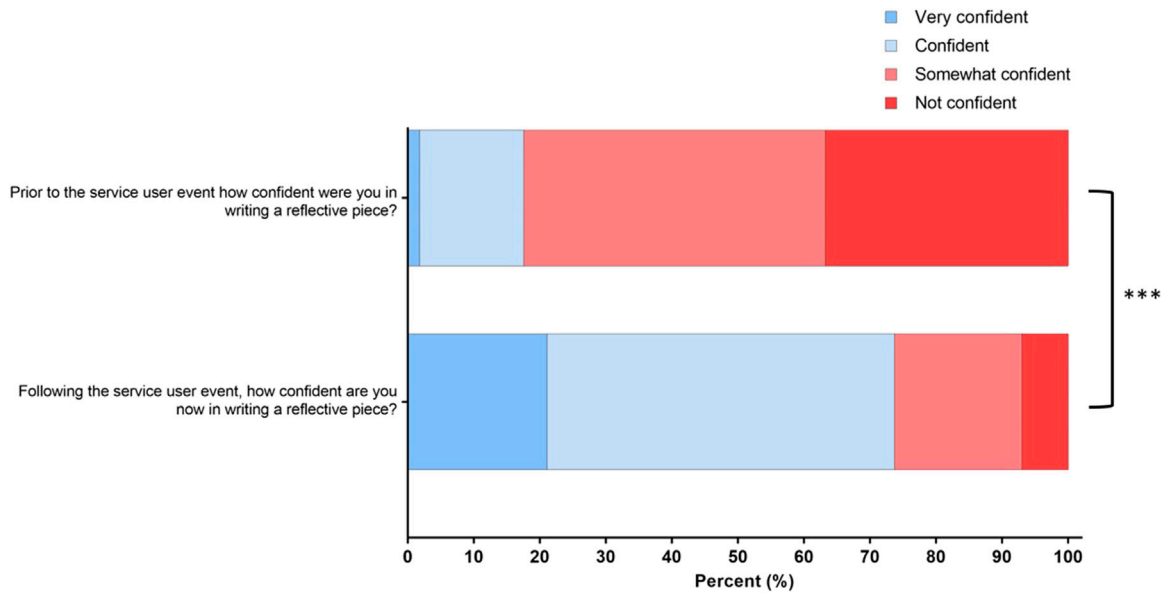

FIGURE 5 | Changes in final-year biomedical science students' confidence in reflective writing between pre- and post-assessment. Responses to the four-point Likert scale for each statement are shown as percentages ***($p < 0.001$).

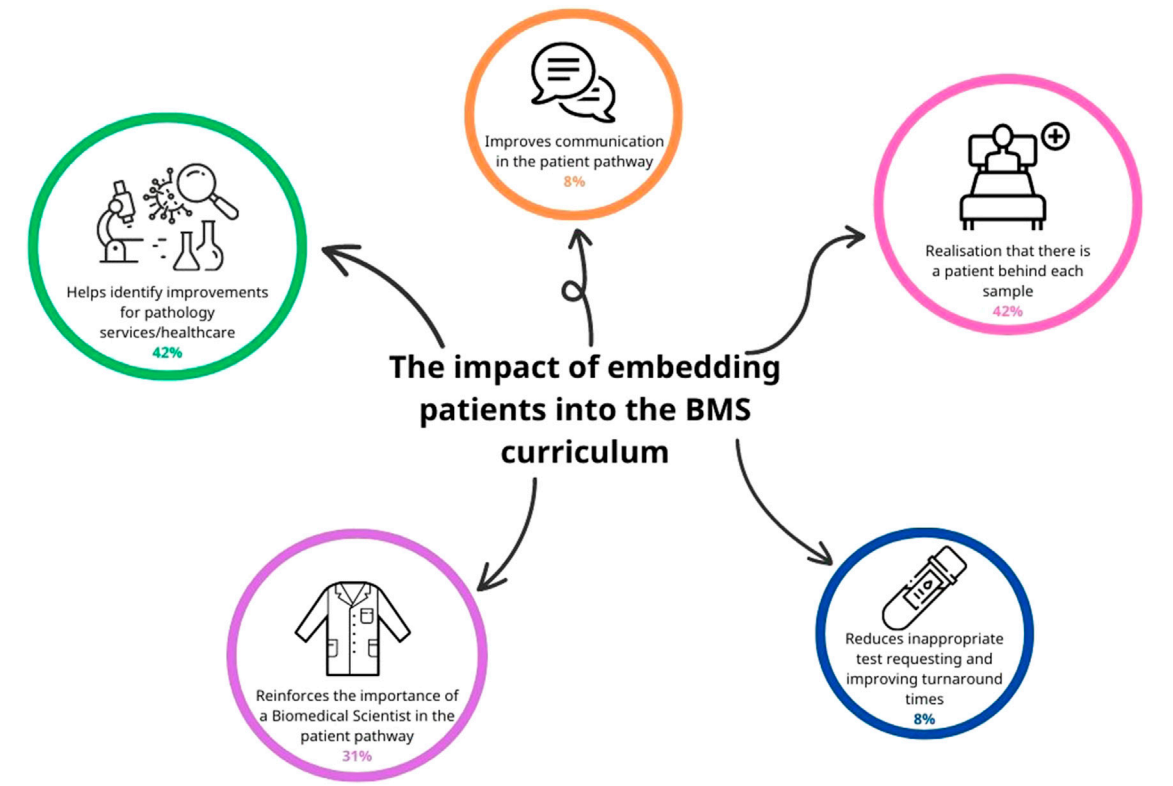

FIGURE 6 | Thematic analysis of open text responses on how embedding service user (patient) involvement in the BMS biomedical science curriculum can improve the delivery of healthcare. Five main themes were identified, and the occurrence of each of these is represented by the size of each circle in the schematic. Some respondents' open-text responses included more than one theme.

agreed" or "agreed" that the service user reflective assessment reinforced that "*communication amongst Biomedical Scientists*" and "*listening to service users*" are essential in delivering effective patient care through service improvement. Furthermore, 94.8% of respondents either "strongly agreed" or "agreed" that the reflective piece emphasised the importance of both "*the role of the Biomedical Scientist within the pathology laboratory*" within "*the patient treatment pathway*" and the "*limitations that may negatively impact*" the service and ultimately patient results. Lastly, on average, over 90% of respondents either "strongly agreed" or "agreed" that the reflective assessment has increased their understanding of "*POCT and other laboratory advancements within the NHS*" available to reduce diagnostic turnaround times for "*effectively treating patients*" (**Figure 3**).

Benefits of Embedding Patients into the Biomedical Science Curriculum

Students were asked for their views regarding the inclusion of patients into the curriculum. Remarkably, 100% of respondents either "strongly agreed" or "agreed" that "embedding patients in the biomedical science curriculum can improve the delivery of healthcare."

Furthermore, 94.8% reported that *"contact with the patient lies at the heart of clinical education,"* and 98.3% saw *"the value of self-reflection and its role in asking difficult questions and finding meaningful answers"* (**Figure 4**).

Improved Confidence in Reflective Writing for Biomedical Science Students

Prior to the completion of the service user reflection, only 17.6% of final-year respondents were either "very confident" or "confident" in reflective writing, compared to 76.3% post-service user assessment ($p < 0.001$) (**Figure 5**).

Free Text Responses for Thematic Analysis

To gauge a better understanding of what students felt about the impact of embedding patients into the biomedical science curriculum, a thematic analysis was conducted. From the responses to the free text question "*Q11. What is the impact of embedding patients into the biomedical science curriculum?*" 46% (n = 26) of the respondents answered question 11. Some of the students' responses fell into multiple themes, and once these were analysed, the five final themes identified were categorised as shown in **Figure 6**. The most prominent themes identified were 1) realisation that there is a patient behind each sample, 2) helping to identify improvements for pathology services/healthcare and 3) reinforcing the importance of a Biomedical Scientist in the patient pathway.

Theme 1: Realisation That There is a Patient Behind Each Sample

A total of 42% of respondents reported that embedding patients in the curriculum reinforced that there is a patient behind each sample and that BMS must always work to a high standard. Listening to the service users reinforced how important each test result is to the patient. Comments included:

> *"The event reinforced the importance of pathology results for patients. It can sometimes feel like a process in the laboratory, but each sample is linked to a patient outcome."* [SIC]
>
> *"Directly including patient experiences in education helps future BMS to recognise the role they play in the patient pathway and emphasises the potential impact they can have on patients, e.g., high standards can save lives, but low standards can cause harm."* [SIC]
>
> *"One of the core principles of the NHS and public health is ensuring patient is at the "heart" of everything it does. Embedding this principle into student mindset early is integral in ensuring they efficiently perform their particular roles in the future. Future events where we listen to the voice of service users, and their experiences will be progressively beneficial in developing our character so we can best serve our patients and their communities."* [SIC]
>
> *"Working in laboratories often means little to no patient contact, so hearing patients' stories helps to reinforce that there's a patient behind each sample and how what we do in the lab directly impacts patients."* [SIC]

Theme 2: Helps Identify Improvements for Pathology Services/Healthcare

As seen in Theme 1, 42% of respondents also reported that reflecting on service user experiences enabled them to identify improvements for pathology services. These included reducing sample turnaround times, identifying bottlenecks in current service provision, and understanding complex diseases and the impact of complications on patients. Comments included:

> *"Patient experiences can help us to identify weaknesses/areas of improvement in the NHS so this has a key role in improving services for its users."* [SIC]
>
> *"Understanding patient perspectives can help improve services delivered by BMS."* [SIC]
>
> *"It is important to include patients where necessary into education of healthcare so that we can further our knowledge in terms of a particular disease, its symptoms and any unpredictable complications."* [SIC]
>
> *"This would improve the time taken to provide patients with relaying test results and any form of diagnostic tests needed to be performed. This would also prevent tests that are not relevant from being tested for that patient as BMS are equipped with much more knowledge within this region."* [SIC]

Theme 3: Reinforces the Importance of the Role of a Biomedical Scientist in the Patient Pathway

The third most common theme, identified by 31% of respondents, was the essential role played by Biomedical Scientists in the diagnosis, monitoring, and treatment of patients. Specific comments made by respondents included:

"Embedding patients into the curriculum is important for biomedical science students. I feel that it provides perspective of the effects that your decisions can ultimately result in when working as a Biomedical Scientist." [SIC]

"The patient experiences were enlightening. Biomedical Scientists play a crucial role in patient care and should remember how important test results are for individual patients."[SIC]

DISCUSSION

This study aimed to create an opportunity for final-year biomedical science undergraduate students to engage with service users. The "service user event," accompanied by the reflective writing assessment, involved active student engagement with pathology service users, including both patients and practitioners, to foster a culture of reflective practice among students. The reflective assessment increased students' awareness of the critical role of pathology laboratory results in ensuring optimal patient care while highlighting strategies to improve existing NHS services to enhance patient experience and outcomes.

Incorporation of Revised HCPC Standards of Proficiency

The Biomedical Science degree at Aston University is an HCPC-approved course and an IBMS-accredited degree programme. The event and the assessment clearly met and highlighted the importance of the revised 2023 HCPC Standards of Proficiency [3], with an overwhelming number of respondents reporting an increased understanding of how to meet the needs of service users, with key themes being communication, consent, leadership, and use of information (**Figure 1**). Other studies involving patients within the undergraduate curriculum have reported the importance of creating a diverse learning environment to make education more engaging, powerful, and transformative while ultimately empowering patients [12]. Patients have reported that their involvement in the undergraduate curriculum allows students to hear an alternative perspective in order to better understand their conditions, thus highlighting their empowerment [18].

Our study identified a creative teaching and learning method involving patients and service users [19]. The workshop itself created an environment that was student-directed, participatory, and constructivist by allowing students to openly ask patients about their experiences of [20]. The students produced a 750-word reflective assessment to evaluate patient experiences, which was underpinned by Bloom's revised framework, which requires students to remember, understand, apply, analyse, and evaluate patient experiences and pathology services [21, 22].

A total of 94.8% of final-year respondents reported an increased understanding of "*public health and prevention of service users' ill health*" (**Figure 1**). Students are taught about the clinical presentation, diagnosis, and treatment of haemoglobinopathies as part of the biomedical science curriculum. However, through the service user event, they learned about the experiences of a patient living with beta-thalassaemia major, where the patient highlighted how errors made in the laboratories have substantially impacted their lives. Through a reflective assessment, the students were able to identify instances of good practice and laboratory advancements that could have potentially prevented the transfusion reaction experienced by the patient. Moreover, the students drew attention to emerging technologies such as point-of-care testing (POCT) devices, which offer swift and accurate results, enabling patients to actively manage their conditions and Biomedical Scientists to participate remotely in their care (**Figure 2**).

Similarly, students are taught the fundamentals of cancer biology as part of their undergraduate degree. However, the inclusion of a patient with a history of a giant cell tumour introduced students to a new malignancy that they would not otherwise have studied. After listening to this patient's experience, the students acquired new knowledge about the aetiology of a giant cell tumour, the difficulties surrounding the patient's original misdiagnosis, and the long-term complications that they experienced as a result. After listening to this service user experience, the students were encouraged to undergo the three-stage process of reflection, which includes a recollection of the experience, attending to one's own feelings, and re-evaluating the experience [14]. Students resonated and empathised with the patient's difficult experience, and upon re-evaluation, the majority felt that this patient's experience could have been improved. Suggestions included reducing turnaround times for both pathology and medical imaging tests, improving clinician-patient communication to empower the patient, and increased application of POCT as part of the initial diagnostic testing in an emergency care setting (**Figure 3**).

The COVID-19 pandemic has hastened changes that were already happening within the biomedical science profession, with regards to greater automation and POCT [23]. The Microbiology Consultant introduced students to the dynamic profession of a Biomedical Scientist, with wider adoption of molecular technologies and laboratories being much more responsive to clinical needs [24]. Furthermore, he showcased how clinical services are also changing and the need for greater efficiency [25]. On reflection, students highlighted that medical staff are often less experienced in understanding and requesting appropriate tests, highlighting the role of the Biomedical Scientist for undergraduate students. Furthermore, students recognised that patient conditions are becoming increasingly complex, requiring more expert advice from laboratories. Students recognised that the traditional role of a Biomedical Scientist will continue to be an important part of the patient pathway in the future while also recognising the need for the role to adapt to reflect technological advances and changing clinical needs (**Figure 5**). The adaptation of the traditional role of a Biomedical Scientist is already evidenced by the advent of the "Advanced BMS Practitioner" role being introduced into clinical practice [26]. Additionally, the revised HCPC SOPs

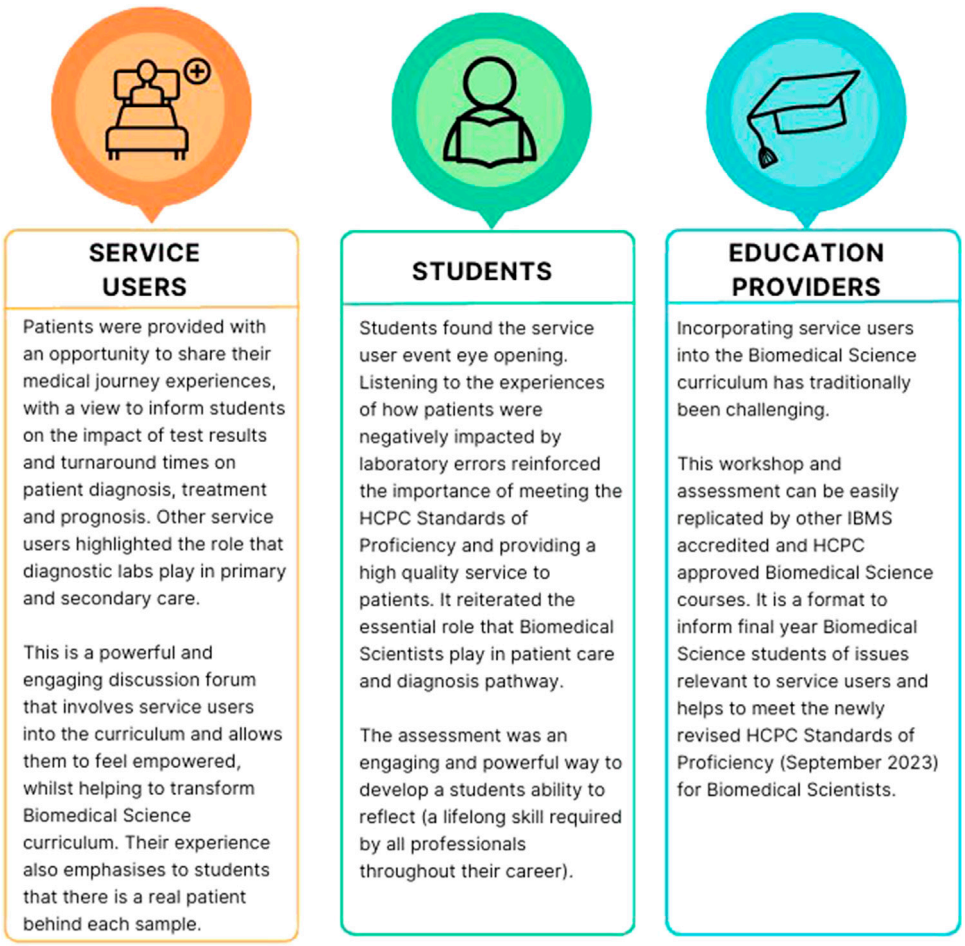

FIGURE 7 | The main benefits and outcomes of the innovative workshop for service users, students, and education providers.

emphasise the importance of "digital skills and new technologies," where registrants must be able to "change their practice as needed to take account of new developments, technologies, and changing contexts" [3].

The student survey (**Figure 2**) identified the importance of effective communication as a key theme. The primary care provider gave examples of the impact of transcription errors in labelling specimens and highlighted the negative impact this had on patients awaiting test results. This situation emphasised to the students how errors that are not communicated to the patient can heighten health-related stress, a theme that was identified by the students as part of their reflective assessment (**Figure 5**). The patient referral optimisation officer provided insight into the NHS specialist allocation scheme [27] and highlighted to the students some of the challenges that patients can face when enrolled in this scheme. Students reflected on how a negative interaction with a service provider can have a devastating long-term impact on patients. Students saw the value of communicating effectively while asking difficult questions and finding meaningful answers through the use of reflection (**Figure 3**). As the students identified the importance of effective communication with service users and stakeholders, this workshop met both the HCPC SOPs and the new QAA benchmark statement regarding communication [3, 28]. Other work has highlighted the importance of developing communication and interpersonal skills in undergraduate students [29].

Reflection constitutes a crucial element of continuing professional development (CPD) for healthcare professionals. It is firmly ingrained in the Standards of Proficiency for Biomedical Scientists, serving to safeguard ongoing standards of practice [29]. Following the completion of the reflective assignment, there was a significant increase in students' confidence when writing reflectively (**Figure 4**). The ability to reflect is an important and necessary lifelong skill that is highly sought after by employers in an ever-increasingly competitive graduate market. Despite biomedical science programmes effectively educating individuals in highly specialised areas, the transferable skills required, such as critical thinking, effective communication, and the ability to reflect, are often lacking [30].

Biomedical science programmes need to prioritise the inclusion of skill development opportunities through their portfolio of assessments, not only for current students but for them to become lifelong practitioners [30].

The benefits of patient involvement in the biomedical science curriculum are multifactorial, positively impacting patients, students, and education providers. These benefits are summarised in **Figure 7**. We hope the workshop can be widely adopted by other higher education institutes.

Future Work and Study Limitations

Several improvements were suggested by respondents through the open-ended component of the survey. These included increasing the number and diversity of speakers within the workshop to provide a greater overview of the service users of the pathology laboratories within the NHS. In line with this, respondents were in favour of incorporating more patient-focused speakers, as sharing their direct experiences will improve the services within public health. Students also expressed a preference for the opportunity to discuss high-profile cases involving pathology services that affected patient outcomes, such as the case of Dr. Bawa-Garba [31]. Students recognised inequalities in the way that Dr. Bawa-Garba was treated in relation to other medical professionals involved with the patients, highlighting the need for embedding equality, diversity, and inclusion training in education and as part of CPD [32]. The inclusion of ethnically diverse patients and speakers from a wider range of healthcare roles will help to better prepare students for future employment where they will have to work with a more varied population, which will require personalised approaches to their healthcare [33]. In line with other literature, respondents in the current study recognised the value of reflection and expressed an interest in its incorporation as both a formative and summative assessment throughout their biomedical science degree. Previous literature has emphasised the use of curriculum mapping to identify gaps in the curriculum and allow for the constructive alignment of graduate outcomes and assessments [34]. Through the use of curriculum mapping, reflective assignments will be further embedded within the biomedical science curriculum.

In terms of study limitations, at this year's service user event, we were unable to include Biomedical Scientists and Advanced Practitioners due to timetabling constraints and their availability on the day. In previous events, we have had both professions attend and in the future we will endeavour to include representation from Biomedical Scientists and Advanced Practitioners. Additionally, to enhance attendance and accessibility, we will explore the option of adopting a hybrid approach. This may involve facilitating online participation for professionals, allowing them to connect remotely and interact with students during the event. Furthermore, the overall response rate to the post-workshop survey was 57.5%. While this is higher than the average response rate for similar surveys that usually generate a 30%–40% uptake [35], this could be improved. One suggestion for future work is to collect "before" evaluation data, as this would provide a useful comparison with students learning and skill development following the service user event. In addition, offering financial incentives, such as gift vouchers, would increase the number of survey responses collected, an initiative that is widely used [36]. Finally, the service user event was held face-to-face on campus. Due to the increasing size of the biomedical science student cohorts each year, this can often present logistical challenges, such as finding suitable learning environments and space [17]. Moreover, it can be difficult for patients and service users to travel to university campuses, which may not be local or easily accessible due to their conditions. One potential solution to overcome this is to host an online service user event, although this may come with its own challenges, such as negatively impacting student-service user discussions.

CONCLUSION

While professional bodies require programmes to include service users within the biomedical science curriculum, pathology service users are often hard to identify. This large-scale workshop was successful in creating a platform to encompass a range of pathology service users while evoking meaningful discussions between students and these service users. The reflective assessment deepened students' understanding of the need for efficient NHS pathology services and the crucial role of a Biomedical Scientist in the diagnosis and monitoring of disease. The workshop was an important activity not only in terms of addressing the HCPC SETs in relation to service user involvement but also provided an opportunity to ensure that undergraduate biomedical science students gained an active appreciation of all the current revised HCPC SOPs. Through the reflective assessment, an overwhelming number of students saw the benefits of including pathology service users in the curriculum and developed important transferable skills that are required in graduate careers. We recommend that other IBMS-accredited and HCPC-approved Biomedical Science programmes adopt and embed this innovative workshop into their programmes to help them meet these service users' standards while fostering important transferable skills in their students.

SUMMARY TABLE

What is Known About This Subject

- Medical and Nursing programmes have successfully included patients in their undergraduate curriculum.
- The revised HCPC SETs require Biomedical Science courses to include service users in the curriculum.
- Including patients into a medically focused curriculum facilitates the development of essential transferable skills.

What This Paper Adds

- A novel approach to embedding pathology service users and revised HCPC SOPs into the Biomedical Science curriculum.
- Using a pedagogical framework, the reflective assessment encourages students to become reflective practitioners.

- The reflective assessment enhances students' knowledge and understanding of the impact of pathology results on patients.

CONCLUDING STATEMENT

This work represents an advance in biomedical science because the innovative workshop developed reflective students who value pathology service users and improvements in NHS service delivery.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Aston University HLS Ethics Commitee (1494). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AB contributed to the conception of the study and designed the research approach and survey. All authors contributed to the organisation of the interactive workshop and the design of the marking schemes for the reflections. All authors designed and carried out the post-workshop survey. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2023.11584/full#supplementary-material

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ORIGINAL RESEARCH
published: 29 June 2023
doi: 10.3389/bjbs.2023.11494

The Benefits of Using Case Study Focussed, Problem Based Learning Approaches to Unit Design for Biomedical Science Students

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As part of the Biomedical Sciences undergraduate degree course students are required to apply biological principles to the interpretation of clinical case studies and the diagnosis of patients. Case study-based learning, i.e., application of knowledge to patient diagnosis, is new to most students as case studies do not form part of non-applied A level courses in biological sciences. This approach is an example of Problem Based Learning (PBL) which has been shown to support higher levels of student learning, encouraging critical thinking and analysis. PBL approaches have also been shown to increase academic satisfaction and student engagement. In recent years we have observed a downwards trend in student engagement and historically student performance in applied case study-based assessments to be lower than that observed for assessments based on detailing fundamental biological principles. We hypothesised that PBL teaching delivery would support students in preparing for case study-based assessments, helping them to demonstrate their critical evaluation and problem-solving skills, and hence, improve student performance. We also hypothesised that the student learning experience would be enhanced by a PBL teaching delivery approach which would improve overall engagement. We therefore redesigned a second year Biomedical Sciences degree haematology and clinical biochemistry unit: "Blood Science," with a stronger focus on PBL, including case study focussed activities throughout the unit. We subsequently analysed whether this PBL-focussed unit design improved student experience and feedback, student engagement and student confidence for biomedical science undergraduate students. We present here, our teaching strategy and the impact our changes had on student feedback for the 21/22 and 22/23 academic years. Our findings demonstrate that case study-based activities and tutorial PBL exercises, when incorporated into the curriculum design, can improve student experience in the Biomedical Sciences and other biological science undergraduate degree courses.

Keywords: problem based learning, case studies, tutorials, biomedical sciences, blood science

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Received: *18 April 2023*
Accepted: *20 June 2023*
Published: *29 June 2023*

Citation:
Posner MG, Dempsey NC and Unsworth AJ (2023) The Benefits of Using Case Study Focussed, Problem Based Learning Approaches to Unit Design for Biomedical Science Students. Br J Biomed Sci 80:11494. doi: 10.3389/bjbs.2023.11494

INTRODUCTION

Over the past two decades there has been a substantial shift in approaches to higher STEM education. Traditional lecture-based delivery strategies, whilst efficient for delivery of material to large cohorts, are considered too passive and can mean they are ineffective for many students [1]. Tutors are increasingly being encouraged to replace lectures with active student-centred methods, which inspire university students to lead their own learning [1–3].

In Life Science subjects, student-centred learning, such as Problem Based Learning (PBL) has been shown to support higher levels of student learning and is particularly effective with medical students [4–6]. A PBL approach is student-centred, where students learn about a subject through the experience of problem solving and group discussions. PBL encourages active learning and meta-analyses have shown PBL to be the most effective approach for student learning [7], with students preferring PBL courses over standard lecture delivery for the long-term retention of course content, and the application of clinical skills and critical reasoning [8]. In addition to improved student performance, PBL approaches have also been shown to increase academic satisfaction and student engagement amongst biomedical science students [9].

Elements of the Biomedical Sciences undergraduate degree courses, particularly those units (modules) that are required for accreditation by professional bodies, require students to be able to apply biological principles to the interpretation of clinical case studies and diagnosis of medical conditions [10, 11]. Students must base their diagnosis on clinical presentations and laboratory findings and are required to explain the reasoning for performing certain diagnostic tests and for the results obtained. Students are further required to diagnose and then evaluate, based on clinical presentation, the most suitable treatment strategy for the patient [11].

Interpretation of clinical case studies is a key element of the Blood Science, Level 5 (second year undergraduate) unit, which combines Clinical Biochemistry and Haematology content and is studied by students on the BSc (Hons) Biomedical Sciences, Integrated Masters in Biomedical Sciences (MBioMedSci) and BSc (Hons) Human Biosciences at Manchester Metropolitan University [12].

In the majority of cases, prior to their undergraduate University degree, students have little experience of this, as interpretation of clinical case studies is not part of the curriculum or requirements for current A levels in Biological sciences in the UK (AQA, OCR examination boards) [13, 14]. Learning how to apply their knowledge to real life biomedical situations is a skill students need to develop during their course. In contrast, students who completed more applied Level 3 courses such as the BTec National Certificate in Applied Human Biosciences [15] are often more confident earlier in their degree course, when it comes to patient diagnosis and data interpretation as they are introduced to this at college (post 16 years) level study [15] (anecdotal conversations with students).

Previous student feedback surveys have identified that students struggle with applying the biological principles they learn in lectures to practical case studies, particularly as part of assessments. Feedback indicates students find case study interpretation difficult and would like more opportunity to practice.

To address this, and provide additional support for students, we introduced weekly (online) PBL, case study centred tutorial sessions for the 20/21 academic year.

In the 21/22 academic year, taking into consideration that students had faced 18 months of online learning due to the COVID-19 pandemic, we made further changes to the Blood Science unit design to improve the student experience. The unit was redesigned with a stronger focus on PBL activities with an increased number of student-led, in-person interactive tutorial-based sessions. A delivery approach that was continued and enhanced for the 22/23 academic year.

We present here, our teaching strategy and the impact of our changes on student experience for the 21/22 and 22/23 academic years.

Aims of the research: To analyse whether a PBL focussed unit design improves student experience and engagement.

METHODOLOGY

Ethical Approvals

This study was reviewed and approved by the Manchester Metropolitan University, Faculty of Science and Engineering Research Ethics and Governance Committee (Ref: 41585). There was no potential harm to participants; anonymity of participants was guaranteed. Feedback data was collected from anonymised Mid-Unit and End of Unit feedback surveys.

Study Cohort

The Blood Science unit is a large unit, with, on average, more than 200 students per academic year over the last 5 years. The 21/22 academic year saw the largest cohort size with 321 students (**Supplementary Table S1**). The cohort represents second year undergraduate students studying BSc (Hons) Biomedical Sciences, Integrated Masters in Biomedical Sciences (MBioMedSci) and BSc (Hons) Human Biosciences. Mid-Unit and End of Unit feedback surveys were available to all students via the student learning platform Moodle and in class surveys, with an average 15% completion rate over the academic years investigated (**Supplementary Table S1**).

Unit Design

The Blood Science unit looks at the roles of haematology, blood transfusion and clinical biochemistry laboratory tests in the diagnosis, treatment, and monitoring of disease processes. The aims of the unit are to enable students to appreciate the nature of biochemical and haematological disorders and the value of laboratory investigations in disease processes. The learning outcomes for the unit are shown in **Table 1** and are assessed via coursework and examination, each contributing 50% to the overall unit grade. The coursework is an essay on a current topic in Blood science, whereas the examination comprises three elements designed to test varying levels of learning and

TABLE 1 | Blood science learning outcomes.

LO1	Discuss the mechanisms underlying selected biochemical and haematological disorders
LO2	Know the role of and limitations of biochemical and haematological tests when investigating diseases
LO3	Describe the changes that occur in selected biochemical and haematological diseases and how these changes form the basis of laboratory investigation
LO4	Appreciate the importance of experimental approach and methods used in clinical biochemistry and haematology
LO5	Develop independent learning and critical thinking

knowledge [16]: clinical case study analysis and interpretation (apply, analyse and evaluate), multiple choice (MCQ) (remember, apply, analyse) and short answer questions (SAQ) (understand, apply).

Interactive learning is easier to deliver in small group teaching and more beneficial to students' learning [17, 18]. Delivering interactive learning for large student cohorts is a significant challenge for education providers and posed a significant challenge for the academic unit team for 21/22 and 22/23. Given the average cohort size of the Blood Science unit, these aspects were carefully considered when redesigning the unit delivery.

Previous Unit Design (Pre 2020)

Prior to the 20/21 academic year (prior to the COVID-19 pandemic), the Blood Science unit ran over 14 teaching weeks, with approximately 4 h of standard traditional lecture delivery per week, supplemented with a further 3 h of tutorials and 6 h of practical classes spaced throughout the 14 weeks. Practical classes included two clinical biochemistry laboratory classes, and one haematology practical class. Practical classes typically included a patient diagnosis element, focussing on the diagnosis of one condition/disease. Tutorials, were single case study discussions with associated background worksheets. These tutorial activities required completion before the in class tutorial session and discussions, and were uploaded to the unit Moodle area for access by students at the start of the unit. Whilst practical classes and lectures were frequently well attended, the tutorials were poorly attended, with limited engagement in class and lack of pre-class preparation (anecdotal evidence, as attendance figures not available).

Unit Redesign 1: 20/21 (the COVID-19 Pandemic)

During the 20/21 academic year, in response to the COVID-19 pandemic, the University switched its teaching delivery online and into short, focussed "block delivery" [19], with students completing one unit at a time, over a 6-week period. During this time the Blood Science unit was restructured into "theme weeks," 3 clinical biochemistry weeks, and 3 haematology weeks (**Supplementary Table S2**).

Each week contained on average 6 h of lecture/delivered content, delivered as a mix of live online lectures and pre-recorded online videos, and an online case study focussed tutorial, containing two case studies based on the weeks' content which required completion ahead of the online session (**Figure 1**). The tutorial case study based activity worksheets were uploaded to the unit Moodle area and made available to students from the start of unit. As observed in previous academic years,

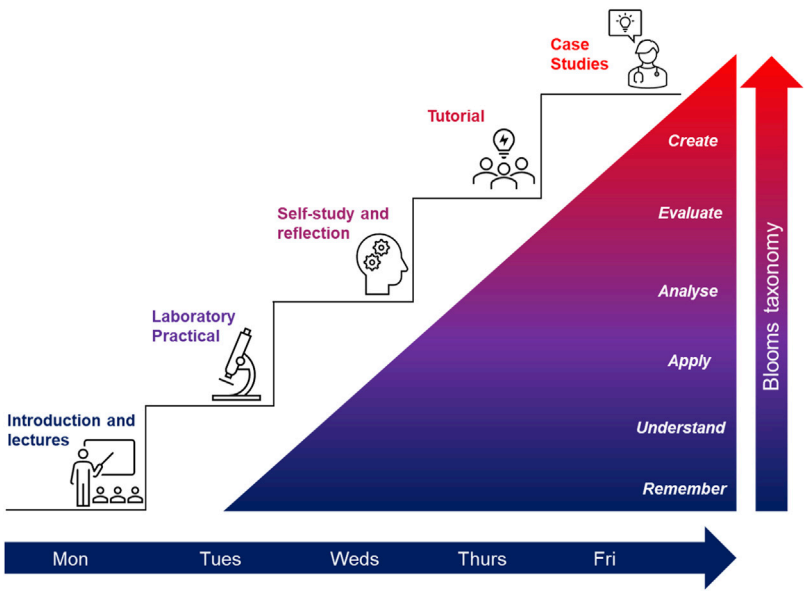

FIGURE 1 | Overview of the weekly delivery in Blood Science for block delivery 2021/22. At the beginning of each week students were introduced to a specific topic. Students were assigned to lab groups which rotated, i.e., students had their labs either in weeks 1 and 3, 2 and 4 or 3 and 6. This meant students had an additional day for self-study and to prepare for tutorials in addition to day 3, which is dedicated to students' self-study. The tutorials on day 4 were an opportunity for students to review and consolidated the material covered during the week. The week ended with case studies giving students the opportunity to apply their knowledge and deepen their understanding through a PBL approach.

these online tutorial sessions were also poorly attended, with contributions from only a few students in the discussions (using microphone and/or chat function within MS Teams). In addition to weekly lectures and tutorials, despite the move to online delivery, we were able to run one in-person laboratory class which was supplemented by two online practical classes using the Labster® online virtual platform.

Unit Redesign 2: 21/22—Case Study Focussed Delivery

Further changes to unit format and delivery were introduced in the 21/22 academic year to improve the student experience and maintain student performance following the return to face-to-face teaching and removal of 24 h, open-book examinations. For the 21/22 academic year, the 6-week Block delivery format with the themed weeks from the 20/21 academic year remained the same (**Supplementary Table S2**).

The Introduction of Interactive PBL Tutorials

Instead of the traditional lecture focussed delivery of previous years, the unit team delivered one 2-h on campus lecture per week, with the remaining topics covered in pre-recorded online material uploaded to the unit Moodle area. This allowed staff to focus on in-person interactive smaller group teaching with weekly Topic tutorials (2 h) and weekly Case Study tutorials (2 h). Topic tutorials were focussed on the understanding of biological concepts and required students to work in small groups to complete a series of workbook activities (**Supplementary Figure S1**). Case study-based tutorials were tailored to focus on the application of knowledge and clinical practice. These sessions required students to work in small groups to diagnose patients based on clinical presentation and laboratory findings and evaluate suitable treatment and management strategies (**Supplementary Figure S2**). Topic tutorial and case study tutorial worksheets were published at the start of the unit and available to students to access ahead of time to accommodate their own learning styles. Whilst students were expected to have attended the weekly lecture, and to have watched the weekly online content ahead of the tutorial, neither of the tutorial sessions required pre-session work or completion of the activities prior to the session, in contrast to previous years. Students were instead, encouraged to work through the problems in class and discuss their findings and conclusions. Staff were present to facilitate discussion and provide assistance.

Redesign of the Unit Practical Classes—Introduction of Additional PBL Resources

When redesigning the unit with a focus on PBL, both the clinical biochemistry and haematology practical classes were also redeveloped, as clinical laboratory-based case studies. In the practical classes students perform a series of clinical biochemistry or haematology laboratory assays to facilitate the diagnosis of four separate patients. As Manchester Metropolitan University uses Moodle, we have free access to the H5P platform via a Moodle plugin. Using the platform we created complimentary interactive online practical related activities, similar to those we have described before [20]. This platform provided additional practical support for students and assisted in the analysis of their laboratory findings alongside other clinical laboratory data (**Supplementary Figure S3**). Enabling them to combine both their practical and theoretical knowledge to the case studies.

Unit Redesign 3: 22/23—Updated Case Study Focussed Delivery

Further changes to unit format and delivery were introduced in the 22/23 academic year to accommodate the University's return to "semesters," with students completing two units simultaneously over a 12-week period. To accommodate this change in delivery format, the Blood Science themes were retained, but spread over multiple weeks (**Supplementary Table S3**), with two unit specific days scheduled per week (**Figure 2**).

The content delivered in the 21/22 academic year was retained, but in response to student feedback, lecture delivery hours were increased to 2 h per week over 12 weeks. A 2 h PBL focussed tutorial was held weekly, which mixed the previous years "topic" and case study based tutorials together in line with weekly content. Similarly to that observed in the 21/22 academic year, tutorial activity worksheets were made available at the start of the Unit semester, although students were not expected to complete the material before the session. Practical classes offered were the same as 21/22, with associated interactive material. The only addition was the inclusion of a "Unit case study tutorial" in the final week (week 12), which involved an extended case study tutorial that incorporated content from across the unit, bringing clinical biochemistry, haematology and transfusion elements together. Extra online interactive case study activities created using H5P platform via a Moodle plugin were also available and provided as additional tools for students to assess their knowledge and understanding (formative assessments) (**Supplementary Figure S4**).

Data Collection and Analysis

Student Feedback

Anonymised student feedback results from the 20/21, 21/22 and 22/23 programme standardised "mid-unit" and "end of unit" feedback surveys, adopting 5-point Likert scale type questions, and free open text fields (**Table 2**) were collated and analysed. Students were asked in the Mid-unit and End-of unit feedback questionnaires to rate whether they agreed with a set of statements regarding their enjoyment of specific unit activities (**Table 2**), on a scale of "definitely disagree, mostly disagree, neutral, mostly agree, definitely agree." Student responses were anonymised, and a 15% average response rate was achieved across the cohorts with the highest feedback response rate achieved in 22/23 (22%). Data were collated and expressed as positive ("mostly agree and definitely agree"), neutral, and negative (mostly disagree and definitely disagree) due to small sample sizes.

Engagement

Attendance Rates

Average student attendance figures (% attendance) were collected and compared for tutorial sessions selected at random for the

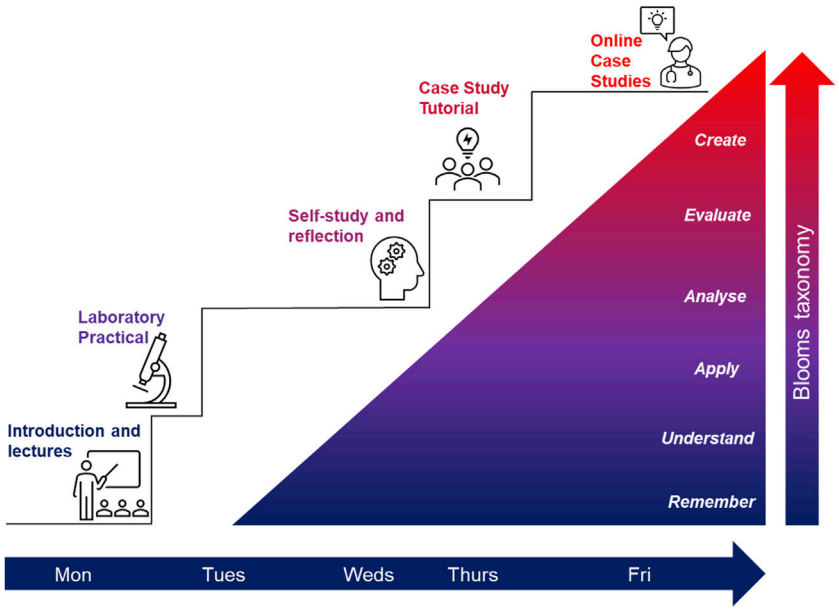

FIGURE 2 | Overview of the weekly delivery in Blood Science for semester delivery 2022/23. On Mondays of each week students were introduced to a specific topic. Students were assigned to lab groups which rotated, i.e., students had their labs either in weeks 1 and 7, 2 and 8, 3 and 9, 4 and 10, 5 and 11. This meant students had additional time on Mondays for self-study and to prepare for tutorials in addition to Wednesdays, which were dedicated to students' self-study. The tutorials and case studies on Thursdays were an opportunity for students to review and consolidate the material covered during the week, and an opportunity to apply their knowledge and deepen their understanding through a PBL approach. Fridays were additional study days, where students could work through online activities and case studies to further test their knowledge (formative assessments).

TABLE 2 | Feedback questions.

Statement	Possible answers
The laboratory practicals were engaging and supported my learning The online practicals were engaging and supported my learning The Case study-based tutorials were engaging and supported my learning I enjoyed the Blood Science unit	• Definitely Agree • Mostly Agree • Neither Agree nor Disagree • Mostly Disagree • Definitely Disagree

academic years, 21/22 and 22/23, using the University PRESTO attendance recording software and in class head counts. Attendance figures for the 19/20 and 20/21 academic year were unavailable and could not be included in this analysis.

Moodle and H5P Usage

Student engagement with interactive H5P Moodle activities; including the interactive practical activities (21/22 and 22/23) and case study activities (22/23) were measured by downloading the Moodle "Activity completion" reports. The proportion of students completing the activities was then calculated and presented as a percentage of the cohort. Activity completion rates of weekly formative MCQs, which were made available to students on Moodle, were also collected for comparison.

RESULTS

Evaluation of the Case-Study Focussed PBL Activities in the Blood Science Unit

Student Feedback

To assess the effectiveness of case-study focussed PBL *versus* previous approaches, we analysed students' feedback of all the unit elements that had been updated compared with previous cohorts. Due to changes to the unit team leadership and University reporting systems, we only had comparable student feedback from the 20/21, 21/22, and 22/23 cohorts.

Feedback to all questions was improved in the 21/22 cohort vs. the 20/21 cohort and maintained (or further improved) in the 22/23 cohort (**Figure 3**) to "overall positive" from "neutral positive," with fewer students rating activities negatively. Over the academic years assessed, an increased proportion of students agreed that the unit and unit activities were enjoyable and supported their learning. Changes implemented in the 21/22 and 22/23 academic years to the case study focussed tutorials, led to none of the students surveyed rating the tutorials as negative compared with the 20/21 academic year (**Figure 3B**) with a 25% increase in positive ratings in 22/23 vs. 20/21. An ~35% improvement in positively rated feedback was also observed for the laboratory practicals following their redesign in 21/22 (**Figure 3C**).

We were also surprised but pleased to see an increase in positive feedback with regards to the online practical activities in the academic years 21/22 and 22/23 versus 20/21. We had

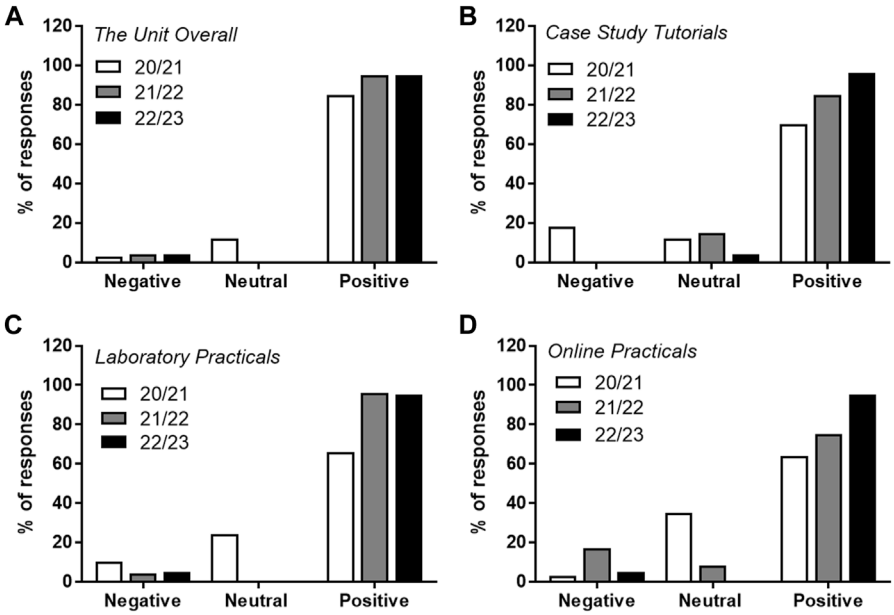

FIGURE 3 | Blood Science unit and session feedback for the 21/22 academic year compared with 20/21. Data for academic feedback from the 20/21 (white bars), 21/22 (grey bars) and 22/23 (black bars) academic years are presented as the relative percentage of student's responses. Data presented from the results of rating the following statements **(A)** I enjoyed the Blood Science unit **(B)** The Case study-based tutorials were engaging and supported my learning, **(C)** The laboratory practicals were engaging and supported my learning, **(D)** The online practicals were engaging and supported my learning. Data was collated and expressed as positive (mostly agree and definitely agree), neutral, and negative (mostly disagree and definitely disagree).

anticipated that our tailor made online practical supporting material (designed in H5P) may receive less positive feedback when compared with the online/virtual Labster activities used in 20/21. However, the feedback shows students appreciated the bespoke focussed nature of the material, that were directly relevant to other elements of the unit.

As part of the feedback survey, students were also provided with an open text box to write any additional comments they had regarding the Unit. No neutral or negative comments were received in relation to unit PBL based design, the practical sessions, tutorials, or case study sessions. Negative comments received were in relation to group/class allocations, lecture delivery, room allocations and timetabling, most of which were out of the control of the Unit team. An anonymised representative selection of feedback comments regarding the Blood Science unit 21/22 and 22/23 PBL based delivery can be found in **Table 3**.

In further support of our strategy to incorporate PBL activities within our unit design, comparison of student feedback for the Blood Science unit compared with other Biomedical Sciences units with the same student cohort in 22/23, demonstrates a substantially higher rate in positive feedback for the Blood Science unit (+30%). This feedback indicates that the in-person PBL case study focussed activities are enjoyed by students.

Student Engagement

To assess student engagement with the Blood Science unit, tutorial attendance was compared between the academic years 21/22 and 22/23. Tutorial attendance was used as a measure, as increased attendance would indicate students enjoy and recognise the benefit of the sessions. We observed an increase in student engagement with the case study tutorial sessions, with attendance increasing by 20% for the academic year 22/23 compared with 21/22.

Student interaction and engagement with the interactive bespoke H5P Moodle activities was also compared, following implementation of our PBL unit delivery approach. A 5% increase in students completing the online practical support package was observed from the 21/22 to 22/23 academic years, although we observed overall low engagement with this activity (<20%) which is not unexpected as the in-person laboratory practical classes were very well attended. Online H5P interactive case study activities were introduced for the first time in 22/23 and we observed a 30% engagement rate with these activities. In comparison, a 65% completion rate of weekly formative ("practise") MCQ questions (available on Moodle) was observed, indicating we can do more to sign post students to these interactive activities.

In further support of our strategy to incorporate PBL activities within our unit design, comparison of student attendance for the Blood Science unit (total unit attendance rates)_compared with other Biomedical Sciences units with the same student cohort in 22/23, demonstrates a +10% higher attendance rate for the Blood Science unit. Increased attendance rates for the Blood Science unit indicates that the in-person PBL case study focussed activities, including the tutorials and practical activities are enjoyed by students and encourage their engagement with the taught material.

TABLE 3 | Blood Science unit feedback comments.

"The format was good. Learning the content, going through the workbook and then looking at case studies was good"
"I loved the Thursday and Friday sessions! It was really useful to go through the content and know that I was understanding it correctly and in enough detail"
"I enjoyed the whole layout of the unit and the content"
"I enjoyed the tutorials, applying the knowledge to real life scenarios/diseases was very helpful"
"The way this unit was organized was very helpful. Tutorials were amazing"
"The tutorial and case study sessions really helped consolidate my knowledge"
"Enjoyed having a case study session every week"
"The tutorial worksheets should be applied to all Units as it helps structure your revision and content"
"I really enjoyed how interactive the unit was especially the tutorial sessions"
"Tutorial and case study sessions were extremely helpful"
"I really enjoyed doing the case studies"

Taken together and in support of findings made previously by others, we demonstrate that a PBL unit design and delivery can improve student feedback and engagement in Biomedical Sciences [1, 3].

DISCUSSION AND REFLECTION

The Higher Education (HE) sector plays a critical role in preparing students for their future careers [21] and meeting the Institute of Biomedical Sciences (IBMS) [10] accreditation criteria is vital to deliver courses relevant to current professional practice. Here we report the delivery design strategy for PBL-focussed [22] unit and assessments for the Blood Science unit (L5) that forms part of the Biomedical Sciences undergraduate degree course at Manchester Metropolitan University, which meets accreditation standards and benefits student enjoyment and engagement. The student centred, PBL approach is used in various disciplines but finds particular application in medical related teaching [2, 4, 23]. PBL is associated with improved long-term knowledge retention and improved student satisfaction [22]. Considering the value and importance for students to acquire skills in interpreting real life scenarios, PBL should be the preferred approach. In addition, student feedback highlights improved student satisfaction when active learning approaches are used, and increased student satisfaction is associated with decreased drop-out rates and enhanced student outcomes [24].

Challenges to implementation of PBL activities within programmes, include large student numbers, low staff: student ratios and initial "buy-in" from students, who frequently raise in their feedback that they like and want more lecture content. Whilst traditional lecture-based delivery is an efficient way to deliver material to large cohorts with lower numbers of staff, there is an abundance of evidence, that demonstrates that lectures are not the most effective method of learning for most students [1, 2]. Lectures also fail to develop key problem solving, critical thinking and evaluation skills, with limited opportunities for student led learning [1, 3, 25].

We demonstrate here, that PBL activities can be incorporated throughout unit (module) design and can be successfully implemented in programmes that cater for large cohorts, resulting in improved student engagement and an improved student experience. To meet our accreditation requirements and prepare our students for working professional practice requirements, we aligned our unit design and delivery to clinical case studies, providing real-life examples to promote and encourage student engagement and interaction with the unit content [26]. In our initial redesign of the unit, despite large student numbers, we favoured smaller group in-class PBL over traditional lecture delivery. Flipped learning exercises have been shown to be successful with pharmaceutical students, increasing student attendance and improving student learning [2]. By introducing these flipped learning tutorial sessions as our tutor facing "in person" contact sessions and providing online "lecture" content, we placed an emphasis on discussion and group work in our teaching sessions instead of passive learning activities. Incorporating group discussions as part of teaching delivery enables students to explore different perspectives, develops collaborative learning, increases "intellectual agility," and promotes "connection" to a topic [27]. These more interactive sessions require students to fully engage with the session, encourages group working and improves critical thinking [25]. On reflection, we did find that students were initially hesitant with this more interactive student led approach, with poorer attendance at these sessions compared with traditional lecture delivery (−5%). We would therefore advise introducing group work activities as early as possible at undergraduate degree level and perhaps even earlier, to encourage students to fully engage in the sessions. Despite this, we were pleased to observe that attendance rates for the global Blood Science unit were higher than those for other Biomedical Science units (+10%), indicating that our PBL focussed activities, encourage student engagement with the unit content and sessions. We do recognise that engagement with interactive online activities could be improved, especially when compared with our formative MCQ quizzes, and will signpost these more regularly to students in the future.

The application of knowledge in the form of weekly case studies and practical sessions throughout the Blood Science unit, helps our students to reinforce their learning throughout the unit, and develop their critical analysis skills. "Reinforcement Learning" has been shown to increase in student performance and student satisfaction, and improve tutor experience [28]. Feedback from staff delivering tutorials and practical sessions in the Blood Science unit described an increase in student confidence and participation in the sessions and ability to complete the case study activities as the unit progressed. We also observed an improvement in student feedback regarding the case study-based tutorials from the "mid-unit" feedback to "end of unit" feedback surveys (44% (mid-unit) vs. 69% (end of unit) of students selecting "Definitely agree"). Staff feedback was also improved regarding the perceived success of the case study-based unit delivery, including appreciation for delivering the newly developed sessions and being more confident that students were able to apply their knowledge gained from the lecture material by the end of the PBL sessions. Students throughout the discussions showed a good grasp of the subject content, and were able to describe, discuss and evaluate patient diagnostic and treatment

strategies for a range of clinical biochemical and haematological disorders.

We acknowledge that the current study is limited by the low response rates to our feedback surveys, with an average 15% participation rate. This low response rate may also inadvertently bias the study findings, by self-selecting for those students who rate the unit positively more likely to take part in the survey. However, we believe our findings are representative as our unit achieved higher rates of positive feedback (+30%) compared with other biomedical science units with similar feedback response rates (15% or less), thereby demonstrating our PBL approach to unit delivery improves the student experience. We believe our data demonstrate that our strategy was not only successful in meeting the key objectives and learning outcomes of the unit, our session design also provides additional support to students enabling them to achieve the higher levels of learning expected at undergraduate degree level [16] that is more difficult to achieve using traditional lecture delivery [1, 4]. Interestingly however, we do continue to see repeated requests from students in the mid-unit and end of unit surveys for the inclusion of more traditional lecture delivery. This demonstrates that whilst PBL learning approaches have been shown to be more effective for student learning, students may not fully appreciate the positive impact PBL approaches can have on their own learning and development.

In the future, it will be of interest to analyse whether participating in a PBL-based learning approaches not only improves student experience and engagement but whether these approaches will improve student attainment. Due to the changes in assessment design and "take at home" examination conditions required during the COVID-19 pandemic, we do not have comparable unit assessment data, and were unable to perform this analysis. In the 22/23 academic year, which saw a return to closed book, on campus examinations for all units, the Blood Science unit did see increased student performance compared with other biomedical science units taken in the same assessment period by the same cohort, with higher pass rates on first attempt (+14%) demonstrating our PBL approach supports student attainment. We will continue to monitor unit performance in the future to assess the success of this new delivery strategy. It will also be of interest to see whether participation in PBL-based learning, benefits students in their final year of their undergraduate degrees and improves overall student attainment, and whether the use of this PBL based approach in their second year helps students with the critical evaluation and problem-solving required in their final year haematology units and research projects.

Advance HE's recommendations for an inclusive curriculum include student-centred collaborative approaches, such as small group work and facilitating peer-led learning approaches that are supported in our delivery strategy [29]. We are therefore keen to ascertain whether our PBL-approach will have a positive effect on the ethnic minorities attainment gap observed in biomedical sciences [30, 31]. During preparation of the case study material staff were encouraged to include inclusive practical examples. Lack of data, and pandemic related disruption to assessments, however, prevents this analysis from being performed as part of this project.

STUDY OUTCOMES

Case study based tutorial and laboratory PBL exercises, when incorporated into curriculum and unit design can improve student experience and feedback in biomedical science and other biological science undergraduate degree courses. The authors believe this approach would also work with blended/hybrid models of teaching delivery, although we strongly recommend face to face "in person" tutorials to increase active participation and engagement. We also believe that this approach could be used to incorporate "real life" interactive scenarios into the teaching delivery of various disciplines outside of the life and medical sciences.

SUMMARY TABLE

What is Known About the Subject?

- PBL encourages active learning and has been shown to increase student outcomes, academic satisfaction and student engagement.
- Accredited Biomedical Science taught courses require students to be able to apply biological principles to the interpretation of clinical case studies and diagnosis of medical conditions.
- Students find case study interpretation difficult and historically have underperformed on case study based assessments.

What This Paper Adds

- A novel approach to PBL unit design for a second year Biomedical Science undergraduate degree course.
- Case study-based practical activities and tutorial problem-based learning exercises, improves the student experience.
- This novel PBL haematology and clinical biochemistry unit design leads to increased positive student feedback and engagement in Biomedical sciences.

SUMMARY SENTENCE

This work represents an advance in biomedical science because we demonstrate effective incorporation of PBL into a biomedical science unit that improves the student experience and is compatible with delivery to large cohorts.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Manchester Metropolitan University, Faculty of Science and Engineering Research Ethics and Governance Committee. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

AU drafted manuscript; MP, ND, and AU edited and revised manuscript. All authors contributed to the article and approved the submitted version.

FUNDING

MP, ND, and AU were funded by Manchester Metropolitan University.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Ahmed, Mr. Broughton, Dr. Crescente, Dr. Humphries, Dr. Guo, Ms. Moore, Dr. Ogbodo, Dr. Page and Dr. Pritchett for their assistance with design and delivery of the Blood Science unit taught content across the 20/21, 21/22, 22/23 academic years.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2023.11494/full#supplementary-material

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ORIGINAL RESEARCH
published: 19 April 2023
doi: 10.3389/bjbs.2023.11284

Embedding Scientific Communication and Digital Capabilities in the Undergraduate Biomedical Science Curriculum

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Introduction: Scientific communication, particularly the dissemination of research findings to both the scientific community and the general public, are skills required of graduates embarking on post-graduate studies and employment within the biomedical sciences sector. The aims of this action research project were to i) co-design an online scientific communication and digital capabilities resource, constructively aligned to the learning objectives of a final year undergraduate investigative research project; ii) ensure resource flexibility for future adaptation by others iii) embed authentic scientific communication learning assessments, namely, the preparation of a lay summary and visual abstract and iv) promote students' awareness of developed digital capabilities and transferable skills through written reflection.

Materials and Methods: Student engagement, self-efficacy, experiences and performance and staff perceptions (n = 15) were evaluated by a mixed methods approach. Qualitative data was gathered from focus sessions, free text responses within questionnaires and content analysis of students' written reflections (n = 104). Quantitative data from 5-point Likert responses within student questionnaires (n = 31) and analysis of student scientific and lay writing (n = 146) using the readability parameters Flesch-Kincaid Grade Level and Flesch Reading Ease were analysed using non-parametric statistical methods.

Results: A learning resource was co-designed with students, staff, local, national and international contributors and valued by both students and staff, enabling students to prepare scientific communication outputs of a professional standard by application of digital, analytical and scientific communication skills. Students prepared lay summaries which were statistically ($p < 0.0001$) more readable than their paired scientific abstracts. Significant correlations between easier readability of lay summaries and awarded marks for the written elements of the module were noted. Students reported their digital and communication capabilities increased significantly ($p < 0.0001$) throughout, from limited to good/excellent and reflected on the numerous transferable skills developed during preparation of assessments, with 75% reflecting on their digital capabilities.

OPEN ACCESS

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Received: *17 February 2023*
Accepted: *28 March 2023*
Published: *19 April 2023*

Citation:
Millar BC, Tarasov A, Ternan N, Moore JE and Murphy C (2023) Embedding Scientific Communication and Digital Capabilities in the Undergraduate Biomedical Science Curriculum. Br J Biomed Sci 80:11284. doi: 10.3389/bjbs.2023.11284

Discussion: Undergraduate students developed, appreciated and used varied scientific communication and digital skills to articulate research findings. The embedding of such activities throughout all levels of higher education will enable students to develop their digital and scientific skills and reflect on the development of such transferable skills for application in their future careers.

Keywords: biomedical science, lay summary, scientific communication, visual abstract, digital capabilities, curriculum, reflection

INTRODUCTION

Pivotal to the effective and inclusive delivery of healthcare, is the ability to draw upon scientific evidence to inform healthcare practice as well as communicate with varied stakeholders and patients. Effective communication is a skill which all employers seek irrespective of the type of employment or the role an employee fulfils within the employer's institution. Within the healthcare sector effective communication is an essential competency which the regulatory body, Health and Care Professions Council (HCPC), insists that healthcare professionals, including biomedical scientists, must meet in order to fulfil their Standards of Proficiency, which have been modified and are effective from 1 September 2023 (1). These modified standards reinforce the importance that healthcare professionals possess essential verbal and non-verbal skills to engage and effectively communicate with multi-disciplinary members of the professional healthcare team as well as patients. Furthermore, these modified standards of proficiency now place greater emphasis on registrants using information, communication and digital technologies to communicate effectively (1). Such skills will aid to ensure that factors such as age, capacity, learning ability and physical ability are considered to ensure inclusiveness in order that service users and their carers can make informed decisions on the current information or evidence available (1).

Lay communication is important for several reasons, namely, in relation to public awareness and engagement, trust in scientific research, influencing public behaviours and opinions, improving scientific and health literacy, recruitment in clinical trials, as well as political and funding support (2, 3). Additionally, Editors of peer-reviewed journals have focused on innovative modalities to disseminate research digitally and the visual abstract provides one such approach to convey research findings visually and succinctly (4). Digital literacy is of fundamental importance in enabling the successful development of scientific communication competencies, both in relation to digital technical skills, as well as encouraging a positive approach to utilising these skills within a varied employment sector (5, 6).

Central to biomedical science undergraduate research programmes are final year research/investigative projects which promote the development of practical research skills including technical, experimental design, data acquisition, analytical and problem-solving skills. The professional body, the Institute of Biomedical Science (IBMS) which accredits these undergraduate degree programmes (7) and the recent Quality Assurance Agency (QAA) for Higher Education Benchmark statement for Biomedical Sciences (8) have set the requirement that the development of key transferable skills should be encouraged including, competency in a range of appropriate communication platforms, both digital and physical, for the effective dissemination of information to scientific and lay audiences. The QAA Benchmark also states that authentic assessment in Biomedical Science degree programmes should include various types of communication, e.g., graphical, posters, video, website and written formats targeting a varied audience (8). It is therefore important that students comprehend the various implications of research findings and be taught why and how the significance of these findings are disseminated, to both the scientific community and the general public who have varied levels of understanding (9).

An engaging innovative curriculum designed as per the Integrated Curriculum Design Framework (10) and underpinned by pedagogical methods would ensure a focus on the development of such scientific communication skills and associated digital capabilities thereby enhancing the student experience. An online resource developed with students and staff in collaboration and partnership with other related professional communities would support students prepare learning/assessment activities enabling the development of higher order critical thinking skills and communication competencies required by employers, including those within the healthcare and scientific sectors.

The aims of this action research project (ARP) were to i) co-design an online scientific communication and digital capabilities resource, constructively aligned to the learning objectives of a final year undergraduate investigative research project; ii) ensure resource flexibility for future adaptation by others iii) embed authentic scientific communication learning assessments, the preparation of a lay summary and visual abstract and iv) promote students' awareness of developed capabilities and transferable skills through written reflection.

The objectives of this ARP were to i) measure the extent to which students utilised the co-produced online resource, ii) measure the effectiveness of a standardised approach to assessing the students' professionalism and skills development *via* two novel learning activities, namely the preparation of a lay summary and visual abstract, iii) evaluate student perceptions of how their confidence, competence and capabilities were developed through the scientific communication and digital skills learning activities and iv) evaluate the potential of the

shared resource to be modified and used in other levels of teaching and assessment.

MATERIALS AND METHODS

Participants

All undergraduate students (n = 148) enrolled the final year undergraduate research project 60 credit point module during the academic year 2020–21, within the School of Biomedical Sciences at Ulster University were invited to participate in this study. Students who completed the module (n = 146) in the normal timeframe were enrolled in different Honours degree programmes, namely Biomedical Science 3y programme (n = 79), Biomedical Science Diploma in Professional Practice (DPP) (Pathology) (n = 20), BMS Diploma in Professional Practice (n = 23) and Biology (n = 24). All Biomedical Science courses were accredited by the IBMS. All supervisory academic staff (n = 38) associated with the assessment of submitted investigative dissertations were invited to complete a survey as detailed below.

Evaluation Methodology

A mixed methods approach was used to evaluate this ARP. Qualitative data gathered through reflective feedback, focus groups and free text responses within student and academic staff questionnaire responses were used to evaluate the intervention in terms of perceptions and experiences. Quantitative data and statistical evaluation allowed further refining and evaluation of the outcomes of this project from data gathered through questionnaires and analysis of lay-writing outputs (see below) (11).

Student Focus Groups

An e-mail was sent to all students enrolled in investigative project module from the School office calling for expressions of interest, to contribute to an online focus group to co-design resources to support students prepare novel scientific communication assessments and highlight the importance of transferable employability skills. A virtual meeting was held using the web-based virtual learning environment and learning management system, Blackboard Learn, by means of the online meeting tool, BBL Collaborate Ultra. Five self-nominated students, a Visiting Professor from the healthcare sector, with supervisory responsibilities within the Final Year Investigative Project module and lead study author were in attendance. Students outlined the key materials they felt would be required to successfully complete the novel learning activities.

Following completion of all module assessments for the academic year 2020–21, the School e-mailed invitations to all students enrolled in the investigative project module, seeking expressions of interest to participate in an online reflective focus group. Due to availability, two such sessions were held with three students and two staff members in attendance in each session. One session was attended by three students who also attended the initial co-design focus session. All students who expressed an interest in being involved in any of the focus sessions participated in their requested focus group.

Student Engagement With Online Resource

The online scientific communication and digital capabilities "toolkit" resource was housed on the Blackboard Learn module site. Blackboard Learn statistics tracking enabled an analysis of student access including time periods and frequency of consultation of the online resources.

Surveys

Following completion of all module assessment for the academic year 2020–21, the School e-mailed invitations, containing a link to respective questionnaires managed through Microsoft Forms, to all students enrolled in the final year research program module (**Supplementary Table S1**), and supervisory staff (**Supplementary Table S2**). A single reminder was sent to students 4 weeks after the initial email after the final year examination period.

The student questionnaire provided students the opportunity to qualitatively reflect on the suitability of the resources provided and the acquisition of transferable skills. Using a 5-point Likert Scale, students (n = 31 respondents) quantitatively evaluated: i) the development of their capabilities in relation to the assessment tasks and digital literacy; ii) the support provided throughout the module; iii) the importance of embedding transferable skills development in undergraduate degree programmes; iv) their confidence in applying such developed skills in future studies and/or career and v) their preferences on how information and guidance should be delivered.

The staff questionnaire provided staff the opportunity to qualitatively reflect on the introduction of these new assessment activities. Using a 5-point Likert Scale, staff (n = 15 respondents) quantitatively evaluated: i) the importance embedding transferable skills development in undergraduate degree programmes; ii) the applicability of embedding the preparation of visual abstracts and lay summaries into the module and iii) how the introduction of these tasks helped in their assessment of students.

Readability Analyses

The readability of students' scientific abstracts (n = 146) and paired lay summaries (n = 146) were analysed using the subscription software package, Readable (www.readable.com). The readable package was chosen as it is reliable, easy to use and widely available (12). Two readability measures, the Flesch-Kincaid Grade Level and the Flesch Reading Ease were used to assess whether the students adapted their writing in consideration of a lay audience. These readability measures were chosen as they have been used widely used and accepted by scientific and non-scientific communities alike (13).

Qualitative Data Content Analysis

Students were requested to reflect on their experiences during the completion of the Final Year Investigative project, with a particular focus on employability as outlined in the toolkit. A content analysis was performed on the reflective writing of each student who gave signed consent (n = 104/146; 71.2%) (14). Content analysis is a recognised qualitative approach to analysing data in pedagogical action research studies and guidance on this thematic analysis approach has been provided by Lin Norton (14). In the case of this

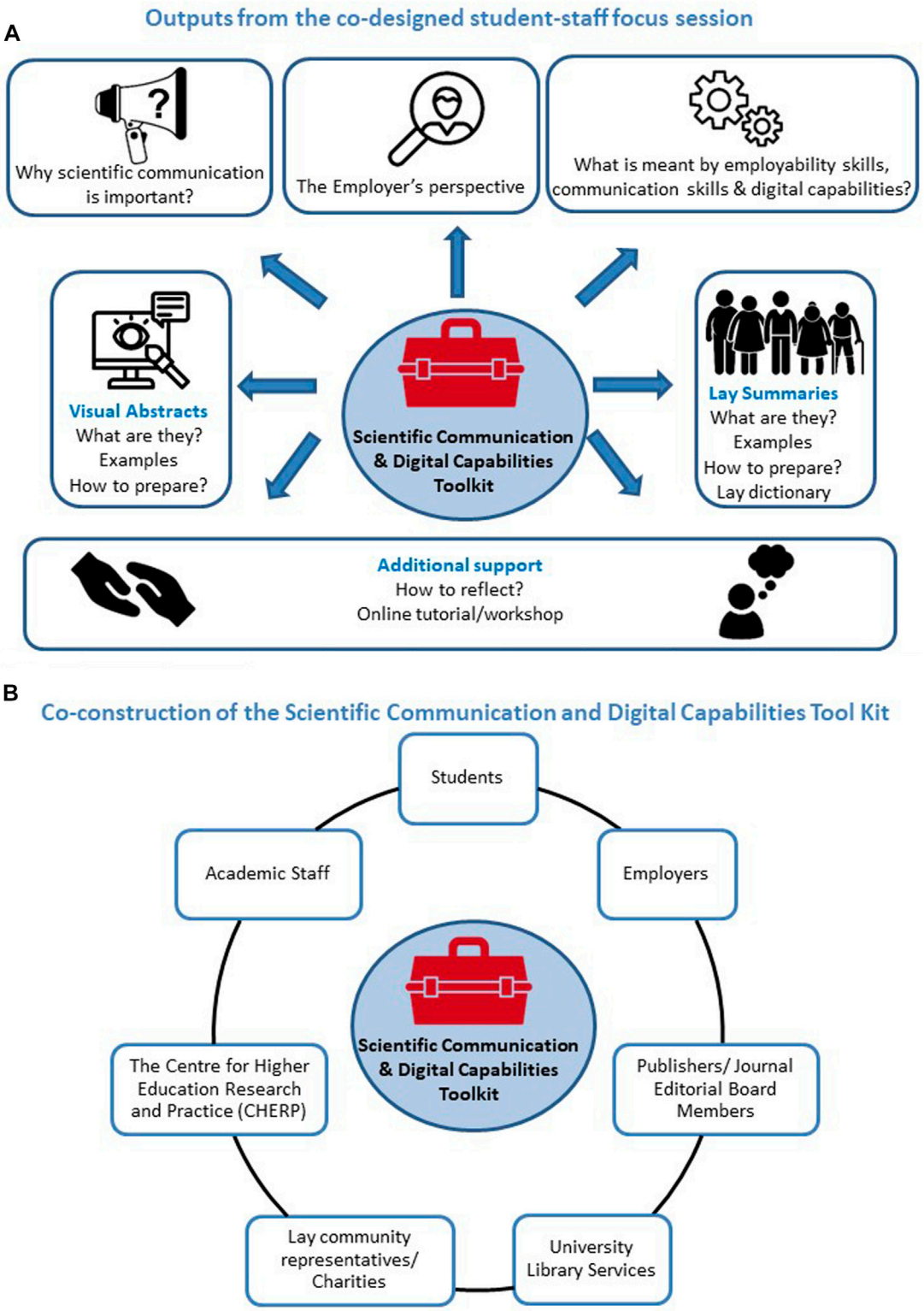

FIGURE 1 | The blueprint of the online Scientific Communication and Digital Capabilities Toolkit prepared following the co-design focus session **(A)** and the various contributors **(B)**.

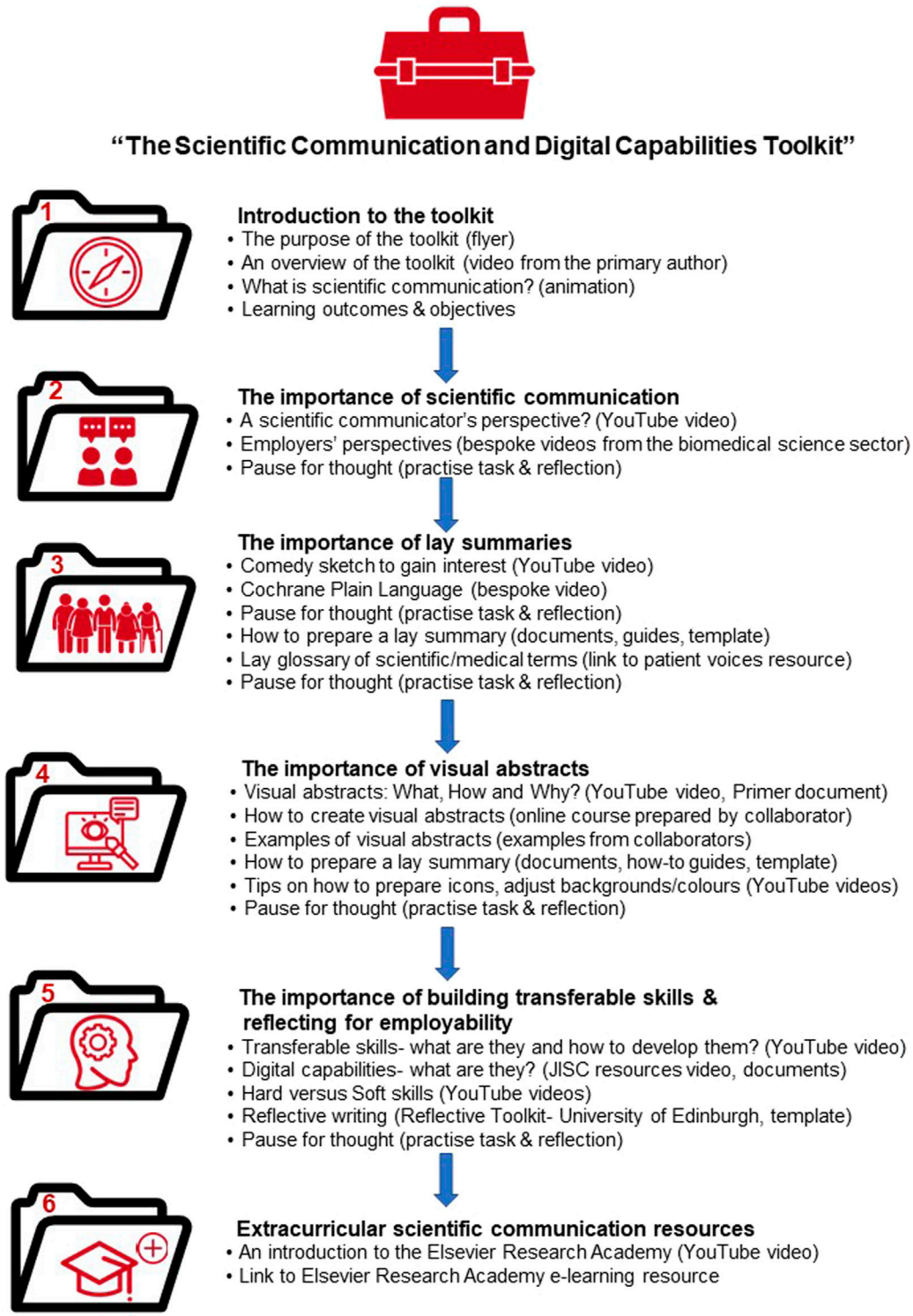

FIGURE 2 | Structure of the scientific communication and digital capabilities tool kit.

TABLE 1 | Examples of technologies used within the online toolkit.

Media form	Technology	Example	Learning experience
Narrative Explain Demonstrate Describe	Text PowerPoint Video	-Top tips- lay writing -Plain Language (Cochrane presentation) -*How to videos?* remove backgrounds, change icon colour in PowerPoint -*What are videos*? -digital capabilities, -transferable, 21st century & soft skills -Employer's perspectives	**Apprehending** content shown, told or read
Interactive Facilitation of reflection, encourage further exploration	Online tasks	Short courses -Elsevier Research Academy -Visual Abstracts (Duke University)	**Investigating/exploring** resources, digital tools
Communicative Facilitation of exchanges between students, staff/students	Online tutorial	Question and answer session	**Discussing** with student peers and staff
Adaptive Facilitation of practise and experimentation	Feedback	Responding to feedback - supervisor/author of toolkit - self-reflection	**Experimenting**
Productive Learners demonstrate their understanding	Preparation of assessment communication and reflective outputs	-Tasks associated with each learning resource to encourage active engagement -Assessed scientific communication outputs	**Articulating/expressing** what has been learnt

study, thematic analysis was based on analysis of the students' reflective text, namely, categories were constructed focusing on key 21st Century skills namely (ii) foundational literacies (ICT literacy, scientific knowledge, scientific communication literacy), competencies (critical thinking/problem solving, creativity, communication, collaboration/teamwork) and character qualities (independence, flexibility, time management, organisation) as categorised by the World Economic Reform (15). The ICT literacies were further categorised in relation to the six digital capabilities as defined by JISC (16). Following dissection of the students' reflective writing, a percentage referenced to each category was calculated.

Statistical Analyses

Data gathered from questionnaire responses and readability analyses (mean ± standard error of the mean) were reported. Statistical analyses were performed using non-parametric methods. For all data, a Kolmogorov-Smirnov test for normality was conducted prior to a Wilcoxon signed-rank test for related groups which were not normally distributed. IBM-SPSS Statistics version 26 was used to perform a one-way analysis of variance to examine for significant differences between courses and a Pearson correlation to examine correlations between readability and awarded assessment marks. Statistical significance was set at p=<0.05.

RESULTS

Development of the Online Toolkit

During the co-design focus session, students outlined the key materials they felt would be required to successfully complete the learning activities and a blueprint was constructed (**Figure 1A**). Subsequently, other stakeholders/contributors, internally, locally, nationally and internationally, were contacted and through active participation they contributed to the further design and creation of the educational resource, ensuring that the students' perspectives were central to this co-produced toolkit (**Figure 1B**, see **Figure 2** for toolkit structure and **Supplementary Figure S1** for key public domain resources). Various narrative, interactive, communicative, adaptive and productive media forms, as classified by Laurillard (17) were utilised to provide varied, engaging and informative learning experiences (**Table 1**).

Student Engagement With Online Resource

From the statistical report within BBL it was observed that 25% of students (37/148) accessed the toolkit within the first 4.5 h following an announcement of its release, with 35.8% (53/148) having accessed it following 2 weeks of release. Further students accessed the tool kit for the first time in subsequent 3 months (18.2%, 34.5% and 5.4% respectively. Nine students (6.1%) never accessed the toolkit (**Supplementary Figure S2**). Following an online "drop-in session" on 12 April, which provided students the opportunity to discuss with their peers and tutor the content of the toolkit and any issues which they had in relation to the preparation of the lay summary and visual abstract, there was a renewed interest in the toolkit. Highest activity was noted during the final week prior to submission of assessment materials (**Supplementary Figure S3**). Various sections of the tool kit were accessed more frequently than others (**Table 2**), namely those areas which provided specific instructions on how to complete the assessed tasks.

TABLE 2 | Percentage of students (n = 148) who accessed different media formats within the toolkit.

Topic	Format	Details	Access (%)
Introduction	Animated video	*"Scientific communication and digital capabilities toolkit"*-An introduction	88.0
	Videos	The employers' perspective	15.8
Lay writing	PowerPoint/video	*"An introduction to communicating healthcare research in plain language"*	61.6
	Word document	*"Tips on how to write a lay summary"*	61.6
Visual Abstracts	Short online course	*"How to create effective visual abstracts"*	69.2
	YouTube video	*"How to remove a background from a picture in PowerPoint"*	71.2
Transferable Skills	Web resource	*"What is digital capability?"* (JISC document)	17.1
	YouTube video	"*Transferable Skills –What are they and how can you develop them?"*	17.8
	YouTube video	*"What are digital capabilities?"*	17.8
	Online toolkit	*"Reflective Toolkit"*	93.2

Surveys

The uptake rate of the student survey was 20.9% (31/148 students), with students enrolled in course programmes as detailed in **Supplementary Table S3**. The percentage of students who ranked the level of support provided in relation the preparation of the new assessment tasks as good/excellent, in the case of the visual abstract (84%) and lay summary (83%), was higher than other historically embedded resources relating to searching (42%) and reading/analysis (50%) of scientific literature, preparation of a scientific abstract (70%), written paper (70%) and poster (60%), (**Supplementary Figure S4**). This highlights the importance of student co-development of educational resources to ensure that educational learning resources are optimal to enhance student engagement and facilitate learning.

Students had highest preference for PowerPoint/with voice over for the delivery of educational materials, with least preference attributed to discussion forums (**Supplementary Figure S5**). The findings shown in **Supplementary Figure S5** are important to consider when developing further educational resources or adapting the toolkit for other student cohorts, particularly when such resources are provided online or *via* a blended learning approach (18).

In terms of self-efficacy, students reported a significant increase in their capabilities in all research focused elements of the investigative project (**Figure 3A**) In relation to preparing a lay summary, 62% of students stated a low rating (poor/limited) on commencement with a statistically improved higher rating (good/excellent) in 84% of students on completion (**Figure 3B**). Similarly for the preparation of visual abstracts (87%, poor/limited at commencement and 93%, good/excellent on completion (**Figure 3C**). Students ranked their confidence in applying developed skills in the future, highly (4–5) in the case of lay scientific communication (89.3%), visual abstract preparation (85.7%) and reflective writing (82.1%) (**Figure 4**).

Fifteen members of academic staff who supervised and assessed students enrolled in the Investigative Final Year Project module completed the staff survey (uptake rate of 39.5% (15/38)). On analysis of free text provided in submitted questionnaire responses, in relation to the novel scientific communication assessments, overall, staff felt that for undergraduate students and further application in graduate careers, the creation of a lay summary was more applicable than the creation of a visual abstract. In the case of the visual abstract, these included analysis, synthesis and summarising of complex scientific approaches and research findings to formulate key take home messages in a simplified, creative and impactful visual presentation by employing a variety of digital skills. In the case of the lay summary, skills included critical thinking regarding real-world application of their research and awareness of how to express and communicate science using simple language to different stakeholder audiences. Staff reported the visual abstract (46%) and lay summary (53%) were of value when assessing the students they supervised and they helped in the understanding of projects which they marked but did not supervise, visual abstract (57%) and lay summary (61.5%).

In responses to questionnaires, students and staff ranked the importance of having opportunities to develop skills within the undergraduate Biomedical Science courses (**Figures 5A, B**, respectively).

Qualitative Data Content Analysis

Written reflections (104/146 students; 71.2%) analysed by means of content analysis revealed that students specifically commented on the knowledge acquired throughout the module (51.9%) and the fact that skills acquired will be used in their future career (54.8%). A large proportion of students reflected on a wide variety of subject specific and 21st Century skills which they had developed as shown in **Figure 6A**.

Further analysis of the digital capability skills acquired indicated that students had an awareness of all of the six digital capabilities to varying degrees, with a primary focus on information, data and media literacies, ICT proficiency, digital creation and digital communication (**Figure 6B**. One quarter of students used digital formats in relation to self-directed learning, particularly in relation to statistical analyses and bioinformatics. Only 5.7% of students acknowledged the importance of digital wellbeing (**Figure 6B**), highlighting the importance to embed such awareness within the curriculum, particularly with increasing teaching and assessment delivered either fully online or by a blended learning approach.

Readability Analyses

Readability metrics of the lay and paired scientific abstracts prepared by the students (n = 146) is shown in **Table 3** which is compared with the readability of scientific abstracts and paired

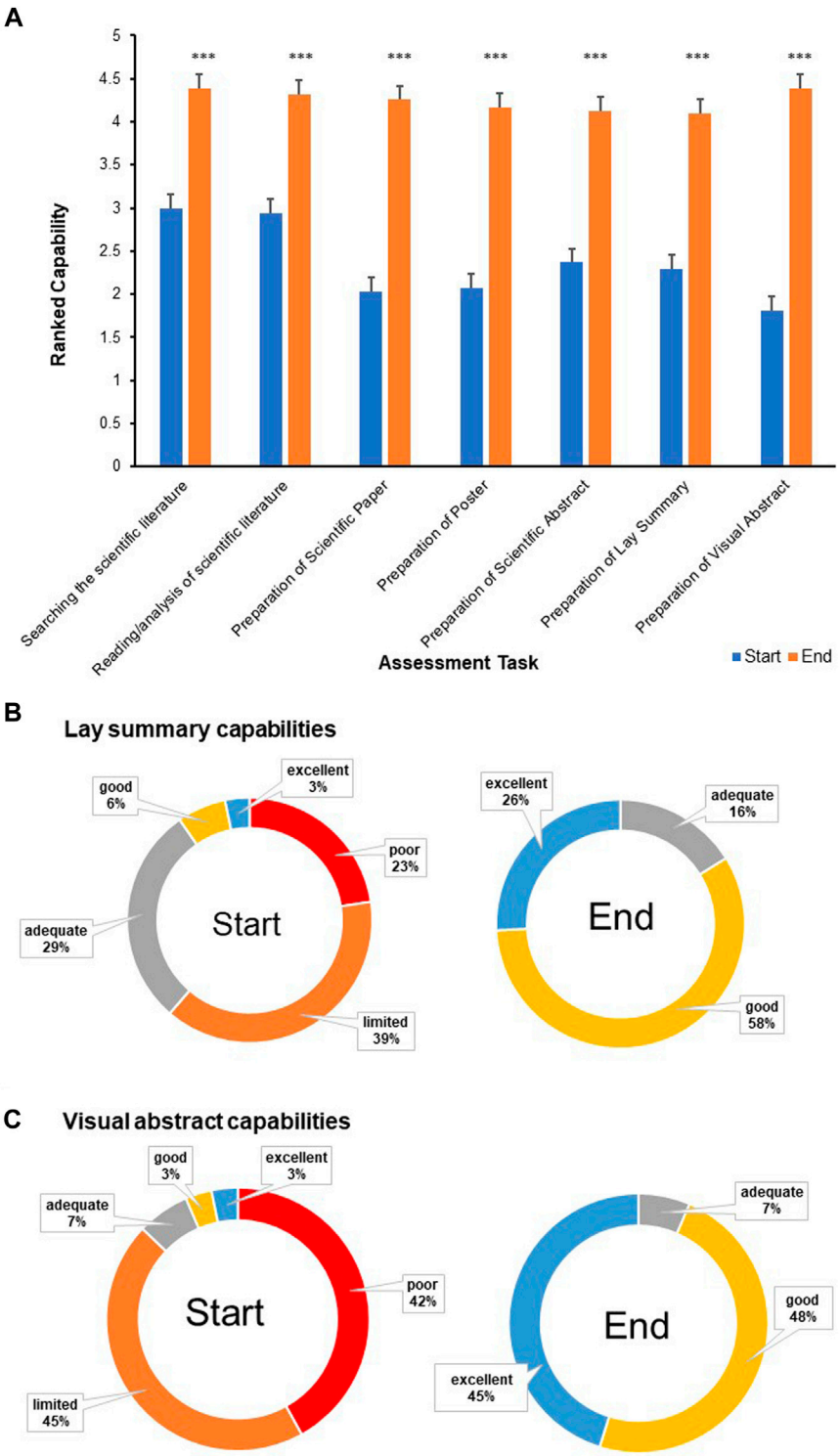

FIGURE 3 | (A) The development of students' capabilities (n = 31) (as ranked using the Likert scale 1 = poor 2 = limited 3 = adequate 4 = good 5 = excellent) mean values; ***p < 0.0001. A comparison of the development of students (n = 31) capabilities in relation to the preparation of **(B)** Lay Summaries and **(C)** Visual Abstracts.

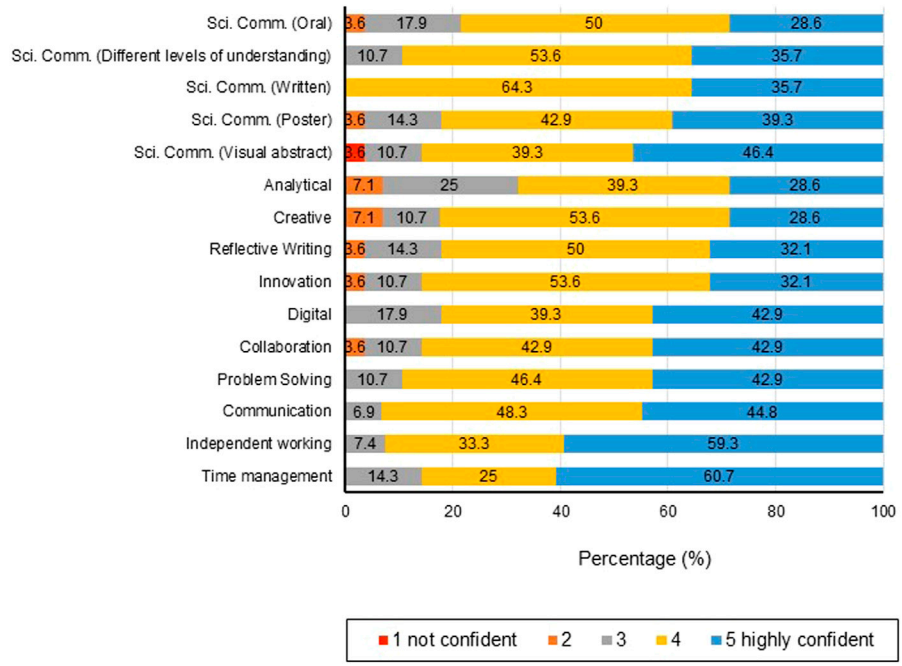

FIGURE 4 | Students' (n = 31) confidence in relation to skills acquired and developed during the investigative research project module.

lay summaries prepared by scientists published in the *Journal of Cystic Fibrosis* and its sister lay journal CF Research News (19). The Flesch Reading Ease (FRE) and Flesch-Kincade Grade Level (FKGL) relating to the student lay summaries were statistically ($p < 0.0001$) higher and lower respectively than their paired scientific abstract indicating improved readability characteristics. There were no significant differences between the students enrolled in the different courses in relation to the readability of either the lay summary or scientific abstract (**Supplementary Figure S6**). There was a small but significant negative Pearson correlation between the lay FKGL and the marks awarded for the project components (review, dissertation, supervisor's mark and poster), which indicates there was a correlation between higher marks being awarded to students who demonstrated the skills to successfully moderate their writing for the lay audience. In contrast a statistical negative correlation was only observed in relation to the FRE and supervisor's mark, when considering the ability to write a scientific abstract for a specialist audience (**Supplementary Figure S7**).

DISCUSSION

The Development of Online Resources

As student and staff participants were central to this action research project, a staff-student collaboration approach was used to enable students to be "*proactive, enquiring and productive participants in the learning process*" by co-designing a knowledge-based resource (21). Such engagement builds students' trust, respect and confidence whilst enabling staff to critically evaluate the feasibility of maintaining the implementation of novel teaching methods within the current module, as well as assessing the validity of embedding such evidence-based pedagogic practice throughout various levels of undergraduate and post graduate curricula in a spiral learning approach (20). The co-design of this toolkit fostered a positive and valued relationship between staff and student, as highlighted in the reflective focus groups. Such a co-design approach should be considered by all staff when developing such teaching and assessment activities, as student outcomes, namely partnership, increased engagement, motivation, ownership, meta-cognitive learning and awareness of the need for the development of transferable skills for employability, as has also been noted by Mercer-Mapstone et al. (22).

An online scientific communication and digital capabilities toolkit was prepared to support students prepare three outputs, namely a visual abstract, lay summary and written reflection focusing on educational experiences within the module and employability. The structure and content of the toolkit, although initially prepared for final year undergraduate students, was not too prescriptive to ensure future adaptability, flexibility and scalability, thereby enabling other teaching staff and users to customise and repurpose for their individual teaching needs. Subsequently, the toolkit was successfully embedded in both MSc and PhD programmes as well as aspects of the toolkit embedded throughout all levels of undergraduate degree programmes.

Central to the design of the toolkit was consideration of all three curricular domains; i) the knowledge of the importance of scientific communication and approaches used; ii) the skills which are required to prepare communication outputs for varied audiences and iii) attributes required to communicate

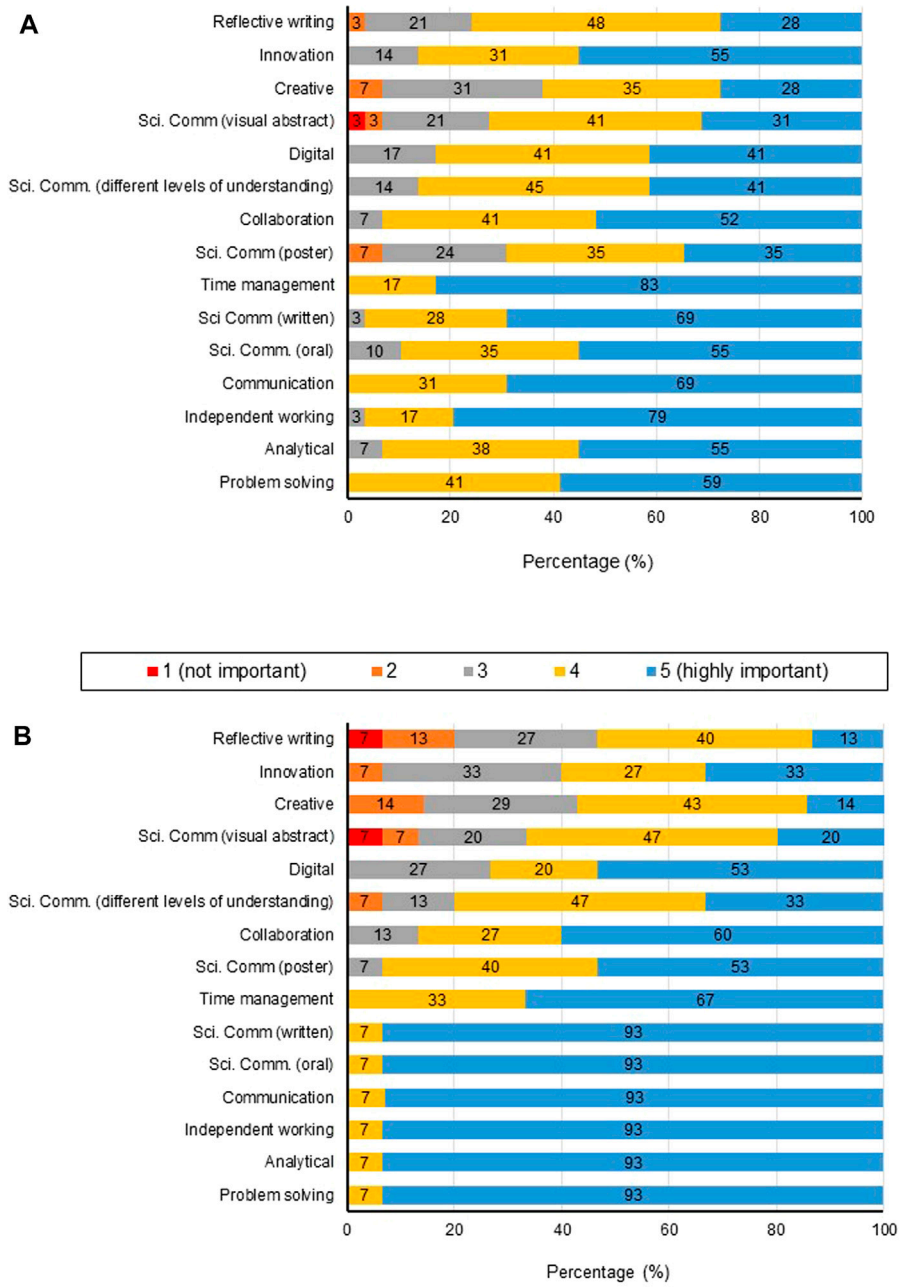

FIGURE 5 | Student (*n* = 31) **(A)** and staff (*n* = 16) **(B)** perspectives on the importance of undergraduate students studying Biomedical Sciences/Biology to have opportunities to develop skills.

effectively, all of which follow the basis of the "Know/Be/Do framework" (23–25). A significant emphasis was placed on the skills domain, with an overlap between all three domains. How to reflect for employability having completed assessment tasks associated with the module, was embedded to ensure that students had an appreciation of their personal development in relation to attributes and skills required for their future career and employment (10).

The construction of the online resource was underpinned with pedagogical approaches which closely aligned with Gagne's neo-behaviourist's theory of hierarchical learning (26). Animation, a comedy sketch and videos from employers' perspectives initially facilitated, encouraged and motivated students to engage with the resource prior to learning. The resource could be viewed in its entirety and was constructively aligned with the module learning outcomes and learning objectives (27) and was presented with a

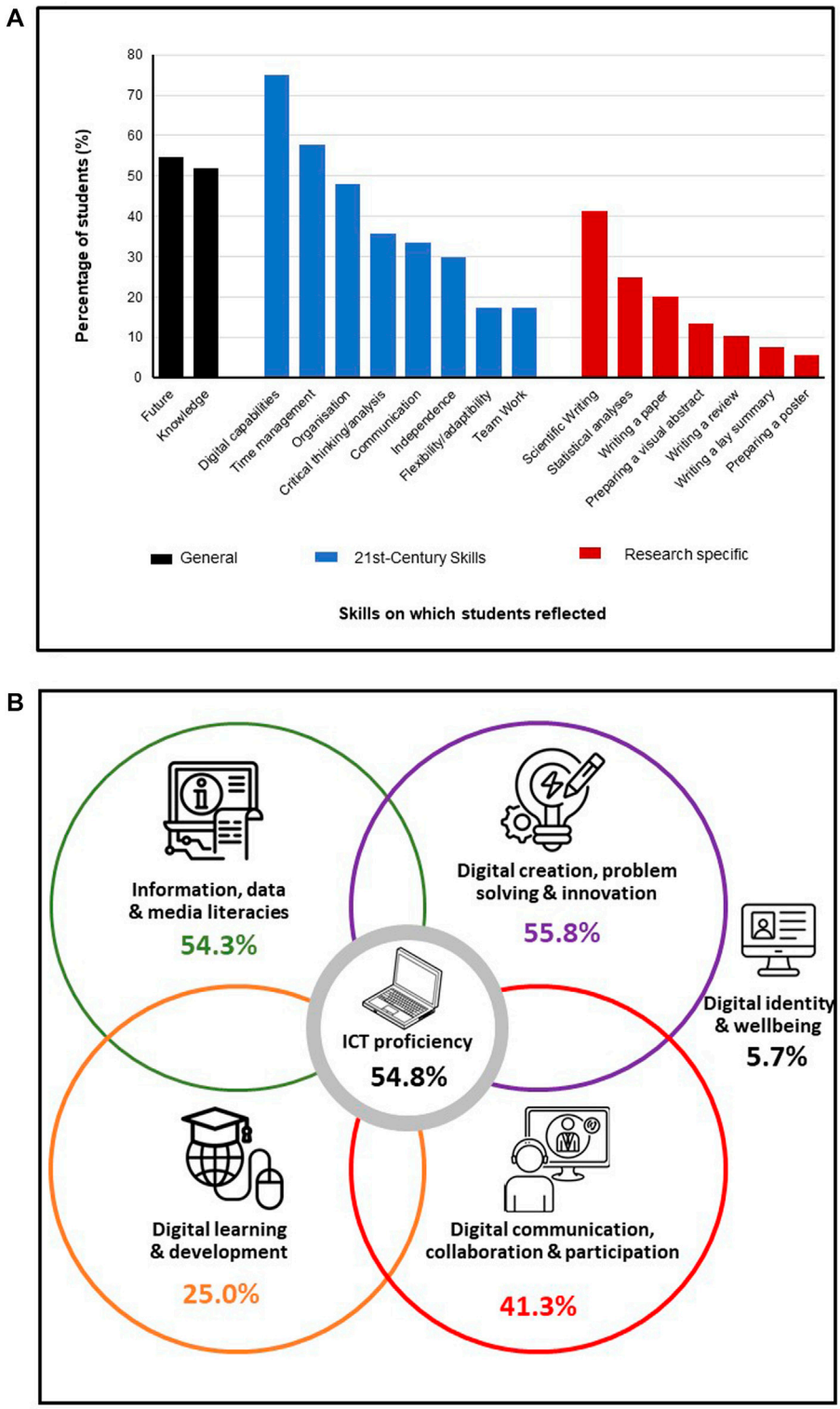

FIGURE 6 | Analysis of student reflections (n = 104) on **(A)** 21st Century skills developed as defined by the World Economic Forum, 2015 (15) and **(B)** digital capabilities as classified by JISC (16).

logical flow in relation to structure and content (**Figure 2**, **Supplementary Figure S1**) to ensure ease of navigation through the various detailed layers. Content was provided by authoritative contributors with professional working examples, key tips, "how to" videos and templates. Students were challenged to demonstrate their understanding of the content as they

TABLE 3 | Readability analysis of student scientific abstracts (n = 146) and lay summaries (n = 146) compared to those published in a scientific journal and lay sister journal (19).

Target	Flesch Reading Ease (FRE) (mean ± SEM)	Median	Range
Scientific abstract range 15-18			
Lay summary 60			
Scientific abstract (Student)	20.3 ± 1.1	20.7	–57.9–45.8
Lay summary (Student)	47.1 ± 1.0***	47.0	–4.1–74.1
Scientific abstract (Journal)	25.2 ± 1.1	25.9	–5.0–56.2
Lay summary (Journal)	43.3 ± 1.0	43.9	11.4–43.9
Target	**Flesch-Kincaid Grade Level**	**Median**	**Range**
Scientific abstract[a]: range 12.6-25.6			
Lay summary: 8			
Scientific abstract (Student)	16.4 ± 0.3	16.1	10.9–50.1
Lay summary (Student)	10.7 ± 0.2***	10.8	6.2–20.6
Scientific abstract (Journal)	14.1 ± 0.2	14.0	9.2–8.4
Lay summary (Journal)	11.7 ± 0.1	11.6	8.1–16.3

[a](20).

***p < 0.0001; Wilcoxon-signed rank test of student lay summary versus student scientific abstract.

progressed through the learning resource by short "*pause for thought*" self-evaluation and reflective activities. Such self-directed learning coupled with an online tutorial session allowed students to discuss and receive feedback in relation to their approaches to the assessment tasks and subsequently apply what they had learnt to experience creative discovery when completing the final assessment tasks. Various methods of flipped (28) and active learning (29) were facilitated by the resource, namely learning by i) acquisition of content *via* videos, documents and images; ii) enquiry *via* online courses/activities and iii) ultimately production a final creative output (30, 31), thereby applying of all levels of Anderson and Krathwohl's revised Bloom's cognitive taxonomy (32).

It must also be considered that the learning styles and approaches used by students of different generations are constantly evolving. Current focus is on the new generation of *Millennials*, the *Centennials,* who are believed to embrace direct involvement in learning through a multimodal approach. Their participation in learning is by *doing* rather than solely *receiving* information through a traditional one-way information pathway of formal lecture style teaching (33). As Centennials students are savvy with respect to whether information is relevant and of benefit to them in terms of self-development, and if so, they will be self-motivated and engaged in the learning activity and if not the opposite is true (33). As such it is important that educators adapt their approaches to teaching and assessment in line with the needs of the current and evolving generation of students. Giray (32) provides a valuable insight into the characterisation of generations and highlights the valuable advice that "*teachers should teach the students, not the subject.*" It is important that educators understand the current students in terms of learning preferences, styles and digital capabilities to fully adapt and develop pedagogical approaches to teaching and assessment which ensure inclusivity of all learners. As such, continual involvement with the students in a co-productive role when developing the curriculum is a symbiotic relationship to promote successful learning outcomes.

Student Engagement

Although access to the toolkit was assessed, it must be realised that such access does not necessarily translate to level of engagement but solely relates to participation in a most basic form of access to information and does not address individual understanding (34). As engagement has several meanings, for the purposes of this project, a perspective of student engagement was considered by the access and extent of utilisation of the toolkit, students' perceptions of the resources, reflective feedback and the successful completion of assessment activities. Access data (**Supplementary Figure S2**) highlights the importance of introducing new learning resources earlier within the module and providing opportunities such as workshops and tutorials to encourage earlier active engagement rather than students only consulting the resource during the final stages of the submission of their assessments.

Lay Writing

Quantitative evaluation of scientific abstracts and lay summaries in terms of readability metrics indicated that students were successful at moderating their style of writing for the lay audience as the FRE (ease of readability) for the lay summary was higher and the FKGL (target educational grade) was a lower than their scientific abstract (**Table 3**). This was comparable to readability metrics from authors of scientific journal articles, highlighting the professionalism with which students prepared these lay writing outputs. It should be noted, however that these

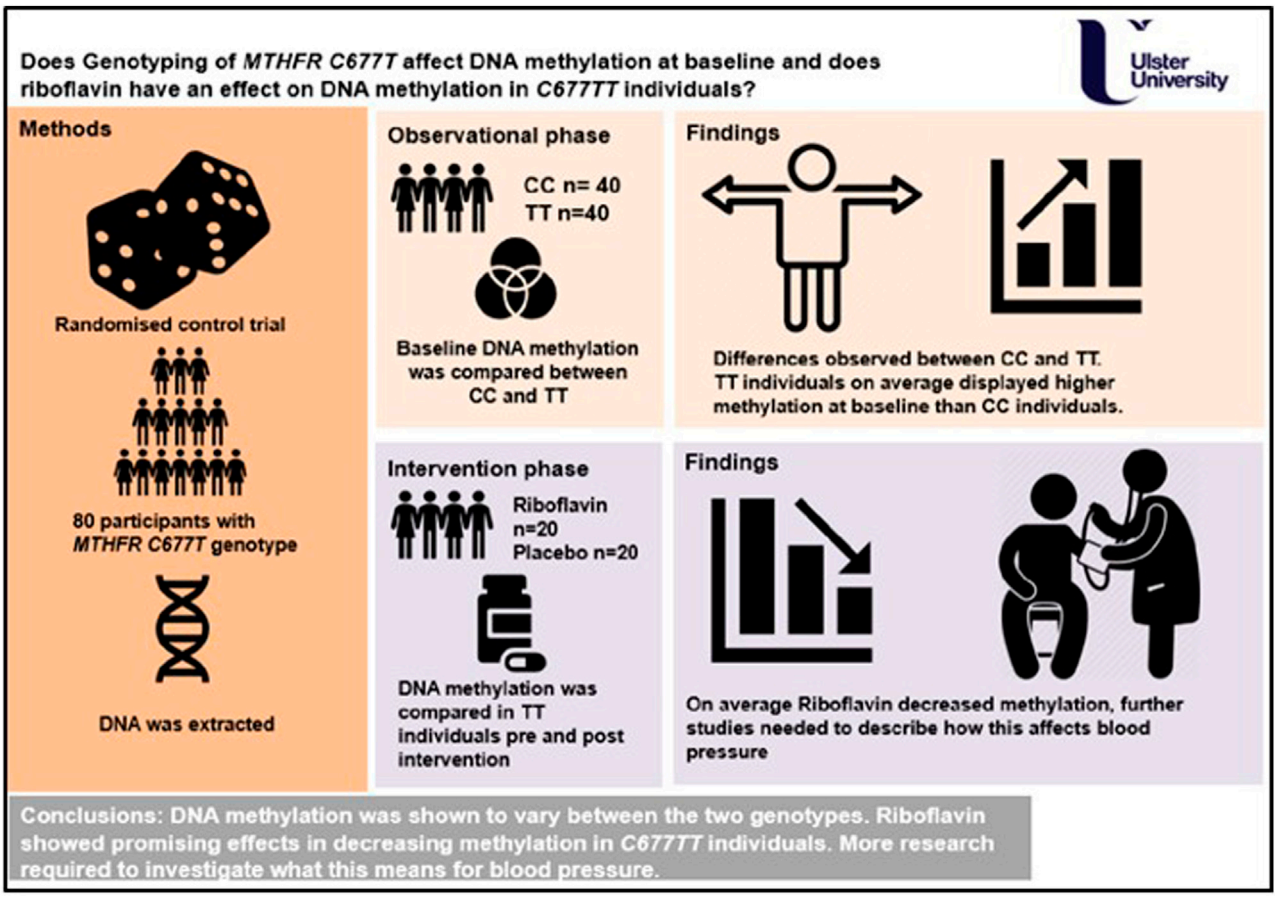

FIGURE 7 | Example of a visual abstract prepared by an undergraduate student studying Biomedical Science.

parameters do not assess scientific accuracy but writing style and readability.

The Importance of Reflection

When conducting an action research project which undertakes the introduction of a novel learning activity into a well-established module, involving a large student cohort from several courses and forty academic staff members, it is essential to reflect together to ensure the validity of the innovation. Collective reflections permit the researcher to reflect from all stakeholder perspectives and allow an in-depth critical evaluation to engender and further develop innovative teaching practice at both an individual and institutional level. Such transformative reflection will result in tangible changes rather than just a deeper understanding of current practice (35). This project instilled the importance of the inclusion of the student voice to understand what motivates students to learn, how they learn and the best approach to ensure opportunities are provided to develop skills to learn coupled with skills to successfully gain employment and ultimately provide a valuable civic contribution (36, 37).

Personal communications and informal feedback from staff indicated that staff, valued the quality of educational resources provided and classed these activities as valuable additions to the Level 6 curriculum with many hoping they would be a permanent feature. Staff acknowledged the further potential of this innovative initiative, particularly through embedding small aspects of these learning activities in first/second year curricula and expansion to Masters and PhD levels. Staff believed that lay writing was an important addition to the module to develop communication skills with key stakeholders which would be of value when seeking employment as graduates in science, healthcare and non-science careers. It was acknowledged for graduates entering careers as biomedical scientists, the ability to communicate with varied audiences was an important regulatory standard of proficiency. One member of staff, however, felt these activities were beyond the capabilities of undergraduate students, however the standard of work produced by the students as indicated by the readability statistics in relation to the lay summary (**Table 3**) and the professional creation of visual abstracts demonstrated in **Figure 7** evidenced that this was not the case. One member of staff believed that these activities were only of value to students pursuing research careers, however the embedding of lay science communication skills have been successfully introduced into undergraduate degree programmes in other universities (38).

Reflecting on Creativity and the Development of Skills

Students reflected that they enjoyed the opportunity to be creative when preparing the visual abstracts, with 90.3% of students reporting in the questionnaire that they had the opportunity to be both creative and demonstrate complex problem solving. Creativity is skill valued by employers in all sectors however, it has been reported that while creativity is the pinnacle of Bloom's cognitive taxonomy, not all Biomedical Science undergraduate degree programmes may necessarily refer to creativity in their curricula nor may students recognise creativity opportunities within the curricula (38). Both staff and students may be unclear as to what is meant by creativity within scientific disciplines and as such do not feel that there are opportunities within scientific degree programmes to be creative nor for students' creative skills to be acknowledged (39). There are many opportunities in Biomedical Science research activities to be creative and indeed when programmes are analysed it becomes apparent that there are many opportunities within the curricula to encourage creativity which can take many formats and output, e.g., the preparation of review and original scientific papers (39). In this novel visual abstract student assessment activity, students could clearly see the creative opportunity and the opportunity to develop higher order critical evaluation of their investigative projects while utilising and developing their creative and digital skills. One student stated they would use these skills to create learning materials for secondary students when they commenced science teaching training in the next academic year, highlighting the transferability of these skills in different employment pathways of successful biomedical science graduates, both research and non-research alike.

There was a difference between student and staff perspectives in terms of ranking skills development. Skills developed within the undergraduate investigative project, which were viewed highly important by staff but a lower ranking by students were problem solving (staff 93%; students 59%), analytical skills (staff 93%; students 55%), communication (staff 93%; students 69%), independent working (staff 93%; students 79%) and scientific communication, written (staff 93%; students 69%) and oral (staff 93%; students 55%).

Students indicated that time management ranked highly important (83%) in comparison with staff (67%). Staff ranked skills associated with poster preparation very/highly important 93%, however students only 70%. A higher proportion of students than staff ranked very/highly important; digital skills (staff 73%; students 82%) and communicating with audiences with varied levels of understanding (staff 80%; students 86%). It is interesting that students indicated a higher very/highly importance regarding the opportunity to develop innovation skills (staff 60%; students 86%), reflective writing (staff 53%; students 76%), creativity (staff 57%; students 63%) and visual abstracts (staff 67%; students 72%). These findings indicate that although the core assessment outputs of this investigative project module focus on traditional laboratory research skills and scientific communication, students value the opportunity to develop other 21st Century skills and higher order cognitive skills such as creativity.

In any module which is delivered by multiple staff members, it is important to consider all individual staff perspectives, prior to further embedding scientific communication skills and reflective practice within undergraduate degree programmes. Furthermore it is important to share the background and rationale prior to the introduction of such scientific communication initiatives with course teams to highlight i) the importance of lay and visual communication approaches; ii) where such approaches are used in careers within and outside academia and iii) how they differ from the current conventional assessment approaches, e.g., poster presentation, as dismissal of the introduction of novel assessment may result from a lack of understanding of these concepts.

Embedding Reflective Writing in the Biomedical Science Curriculum

Although students in previous years were encouraged to reflect on their experiences within this final year Investigative Research Project module, many chose not to do so or provided limited reflective reports. It is unknown as to the reason why many students chose not to do so, however two possible reasons include uncertainty regarding how to prepare such a written refection and the fact that the reflective writing was not assessed. Hence, during the current study, resources in the toolkit were included to provide an in-depth guidance on how to optimally reflect for employability in terms of transferable skills developed including digital competencies, and subsequently in this cohort, 93% of students chose to participate in the unassessed reflective writing activity.

Only half of staff ranked reflective writing as an important/very important skill to develop at undergraduate level, even though this is an essential standard of proficiency required of all biomedical scientists and common practice within the varied biomedical science graduate employment sector. It is therefore, essential to seek opportunities to inform and work together with staff on the importance of reflective activities in relation to critical evaluation of personal and others' capabilities throughout the education experience, as outlined in the SEEC Credit Level Descriptors for Higher Education (40). Further encouragement to embed reflection within the curricula earlier will help students develop how, where and why they learn, which in turn will motivate students providing opportunities to develop competencies related to learning, as well as skills for future use, whether in education or employment (36). The inclusion of written reflection as a form of assessment has been debated; however, it is important that students undertake such activities to develop their personal learning approaches and transferable skills required for future employment (41). Staff may be reluctant to engage students in such reflective activities either assessment or personal reflective logs/diaries, primarily due to lack of knowledge regarding reflection and as such a workshop/shared practice event could be held to highlight the importance of written reflection within the curriculum, styles of reflection and how to successfully reflect (42). Reflection is a key component of the CPD of healthcare professionals and this is embedded within the Standards of Proficiency for Biomedical Scientists, to ensure the continued quality of practice (1).

FIGURE 8 | Reflective recommendations on how to embed novel learning activities into the biomedical science curriculum.

Going Forward

Some interesting approaches to further develop and embed these communication and digital skills in the undergraduate programmes were suggested by students and staff in free text responses to the questionnaires and during the reflective focus sessions. Reflections from students have caused the evaluation

of the teaching staff's educational practice which require development, related to Bandura's social cognitive theory and in particular student self-efficacy, confidence and engagement by including appropriate activities to ensure students reach their personal goals (43). During this study, imposed "*emergency*" distance learning and social implications resultant from the current pandemic impacted on human relationships and interactions which are important in teaching and learning (23).

A return to conventional face-to-face approaches to delivering teaching and the introduction of group-activities will provide opportunities to advance the delivery of teaching through a blended-learning approach. Students indicated that these novel scientific communication skills should be introduced earlier in the degree programmes to enable the continual reinforcement of information and skills development prior to application of these in the final stages of the undergraduate investigative project aligning with Brunner's spiral curriculum (44). It was also suggested that in future years examples of visual abstracts and lay summaries prepared by students could be provided and students advocated the inclusion of a workshop where students could actively learn and co-prepare these communication outputs, enhancing the learning experience through discussion and collaboration (14). Fifty-three students have subsequently consented to share their outputs, indicating the level of engagement students possessed with these activities and willingness to further support and develop educational experiences for future students. Staff indicated role play could practically develop scientific communication skills to a varied audience. This active method of learning has been used in higher education to foster self-efficacy and confidence in relation to scientific communication (45) driving motivation for learning and ultimately academic attainment (46) and warrants further consideration.

This final year module introduced the concept of reflecting for employability and students' written reflections highlighted that they appreciated the opportunities to develop both discipline-specific skills, albeit that the technical skills were greatly impacted due to the COVID-19 pandemic, and transferable skills for their future careers. This concurs with Demaria et al. (47) that capstone modules in such biomedical science degrees should embed a focus on such transferable skills. The opportunity to encourage students to undertake written reflection in such modules, however should not be limited to the final year curriculum, rather embedded throughout all levels of the curriculum further enabling students to be aware of employability skills and develop their capabilities and confidence as they progress through such taught programmes and continue within a varied workplace. Such an approach has been incorporated within our institution.

Figure 8 offers some further reflective recommendations to others who wish to develop and embed novel learning activities into the biomedical science curriculum.

Study Limitations

Small focus groups, by design, were used in this project, however, whole-class co-design/co-creation, although a challenge, due to class sizes and multiple supervisors would have enabled even stronger partnerships to be built, ensured inclusiveness and permitted a more democratic contribution to curriculum development (22, 48). The opportunity of students to reflect and complete respective surveys, however, enabled a holistic contribution to further development of teaching and assessment. Whilst an anonymous online survey approach allowed both students and staff the opportunity to be honest in expressing their feelings and assessing the questions in a non-time dependent manner, it has been reported that such online surveys generally only report a 30%–40% uptake rate (49), which was lower in this study, which may potentially result in a non-response related bias. Furthermore, a reason for such an uptake rate could reflect that as this module was the final module of the students' undergraduate degree programme and invitations to complete the online questionnaire were sent after completion of final modular examinations due to ethical implications to ensure students were not pressurised to complete such questionaries at a time when they were focused on other important study and assessment deadlines. All students, however, were under similar pressures and all students had the same opportunity to complete the questionnaires. Completed questionnaires were received from students enrolled in all degree programmes and as such reflected the views of all student cohorts. Similarly, staff were under pressure with work commitments associated with examination boards. As such it must be considered that the survey data is more of a snapshot of the two populations rather than a total population.

CONCLUSION

In conclusion, the co-designed and co-created toolkit resulted in an informative and valued resource by both staff and students. Successful engagement by students, with the resource, particularly the sections relating to practical guidance, resulted in scientific communication outputs which were of comparable standards to professional scientific authors, as evidenced by the readability analysis of students' work. Students reported, during the reflective focus groups and in the free text responses in the survey, that the activities were enjoyable and as such empowered them to prepare creative outputs which also enabled a large proportion of staff to assess the skills which students had developed, as well as an increased understanding of the significance of the research conducted. Students' written and focus group reflections and questionnaire responses highlighted the capabilities which they developed and used with confidence to prepare outputs which they felt were accomplished and proud of and students acknowledged the value of developing such transferable communication and digital skills for future use in various employment sectors.

SUMMARY TABLE

What is Known About the Subject?

- The HCPC revised standards of proficiency (SoP) for biomedical scientist registrants, are effective from 1 September 2023

- SoPs place greater emphasis on registrants using information, communication and digital technologies to communicate effectively
- QAA (2023) Biomedical Science Benchmark statement promotes authentic assessment of communication to scientific and lay audiences

What This Paper Adds

- Co-creation of a scientific communication toolkit enhanced student engagement and support of authentic assessments
- Readability metrics demonstrated an ability to moderate writing for the lay community
- The preparation of visual abstracts encouraged creativity, critical appraisal and development of digital communication skills

SUMMARY SENTENCE

This work represents an advance in biomedical science because authentic scientific communication assessment promoted the development of key transferrable digital and communication skills for future employment.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available per ethics approval. Further enquiries should be directed to bcmillar@niphl.dnet.co.uk.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ulster University procedures for research involving human subjects (CHERP-20-002-A). The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

BM, conceived, conducted the study, collected and analysed the data and wrote the manuscript, AT performed statistical analyses, NT contributed to the development of the study, JM contributed to the development of the study and gathered feedback for analysis and CM contributed to the development of the study themes, critically guided the study and reviewed the data. All authors reviewed and edited the final submitted manuscript.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/bjbs.2023.11284/full#supplementary-material

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REVIEW
published: 12 April 2023
doi: 10.3389/bjbs.2023.11266

A Review of Clinical Laboratory Education, Training and Progression: Historical Challenges, the Impact of COVID-19 and Future Considerations

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The COVID-19 pandemic had a wide global impact on society, including the clinical laboratory workforce. This historically underrepresented group of highly skilled professionals have now started to gain the attention they deserve. There had already been dramatic changes to laboratory training over the past 2 decades resulting from advances in technology, changes to service needs, and as a consequence of Pathology reform initiatives. The pandemic has had an additional impact. Higher education institutions and students adapted to emergency remote teaching. Clinical laboratories faced unprecedented challenges to meet COVID-19 testing demands and adjust to new ways of working whilst maintaining their usual high quality service provision. Training, assessment, and development arrangements had to convert to online platforms to maintain social distancing. The pandemic also had a global impact on mental health and wellbeing, further impacting learning/training. Despite these challenges, there have been many positive outcomes. This review highlights pre- and post-pandemic training and assessment for clinical laboratory professionals, with particular emphasis on Biomedical Scientists, outlining recent improvements among a history of challenges. There is increasing interest surrounding this vital workforce, accelerated thanks to the pandemic. This new public platform has emphasised the importance of quality diagnostic services in the patient pathway and in the response to national crises. The ability to maintain a quality service that is prepared for the future is grounded in the effective training and development of its staff. All of which can only be achieved with a workforce that is sustainable, invested in, and given a voice.

Keywords: COVID-19, education, training, clinical laboratory, biomedical scientist, professional development, HCPC registration, biomedical science and healthcare science

OPEN ACCESS

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Received: *10 February 2023*
Accepted: *28 March 2023*
Published: *12 April 2023*

Citation:
Pearse C and Scott S (2023) A Review of Clinical Laboratory Education, Training and Progression: Historical Challenges, the Impact of COVID-19 and Future Considerations. Br J Biomed Sci 80:11266. doi: 10.3389/bjbs.2023.11266

INTRODUCTION

After years of global impact on society, the economy, health systems, education and working lives, COVID-19 no longer requires an introduction. However, the effects of the pandemic on clinical laboratory training and assessment have not been well documented. The impacts varied between the stage of career of the professional and the different pathology discipline. Undergraduates transitioned to online learning with fewer opportunities for basic laboratory experience. Post graduate laboratory professionals adapted to new ways of working and virtual methods of

professional development as social distancing measures prevented activities such as conferences and the close shadowing of experienced peers. Workload varied significantly among different disciplines and staff were redeployed to meet service demands.

The global impact of COVID-19 and past pandemics on mental health and wellbeing has been well documented (1, 2), particularly in patient facing healthcare professionals such as doctors and nurses (3–7). There is also increasing research regarding the impact on students (8–11). However, there is limited data and published resources regarding the impact on laboratory professionals' wellbeing (12, 13)—who are paramount to the patient pathway through diagnosis, prevention, treatment monitoring, and were central to the efforts against the pandemic. As poor mental health may impact learning and training, e.g., because of reduced motivation, concentration, engagement, and increased absence rates (14–18), this also falls within the remit of this review. In addition, reports of 'long COVID' are rising, including wellbeing symptoms such as ongoing fatigue, anxiety, depression, and brain fog (19–22), which may further impact an individuals' ability to learn and develop professionally.

Several circumstances had altered the training requirements in clinical laboratories prior to the pandemic. This review aims to highlight the everchanging expectation of this workforce, as well as the further impact of the pandemic. Laboratory professionals and trainees have been instrumental in the pandemic and will be vital in future crises. Understanding and investing in their training and development is key, as we continue to rely on their readiness to provide quality patient care.

PRE-PANDEMIC LABORATORY TRAINING AND ASSESSMENT

Pathology Networks

In the United Kingdom, increased NHS financial pressures, the emergence of the digital era, advances in technology, and the changing needs of healthcare providers and patients prompted the Carter Reports in 2006, 2008 and 2016 (23–25). The reports accelerated the transformation of pathology services into networks; with an emphasis on standardisation, digitisation and IT connectivity, and a more flexible workforce to improve efficiency, cost, and patient care (26). NHS England and NHS Improvement proposed a plan to create 29 Pathology networks in 2017, and as of 2019 they reported ~97% engagement in networking from NHS Trusts (27). Thus, the clinical laboratory workforce had already been undergoing drastic change and uncertainty prior to the pandemic. Whilst the impact on cost and efficiency had received much attention; little has been investigated regarding the impact on laboratory staff (28). The Royal College of Pathologists (RCPath) published their own concerns about the Carter recommendations. Stating that consistent budget cuts seen by Pathology over previous years had resulted in a decline in workforce numbers through decreased retention and recruitment of laboratory professionals, an inability to fund locums, and the negative impacts on staff morale. Continued budget cuts could result in further consequences and hold serious implications for quality of practice. With some networks reporting a decrease in staff morale and retention, a loss of expertise, and negative impacts on training (29–31). A small 0.7% redundancy rate was reported in 2018 (28), however there were reports of increased early retirement due to mergers (30). Nevertheless, many networks have identified their mistakes, implemented changes to address them, and overall, Pathology networks are now receiving a more positive response (31). Although published research has not explored the impact on laboratory staff in detail, it has been noted that having larger networks will permit access to wider training and development opportunities for staff to expand their scope of practice and achieve increasingly senior roles. Furthermore, a more resilient and flexible workforce has been created, that can respond quickly to service user needs. For this to be realised, however, there is a requirement for continued investment and the process needs to be managed correctly (30–32).

Modernising Scientific Careers

Following the Carter report (23, 24), the Modernising Scientific Careers (MSC) initiative arose in the United Kingdom in 2008 (26). MSC aimed to standardise education and training for healthcare science professionals; building a clear career framework with flexible routes of entry and progression that would attract and retain staff, ensuring training was fit for purpose, and improving value for money from diagnostics. Within the proposed framework, MSC acknowledged that the advances in technology and the changing needs of service users meant appropriate education, training, and continual professional development (CPD) opportunities would be vital in coordinating a flexible workforce capable of the high level of care expected (33, 34). Despite being awarded the Guardian Workforce Innovation award in 2013, the initiative received criticism from the workforce. Although the Scientist Training Programme is in full swing, the Healthcare Science Associate and Practitioner pathways have declined in popularity and availability as standalone degree programs (35, 36). The term "Healthcare Science Practitioner" (HCSP) in itself has caused confusion, as these professionals identify as Biomedical Scientists and are registered as Biomedical Scientists under the Health and Care Professions Council (HCPC), with a professional body called the Institute of Biomedical Science (IBMS). Consequently, the level 6 Healthcare Science Practitioner apprenticeship, is now under review, with the development of a standalone level 6 Biomedical Scientist standard soon to be released.

Training and Assessment Requirements of Laboratory Professionals

The clinical laboratory workforce is diverse and there are various routes of entry and progression that differ with respect to the Pathology discipline. To understand the impact the pandemic has had on training and assessment, some understanding of the career framework is necessary. For those less familiar, a summary of common routes of entry to the HCPC register in the UK are provided in **Figure 1** but this is not exhaustive. The

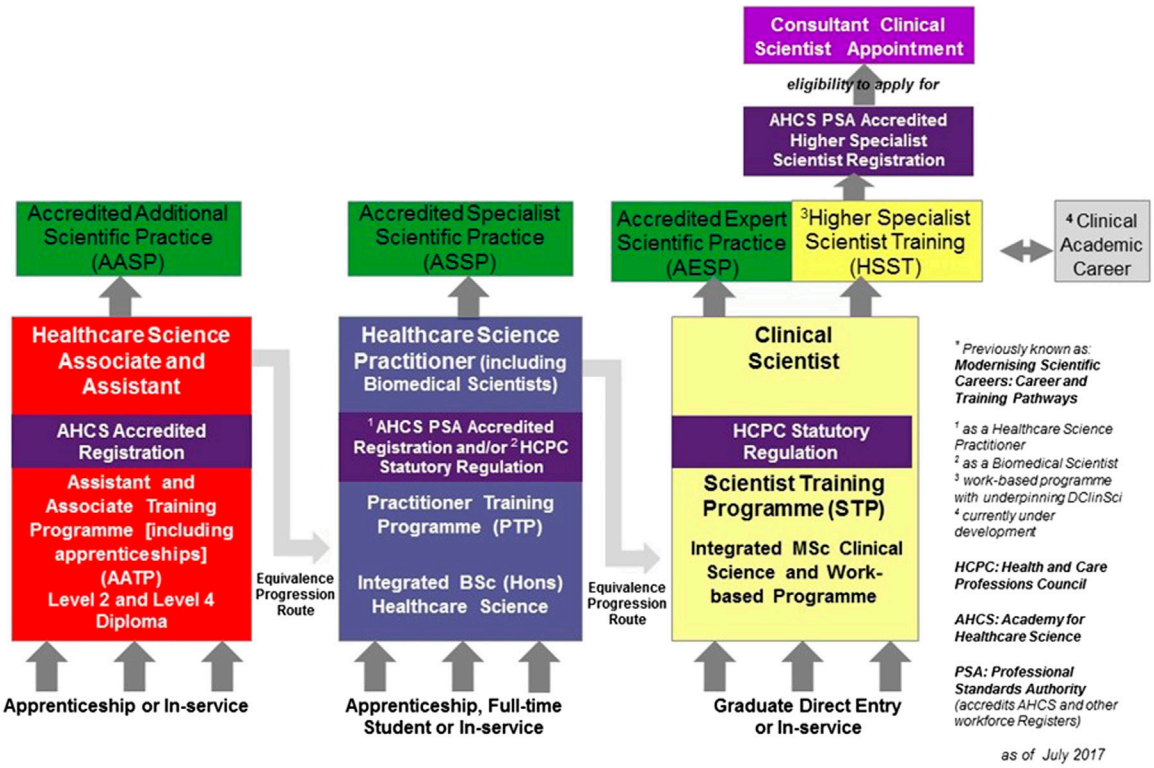

FIGURE 1 | Taken with permission from The National School of Healthcare Science and the AHCS. Showing the NHS England Modernising Scientific Careers framework with adaptations as agreed by the AHCS. Including pathways for support staff (Healthcare Science Assistants/Associates; HSAs), Biomedical Scientists/ Healthcare Science Practitioners (HCSPs), and Clinical Scientists. There are various entry routes, these include: apprenticeships, undergraduate, graduate, in service, and equivalence progression routes (40).

IBMS and the Academy for Healthcare Science (AHCS) are two Professional Bodies which provide accreditation of the educational programs, provide a training and assessment model for registration, and support CPD of clinical laboratory professionals in the United Kingdom. The professional bodies work in tandem with the regulatory body, such as the HCPC, who set the standards for registration. This ensures a robust training and assessment program to promote safe and quality practice. Registered laboratory professionals have a mandated requirement for CPD and lifelong learning. This ensures registrants remain competent to provide a safe, lawful, and effective service. This is emphasised and regulated by the HCPC in line with their standards of proficiency. Registrants are called upon at random during registration renewal periods to provide evidence that their practice continues to meet the standards of proficiency, including documentation of regular CPD activities. Failure to evidence CPD can result in removal from the register (37–39).

For entry level to Biomedical Scientist posts in the UK, potential applicants must be registered with the HCPC. Trainees require both sufficient level 6 knowledge and practice-based competency (41, 42). This is achieved through a work-based competency portfolio, the IBMS registration portfolio, to achieve the IBMS Certificate of Competence (IBMS CoC). As such, trainees require laboratory work-experience in an IBMS approved training laboratory either during their degree or after. The portfolio can be completed through applied courses with a sandwich/integrated placement or *via* an apprenticeship route. It is worth noting that opportunities are limited in comparison to full-time courses. For a summary of entry routes to HCPC Biomedical Scientist registration please refer to **Figure 2**. International applicants may also be accepted on to the HCPC register as Biomedical Scientists through an equivalence assessment pathway.

The verification process for the IBMS CoC consists of a laboratory visit by a trained verifier. The verifier assesses the portfolio to ensure HCPC standards have been met and the trainee provides a commentated tour of the laboratory. Biomedical Scientists can progress further in their role with postgraduate qualifications provided by higher education institutions (HEIs) and/or professional bodies, through qualifications such as the IBMS Specialist and Higher Specialist portfolios.

HCPC registration as a Clinical Scientist can be achieved through HCPC approved programmes including the NHS Scientist Training Programme facilitated by the National School of Healthcare Science, the AHCS Certificate of Equivalence, Association of Clinical Scientists (ACS)

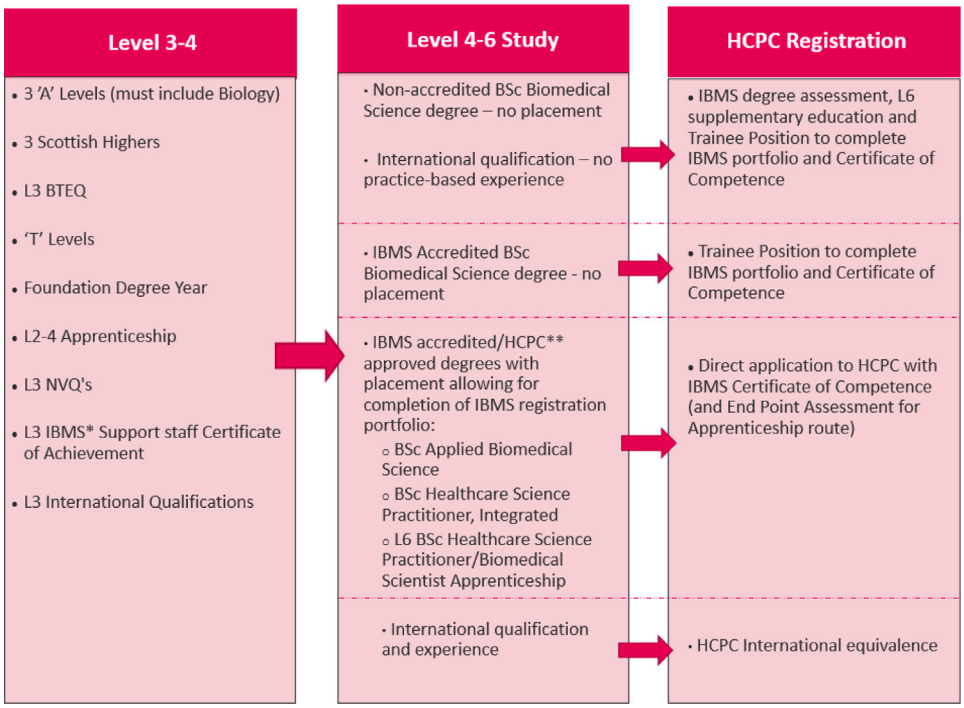

FIGURE 2 | Summary of routes to HCPC registration as a biomedical scientist. *Institute of Biomedical Science **Health and Care Professions Council.

Certificate of Attainment, IBMS Certificate of Attainment in the case of Clinical Biochemistry, Clinical Immunology, Haematology and Clinical Microbiology, and also the HCPC International Route (43, 44).

POST-PANDEMIC LABORATORY TRAINING AND ASSESSMENT

Quality of Teaching and Learning

As the pandemic became a major global health concern with increasing cases and mortality, intermittent lockdowns and social distancing took effect and universities had to rapidly transition to remote teaching to support the progression of their students. Online learning and blended-learning approaches increased in popularity over the years, due to advances in information communication technologies (ICT), increasing class sizes, changes to student needs and expectations, the emergence of Massive Open Online Courses (MOOC) and a drive to improve the quality of teaching and learning (11, 45, 46, 47). Research has indicated that if properly executed, online learning has many potential benefits (48, 49). Including promoting self-efficiency and the skills necessary for lifelong learning (50), which are key requirements of laboratory professionals working in ever changing healthcare environments. However, online learning requires motivation and self-discipline, thus inexperienced learners may need additional support to learn independently and may benefit from synchronous activities, whereas older, experienced learners may benefit from the flexibility of asynchronous styles that more easily accommodate personal and working lives (51–53). There are many other variables that complicate online delivery, emphasised by the development of frameworks that aim to support programme development. Examples include the Community of Inquiry (CoI), and the Technological Pedagogical Content Knowledge (TPACK) models (46, 54–56). Recent reports have sought to clarify the important difference between a well-developed online course and temporary "Emergency Remote Teaching" (ERT). Making this distinction when assessing the global impact of the pandemic on teaching and learning will be necessary to draw meaningful conclusions and reduce the risk of undermining well-established online approaches (46, 51, 57, 58). For example, based on the CoI framework; social, cognitive and teacher "presence" are three components important in creating an online community capable of deeper-level thinking and critical reflection. Social presence does not develop organically or quickly online, as students are physically separated from peers and educators. To combat this, tools to achieve social presence are consciously embedded into course design to promote online collaborative learning (54, 55). This was something there may have been little time to consider in the rapid shift to ERT. Nevertheless, the pandemic has resulted in the acceleration of an established notion that an increase in online learning provision can meet the market demands of the 21st century. The pandemic has highlighted challenges that can be used as opportunities for HEIs. Having a greater online presence with effective course design will help to serve a wider population of students, ensure preparedness for future disasters, and help maintain market

competitiveness as growing numbers of students and professionals seek flexible learning opportunities. This should encourage HEIs to invest in digital technology and staff development to improve teaching and learning (11, 46, 47, 50, 58, 59).

There are several studies that aim to evaluate the impact of ERT on higher education students, and conflicting results have been published (11, 58–61). Key challenges include internet connectivity, use of technology, home life distractions, lack of social interactions, difficulties in concentration, lack of motivation and mental wellbeing consequences (60). The effects of online teaching in general are difficult to measure, as it is a unique experience to the learner with many variables, including course design, interaction with peers/teachers, class size, subject discipline, international/home student, age, gender, ethnicity, personal and work life, digital competency, access to technology and internet connectivity (51, 58, 60). Furthermore, the impact of ERT is being evaluated with different objectives. Including student/teacher perceptions, academic success based on assessment outcomes, student's preparedness for future study/work, and engagement. ERT approaches also differed, influenced by variations in staff digital competency, knowledge of e-pedagogy and resource availability. When narrowing down the search to Bioscience courses, results have also varied. A UK study found out of 151 undergraduate Bioscience students surveyed, open book online exams were preferred, and exam performance improved compared to pre-pandemic figures. This study suggests that there was an increase in engagement, as students found it easier to communicate *via* chat functions. However, there was reluctance to use cameras in live sessions. Students reporting concentration difficulties increased by 39% compared to pre-pandemic survey results but there were minimal concerns over using technology. However, findings of a lack of motivation, household disruptions, and poor internet connectivity were common challenges. In addition, reports of an inadequate working space indicated inequality among students (11). This was further supported by a survey of 75 Bioscience students in Greece which also found using technology was of no concern, but engagement was decreased, and students were uncomfortable turning on their microphones. Students enjoyed the flexibility and convenience of remote learning, however missed the social interaction with peers and faculty and expressed concerns about missing laboratory practicals (59). A study in Malaysia which surveyed 120 undergraduate Biological Science students found students were generally satisfied with their online learning experiences but were also concerned about the lack of practical laboratory sessions. Students reported lower engagement with peers and faculty and found group work difficult as social bonds had not been formed and motivation differed between peers. Unlike the previous two studies (11, 59) students did report difficulties in using technology, in addition to poor internet connectivity. Further challenges included home distractions and time zones being a challenge for international students to attend live classes (61). A study in Malaysia of 112 undergraduate Bioscience students aimed to assess student perceptions. Most respondents found they had increased flexibility. However, 68.8% reported challenges in effective learning, with 45.5% reporting internet issues had a negative impact. When asked about preferred modality, consensus was split between a hybrid approach and face to face, with <2% preferring completely online delivery (62).

Nevertheless, small sample sizes and multiple variables makes it difficult to draw conclusions from such studies and further research is required. In addition to the variables that impact online delivery (**Figure 3**), the geographical impact of the pandemic at any one time varied. Differences in spread, morbidity, mortality, government measures and lockdowns between regions and countries add another level of complexity to understanding the impact on education. In addition, inequality in HEI resources, staff digital competency, the different survey/experimental designs used to assess impact, and how and when engagement, perceptions and learning outcomes were measured will alter research findings. Considering the variables that constitute the learners experience, research within HEI departments should aim to identify the specific needs of their students to personalise learning and share best practice (63).

Online Assessments and Exams

Many HEIs also moved assessments and exams to fully online formats. Universities had to design assessments and exams based on higher-level thinking, application of learning and reasoning, rather than retention and recall to effectively assess knowledge and understanding in open-book and multiple-choice assessments (50). Students were given extended time frames to complete exams to account for time differences, childcare/caring responsibilities, religious commitments, internet connectivity, etc. The transition of exams from conventional lecture halls to online has been well received by students, and some studies report academic achievement has not been negatively affected (11, 50). However, concerns of academic malpractice were heightened (46, 50, 54). Furthermore, difficulties were seen as life returned to "normal" and students either lacked the skills required for on campus assessments or experienced heightened anxiety over these types of assessment. An increase in students becoming increasingly stressed and anxious about readjusting their revision and the mind set required to prepare for timed, on-campus exams became noticeable throughout HEIs. This was particularly increased for students who started university during the pandemic, and thus had only experienced online formats. This precipitated the requirement for increased support to facilitate the change (60).

Virtual Verifications

IBMS assessments also moved to virtual formats. Registration and specialist portfolios were digitised and sent to the verifier or examiner, respectively, to be reviewed before a virtual meeting. Laboratory tours took a variety of methods, e.g., PowerPoint presentations, pre-recorded videos, and live streams. The IBMS took a flexible approach, allowing creativity for laboratory tours and use of multiple ICT platforms such as MS Teams, Zoom, and Skype. With the appropriate platform determined by the parties involved. The IBMS supplied templates for constructing a digital portfolio but urged assessors to be flexible with their approach to

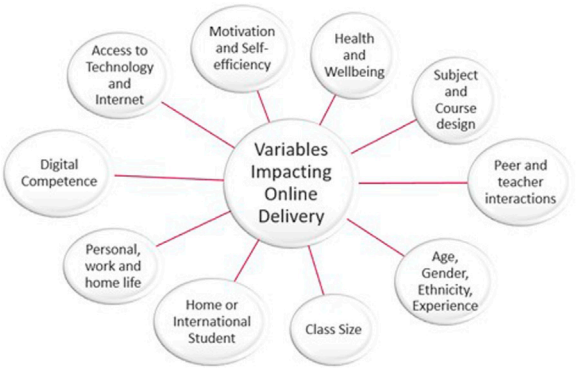

FIGURE 3 | Summary of variables that impact online course delivery and the Learner's experience.

assessing these, prioritising fulfilled HCPC requirements over ePortfolio format (64). To maintain equality and standardisation of the verification process, advice was provided regarding the 90-min time allowance, stating that this should remain for the review of the portfolio, even though portfolios were received prior to the online meeting. The implementation of virtual assessments received positive feedback from both verifiers and assessors. Receiving the portfolio before the meeting permitted missing/supplementary information to be requested and sent before the formal meeting and tour, streamlining the process and avoiding trainees having to send further documents after their assessment and anxiously wait for the verdict (65). Furthermore, in 2020, the IBMS reported an increase in the number of volunteers stepping forward to do assessments following the transition to virtual methods, as geographical challenges were overcome (64), and this may have benefitted trainees in rural laboratories. However, Healthcare firewalls/IT restrictions can make sending large, digital portfolios difficult, and can cause issues with opening documents. Difficulties with virtual laboratory tours included internet/phone connection, risks of filming confidential information, and laboratory health and safety barriers (no mobile phones should be taken into the laboratory). Electronic signatures also caused concerns over authenticity, and IT around authenticating signatures was not well understood by all (65). The volume of evidence for the specialist portfolio caused particular difficulties in evidence transfer.

The IBMS has an online platform for CPD modules, although at the time of this review it is not currently used for registration/specialist assessments, the IBMS aim to move these assessments to an eLearning platform in the future. Thus, the portfolio evidence will be more easily accessed by all parties, which will standardise the process and circumvent some of the current difficulties (65). The IBMS are keen to maintain virtual verifications, especially where verifiers/assessors are not local. As the combination of a steady increase in trainees wishing to achieve HCPC registration or progress within specialist areas over the years, and difficulties in obtaining assessors and examiners that are willing or able to complete assessments have resulted in many trainees experiencing delays in their route to registration/development. It is worth noting that the position of verifier/examiner is currently voluntary, requires training from an IBMS representative, and is mostly carried out by IBMS members as CPD in line with their willingness to support training. The current version of the IBMS registration portfolio is also due to be amended following recent additions and amendments to the HCPC standards for Biomedical Scientists, summarised in **Table 1** (66), effective from September 2023. The results of these reforms may further improve the training process.

Practical Skills

Bioscience students, and other practical courses, are in a unique position. The nature of Biomedical Science requires both an understanding of theory, and competence in practical techniques and professional practice (1,167). This is emphasised in The Quality Assurance Agency for Higher Education (QAA) benchmark for Biomedical Sciences degrees (68), and in the IBMS requirements for accreditation of BSc Biomedical Science degrees (42), which includes a mandatory research project. Pandemic restrictions led to closure of many HEI laboratory facilities. Meaning the opportunity for students to gain practical skills was severely diminished (11, 49). To address this issue, HEIs increased the use of virtual technologies. Examples included commercial laboratory simulations such as Labster and LearnSci (69, 70), HEI recorded videos of staff completing practicals with attached activities, and experiment kits were sent to students to complete in their own homes (63, 71, 72). However, challenges to moving practical classes online differ depending on HEI resources, staff training, and access to technology (71). Not every student had access to a smart phone, laptop, or a good internet connection, and HEIs did not always have the funding to invest in advanced technology infrastructures or take-home experiment kits (63). For those unable to afford commercial laboratory simulations, there were several open access resources available (49, 73) such as LabXchange (72).

There are many advantages to online laboratory sessions, and they have been shown to complement practical sessions well, to improve teaching and learning outcomes by encouraging active learning, prior to the pandemic (49, 74, 75). Online pre-laboratory sessions can help to familiarise students with the experiment and equipment to improve understanding and confidence in performing the practical. This then is followed by an online post-laboratory session to consolidate learning (49, 74). However, the skills gained from the hands-on experience with equipment, working with others, and following good laboratory practice procedures cannot be gained completely by online methods (49, 58, 74). This was emphasised by the guidance from the QAA (76) regarding practical sessions during the pandemic, which allowed for streamlining the requirements as not to delay student progression. The QAA suggested alternative online practical sessions that allowed data interpretation and problem solving, e.g., by providing students with a video of an experiment being conducted, and providing the data generated from previous experiments for them to analyse and interpret. They suggested further that learning outcomes that were assessed, through sessions with outcomes unachievable by a remote

TABLE 1 | Changes to biomedical scientist HCPC[a] standards of proficiency 2023.

Wording changes to include "Must" and/or "Take Action" to ensure movement away from passive understanding of professional requirements towards an active implementation
Inclusion of the promotion of public health and preventing ill-health
The expansion of Equality, Diversity and Inclusion
Centralisation of the role of the service user
Increased emphasis on registrants in looking after their own mental health
Increased emphasis on digital skills and currency
Increased emphasis on the role of leadership

[a]*Health and Care Professions Council.*

alternative, e.g., competence in handling equipment, should be postponed until restrictions lifted to allow them to take place. However, it was further stated that if those learning outcomes have already been achieved in previous laboratory sessions/modules, they could be disregarded (76). In consequence, some universities organised additional laboratory practical sessions post lockdown to bridge any perceived gap (61). Universities realised the benefits to online learning providing flexibility to students and faculty (50, 59, 61) but also recognised the importance of maintaining social interactions and practical skills. Thus, in some circumstances a hybrid approach would be more appropriate to ensure graduates have the skills required for industry, whilst using digital practical sessions to complement learning and improve engagement (11, 62, 74, 75).

Even with virtual simulation, it can be argued that the advanced clinical laboratory workplace skill acquisition cannot be well replicated within a HEI setting. With increasingly automated testing in clinical laboratories, the use of large multi-channel analytical platforms and advances in digital technologies, there is less of an emphasis on conventional discipline specific tasks and manual methods. Instead, there is a need for a flexible, cross-disciplinary workforce with broad skills mix to allow to adapt to service needs. Thus, vital skills now required of graduates may include an awareness of automation and analytical platforms, research and innovation, leadership, digital and ICT competency, method validation, quality assurance and bioinformatics (71, 77, 78). It has been suggested that transforming the curriculum to support the development of such skills is possible through online learning and may better prepare Bioscience graduates for industry needs (71), rather than just those handful that are able to secure one of the limited placement opportunities. Thus, the pandemic may have presented an opportunity to revise and adapt current curriculum to reflect service needs whilst reducing the strain on HEI laboratory resources. Some on campus laboratory classes could be replaced with data analysis projects that promote bioinformatics, problem-solving, and interpretation skills (79) that are highly appliable to many disciplines in biomedical science today. This could also offer increased flexibility and a greater choice to students in their final year research endeavours, which can improve their motivation and engagement (77). Indeed, the Royal Society of Biology (RSB) recognised this prior to the pandemic as evidenced in their updated accreditation requirements (79, 80). The pandemic accelerated the adoption of such strategies by the IBMS, who have published some examples of final year projects that can be carried out remotely and fulfil the IBMS accreditation requirement for Biomedical Science degrees (71, 81). Off-site "dry" research projects also present an opportunity for collaboration between HEIs, students, and industry and a chance to expand placement provision, usually limited by industry resources and willingness (82). Benefits include a wider choice of project types, an understanding of industry needs, and improved employability for students. HEIs can form valuable links with industry and keep up to date with current practice which will enhance teaching. Finally, industry partners can benefit from expanding their pool of appropriately skilled graduates and welcome the introduction of new ideas and innovations into their organisation (71). Projects can be designed around industry needs to have a real-life impact. Although some examples of this are already in place, they are limited. The pandemic has highlighted their potential and as a possible solution for tackling the lack of placement opportunities for students (71). One example of such a venture (83) created a digital internship for Microbiology students that enabled collaboration, research skills, communication, scientific literacy, and digital competency. Students worked remotely with peers in a team, supervised by the faculty, to annotate a series of Microbiology podcasts discussing the latest research and techniques from primary sources. Students were tasked with aligning the podcast content to the professional standards and curriculum learning outcomes, while annotating them accordingly. In addition to the plethora of skills achieved by the students, the internship created work experience opportunities, improved course engagement, and created valuable education resources for teaching (83).

Virtual technologies such a virtual reality, augmented reality, and serious gamification may be a good addition to course programmes to better prepare students for industry, providing they remain up to date and relevant. Such methods can immerse students in a virtual, yet real life workplace scenario, where they can make mistakes and learn from them without causing harm to peers or patients (46, 67). Applications could be tailored to recreate clinical laboratory situations that cannot be well replicated in HEI facilities, e.g., prioritising urgent samples or preventing pre-analytical variables such as incorrect blood tube use, as demonstrated in a recent study (67). Although, more research on the effectiveness of digital simulations for laboratory training are warranted (82), there are clear benefits to incorporating them into teaching practices to improve student understanding and engagement in practical sessions (74, 75).

Laboratory placements are limited to what can be supported by clinical partners and apprenticeship provisions (67, 82), limiting access to the experience required for HCPC registration. It has been stated that the impact of the pandemic on Bioscience placements/internships is not well known but is worthy of attention (71). The pandemic may have decreased opportunities because of social distancing measures and the increase in remote working. In contrast, it may have provided new opportunities for online collaboration (71, 83) and increased the scope for a different kind of laboratory experience. For example, in response to the pandemic, the HCPC and IBMS worked with the UK Government to arrange a temporary HCPC register for some healthcare professionals to increase staffing resources. This register allowed former registrants (left within 3 years) and final year students (on accredited courses) to temporarily practice under protected titles, therefore providing students with the opportunity to be part of the

pandemic efforts. However, the uptake of temporary registrants into the workforce was low at 10% (84). Nevertheless, following closure of the temporary register, 37 Biomedical Scientist and Clinical Scientist students that entered practice were kept on the register as they progressed towards achieving permanent registration (84). A further example of the pandemic generating workplace experience opportunities includes Derby University students involved in COVID-19 testing centres and receiving encouragement to become volunteer vaccinators (85). As diagnostics become more patient focussed and there is a drive towards increased use of point of care testing (86, 87), such experience is valuable to future trends in Biomedical Science (78) and helps to reiterate to students that there is a patient at the end of every sample. In addition, the pandemic accelerated open online learning resources, e.g., *via* social media and podcasts, which extended real industry knowledge to scientific, student/trainee, and public communities. As conferences moved online, education and professional development opportunities became more accessible than ever before. A particular benefit to trainees in rural areas who may usually struggle to access resources due to geographical constraints and the expense involved in travelling long distances, not to mention the sustainability benefits if this trend continues going forward.

The Impact of the Pandemic on Clinical Laboratories

There is very little published information detailing the impact of the pandemic on the clinical laboratory workforce (12, 13, 87). Lee et al (12) examined the psychological impact of the pandemic on laboratory staff, which is discussed later in this review. From the limited data available however, it's apparent that the effects of the pandemic were felt differently between pathology disciplines. Microbiology/Virology took the brunt of the pandemic testing initiatives; validating and implementing new COVID-19 tests and changing working practices to meet the large demand, with many laboratories converting to a 24/7 rota. Whilst other disciplines may have experienced a dramatic decrease in workload due to the cancellation of routine and non-urgent appointments, surgeries, and testing. The decrease in workload provided fewer opportunities for staff training and development, as samples were limited to urgent only requests (89, 90). Lucey and O'Connor (13) conducted a study in Ireland, where they surveyed 272 laboratory professionals at various grades across all major disciplines. Impacts reported by respondents included an increase in working hours (48%), and increased complexity in the types of tests being performed (70%). The impacts of the pandemic can be found summarised in **Tables 2**, **3**. Interestingly, professionals working in multidisciplinary and Biochemistry laboratories reported a significantly greater number of additional hours worked when compared to staff in Microbiology. A possible explanation for this could be the reduction in workforce due to isolation of the vulnerable, sickness and/or an increase in workload through an increase in hospital admissions. This is contradictory to a study in Pakistan that surveyed 50 Clinical Chemistry laboratory professionals and found 80% reported increased ability to maintain accreditation and quality standards as their workload decreased from the decline in non-urgent testing. These are tasks which usually cause stress and are time dependant heavy (88). Notably, the study had a small sample size and focussed solely on one discipline with no comparisons between disciplines. Lucey and O'Connor (13) go further, explaining Microbiology reported the most significant rates of change in rota schedules and higher complexity in the types of tests they were performing in comparison to other major disciplines. The authors attribute this to the implementation and validation of molecular COVID-19 testing platforms, of which a variety were needed to manage the fluctuating availability of reagents and consumables. In addition, 21% of respondents reported disruption to training and this occurred at all levels; undergraduate, Masters, PhD, CPD and professional development activities. However, positive reports included staff feeling a sense of pride for the work they were doing and acknowledging the importance of collaboration to meet service needs, as well as their ability to adapt to new ways of working (13). Many staff working in disciplines that experienced a decrease in workload were retrained and redeployed to areas of need, e.g., to support sample collection, processing, and testing (89). Further emphasising the need for a flexible workforce and training that is fit for purpose to allow staff to respond to crises. In addition, staffing levels fluctuated as the vulnerable and those testing positive isolated, and those with childcare responsibilities were unable to attend following school closures (90). As restrictions have now largely lifted, new challenges arise. There is a large backlog of tests as the NHS catches up on postponed appointments and surgeries (91). RCPath have expressed concerns over cancer diagnostics in Histology and Haematology, and in Blood Transfusion provision. Stating the workforce is currently understaffed to deal with the backlog and the increase in chemotherapy is likely to increase the requirement for compatible blood. Further added concerns include blood donations which were stifled due to restrictions and illness (92). However, one hopeful outcome of the pandemic is that such workforce challenges were highlighted and warranted increased funding from the government's COVID-19 response group. In an IBMS online Webinar discussing developing the scientific workforce (93), Ruth Thomsen (Scientific Director, NHS England) introduces the implementation of Practice Educators into laboratory networks across London thanks to such funding. These Practice Educators are tasked with identifying workforce challenges, including training, development, and progression. They are working across laboratory networks to identify key barriers and skills gaps and share best practice between regions. This new role and collaborative effort in identifying challenges and areas for enhancement will provide key insights and data that may guide improvements to training, development, and service provision for the future.

In the Eyes of the Public

Possibly the largest Impact of the pandemic on the workforce was that the role and importance of biomedical science gained public attention (87). Pathology, encompassing all disciplines, has gone

TABLE 2 | Summary of negative COVID-19 impacts on course and training delivery.

Rapid transition to Emergency Remote Teaching without thorough course design
Practical work and technical skill development limited
Online assessments and exams, and increased stress and anxiety as these returned to campus
Inequality in Higher Education Institution resources and staff/student digital competency
Online interactions only, reduced social interaction and ability to form bonds
Reduced motivation and engagement
Time zone differences and restricted overseas travel due to lockdowns impacted international students
Personal, work and home life challenges, e.g., • nursery/primary school closures impacted childcare • increased home distractions and difficulties concentrating • financial circumstances, e.g., reduced hospitality sector • increased workload and altered ways of working for many hospital staff/ apprentices/placement students
Lockdowns limited access to workspace, technology and internet
Mental health and wellbeing compounded by isolation, risk of infection, finances and concerns over loved ones
Disruption to Clinical Laboratory Training as COVID-19 efforts prioritized

TABLE 3 | Summary of positive COVID-19 impacts on course and training delivery.

Innovative curriculum and revision of healthcare service needs
Potential expansion of project and placement types and provision, e.g., dry data analysis and digital internships
Improved digital technology and competency (utilisation of virtual conferencing tools, e.g., Microsoft Teams/Zoom)
Online verifications and conferences; education and professional development opportunities more accessible and sustainable
Acknowledgement of the importance of Biomedical Science in patient care
Importance of Training and Continual Professional Development highlighted, required to maintain an adaptable and flexible workforce that can meet service user needs and are prepared for future crises
Workforce challenges highlighted leading to increased funding and planning
Greater emphasis on supporting mental health

through substantial transformation, and has faced many budget cutting initiatives throughout the years (29). Despite being involved in 70%–80% of patient care pathways, Pathology is underfunded and has had little representation when NHS budgets are being delegated (23). The lack of wider understanding regarding this workforce's contribution can be seen by the frustration in laboratory staff from media misconceptions regarding who is performing the COVID-19 tests, as these professionals felt unrecognised for their contribution to testing (13). In addition, during the early stages of the pandemic, despite all the work that has gone in to developing pathology networks with good links and communication, the government opted to invest in separate 'light house labs' to increase COVID-19 testing capacity to meet their growing testing targets (94). These laboratories came across several challenges that demonstrate the complexities involved in running a quality assured, fit for purpose, laboratory network. For example, the IT systems were not able to transmit results to NHS patient records (95), defeating the purpose of the 'test and trace' efforts to prevent the virus spreading. Considering standardisation and developing IT connectivity were key aspects in the move to develop pathology networks, as discussed above. If this established, knowledgeable workforce had been given more of a voice early in the pandemic, policymakers may have been able to make better informed decisions on how to boost testing capacity. Furthermore, the rapid implementation of light house labs warranted concerns over the quality of testing and results as they were not held against the usual strict regulation and accreditation of accredited UK laboratories, and mostly did not have HCPC registered professionals performing the tests (96). The pandemic highlighted some poor laboratory practice to the eyes of the public, as televised by BBC panorama when an undercover reporter shared her experience of working in a light house lab, followed by later reports of false negative COVID-19 PCR results being sent to thousands of people (96). This may have unfortunately diminished the respect of highly trained and quality conscious professionals who continuously demonstrate their competence through a variety of means including completing accredited degrees, work-based competencies, and uphold a professional commitment to lifelong learning. It was not until the accumulation of this poor practice was highlighted that the established biomedical science workforce was seen, and registered experts were allowed to engage with the light house laboratory COVID-19 testing (97).

The IBMS 2022 Strategy

As the professional body for Biomedical Science, the IBMS aim to harness this new platform, as demonstrated in their 2022 strategy (87). Now that the importance of the profession and workforce has been realised, they have been able to source more funding and contribute to policy decisions more than before, and they want to ensure it remains this way. They are actively engaging with parliament through a variety of means to ensure the professions expert opinions will shape future Healthcare decisions (98). They are seeking to improve development opportunities for staff, remove current barriers to HCPC registration, maintain the workforce's new high profile and extend their global reach and collaborations. One of the barriers to HCPC registration is the availability of non-accredited Biomedical Sciences degrees. Educating students who are keen to enter the Biomedical Science workforce on appropriate degrees and entry routes will aid uptake of graduates with the required skills and competencies. Furthermore, the IBMS aimed to source funding for non-accredited degree assessments for those graduates wanting to enter the workforce but who will need to complete top up modules to allow for registration. This was successfully achieved in March 2022 as funding from NHS England became available. Furthermore, additional funding was released by Health Education England (HEE) to support the recruitment and training of Level 2, 4 and 6 Healthcare Science apprentices in efforts to develop the diagnostic workforce (99). The IBMS aim to work closely with HEIs and industry to support increased workplace opportunities, in addition to improving development opportunities at all grade levels by expanding their e-learning platform and qualifications. This includes movement away from discipline specific training to modular topics to improve skills mix and flexibility to meet service needs. This extends beyond scientific based learning and includes leadership and management skills to

give members access to more senior roles. The IBMS also aim to expand their provision of advanced practice qualifications to more disciplines, as this is largely unequal, e.g., well developed in Histology but less so in other disciplines. These objectives echo the desires of laboratory professionals wishing to develop their careers (13). To improve public knowledge of the role of Biomedical Science and the importance of the workforce, the IBMS has also increased efforts to promote the profession in the media (100) and are supporting members to engage more with the media (101). The IBMS are also commissioning PhD and research initiatives to address the lack of published resources regarding the profession (87) and supporting the implementation of Practice Educators in Healthcare Science, discussed previously (93, 102). Through this new direction of the IBMS strategy, a more positive outcome in professional recognition is predicted, and other countries have similar aims, as demonstrated by a statement from the American Society for Clinical Chemistry (103). The pandemic challenges have provided the workforce with an opportunity to display their importance, and previous deficiencies in funding and investment are being addressed that will ultimately allow for a better workforce to be built in the future.

Impact on Mental Health and Wellbeing

Mental health and wellbeing can impact training and assessment, owing to the difficulty in completing the necessary tasks and impeded motivation when individuals are negatively impacted psychologically (14–18). With limited resources published on the psychological impact the pandemic has had on laboratory staff, the scale of this is not fully understood (12). However, research regarding students, healthcare staff and the public suggests the pandemic has had a large impact and further research and support will be required. Students are known to be a vulnerable group when it comes to mental health and wellbeing, thus the additional impact of the pandemic has warranted attention (8, 9, 10, 14). A study from Saudi Arabia (104) reported medical students that quarantined for 2 weeks became detached from their peers and family and spent less time studying. They postulate these psychological effects of lockdown could be worsened with time and suggest further research is required. Furthermore, a study in Malaysia (14) found healthcare science students are particularly vulnerable due to the complexity of their training. This could be further exacerbated by the barriers to HCPC registration seen in the United Kingdom. For example, students with non-accredited degrees may find after 3–4 years of studying they need to enrol in further top up modules to be able to become a Biomedical Scientist, in addition to completing the IBMS CoC when placement/trainee posts are limited. A non-accredited degree assessment by the IBMS also costs money and the top up modules can be expensive. Thus, it is promising that the IBMS strategy wants to invest funding to support such students to HCPC registration (87). Furthermore, placements are often unpaid, and during the pandemic there were fewer hospitality jobs for students who may normally be able to make some money whilst studying/undergoing placement. Financial difficulties can worsen mental health and invoke stress which can further impact one's ability to learn/train effectively (14). As employers have recognised the benefits of remote working in providing flexibility for staff and improving environmental sustainability, many organisations are likely to make permanent changes to the way they operate. Thus, learning online and instilling self-efficiency skills into students can better prepare them for the working life of the future. To address challenges such as finding a work/home balance and emotional wellbeing, it has been suggested this can be incorporated into university curriculum to further prepare students (71).

NHS support for staff mental health and wellbeing was expanded during the pandemic (105), however a study in Scotland (3) found that barriers prevented their use for many staff. Although they focussed on front line staff, the key barriers highlighted are likely the same for laboratory workers, e.g., heavy workload, low staffing, and a fear of being judged (3, 110). They suggest it's not enough just to have support resources in place, but organisational plans to allow staff to access resources are required. A study in Singapore (12) highlights the lack of published data on the psychological impact the pandemic has had on laboratory professionals; in comparison to patient facing professionals such as nurses and doctors. Laboratory staff of various grades/experience participated in an online questionnaire to identify levels of anxiety, fear, depression, and physical symptoms such as loss of appetite, reduced sleep quality and exhaustion. Of the 103 responders working with high-risk samples during the pandemic (25th May 2020–8th June 2020), 62.1% expressed mild-severe depression, 53.4% expressed anxiety, and 55.3% generated a moderate-intense fear score. Statistical analysis also found a significant correlation between increased depression scores and the physical symptoms mentioned above ($<p = 0.05$). The authors acknowledge limitations to the study, such as an inability to cross reference medical history and the participants had to conduct the test without supervision due to social distancing. Thus, it is worth noting that whether participants had a history of mental health prior to the pandemic was not fully considered. In addition, the survey results cannot be compared to pre-pandemic scores, preventing solid conclusions. Participant variables whilst completing the survey, such as interpretation of the questions, could also not be moderated. Furthermore, the participants were largely from a blood science background. With Haematology, Blood Transfusion and Chemistry accounting for 81.2% of responses. Whilst a mere 5.7% of responders were based in Microbiology and Serology, which experienced the most dramatic change to working practices (13). Nevertheless, only 65% of responders were aware of support programmes in place, urging more needs to be done in signposting support. The limitations of the study, such as the inability to compare pandemic with pre-pandemic data further highlight the lack of published information regarding the clinical laboratory workforce.

Although there are limitations to the Singapore study, data from the Office for National Statistics Opinions and Lifestyle Survey suggests increased levels of depression in British adults during the pandemic, in comparison to pre-pandemic statistics (106, 107, 108). Albeit showing a generalised impact on mental health and wellbeing on the adult population, rather than on laboratory professionals. Respondents were considered to be experiencing symptoms when achieving a score of 10 or more on the NHS Clinical Depression 8 item score, which generates a score of 0–20. A score >10 is classified as moderate-severe depression. The June 2020 survey is of particular interest as the same group of individuals were interviewed, allowing

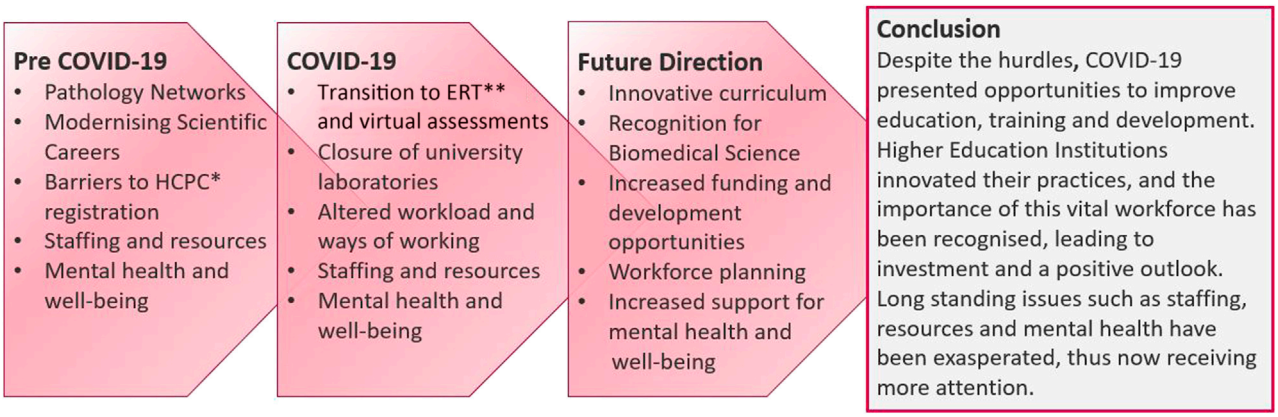

FIGURE 4 | Summary of key challenges pre COVID-19, during COVID-19, and the future outlook for education, training and progression in clinical laboratories. *Health and Care Professions Council **Emergency Remote Teaching.

TABLE 4 | Recommendations for improvements to future education, training and professional development of the clinical laboratory workforce.

Education	Higher Education Institutions to consider: • the specific needs of their students to personalise learning and share best practice • investing in digital technology; including development of staff and student competency • implementation of skills for online working, self-efficiency and maintaining a healthy work/home balance into the curriculum as more employers move to remote working
Training	Consider alternative and simulated placement opportunities to expand placement provision Emphasise and support skills mix in development opportunities to promote a flexible workforce Close collaboration between universities and industry required to ensure education and training is fit for purpose
Assessment	Consider alternative research projects—alternatives to laboratory-based projects include; Bioinformatics/big data; computational modelling; simulation evaluations; systematic reviews containing meta-analysis; surveys/focus groups and educational development evaluations
Workplace Practice	Utilisation of available funding to support education development Prioritisation and investment in training support and provision Consideration of training needs to be embedded into workforce planning and recruitment as Continual Professional Development is a key requirement for maintaining Health and Care Professions Council registration
Mental Health	Encourage self-awareness and reduction of associated stigma Clear signposting of the support available and organisational plans to remove barriers to accessing these
Public Perception	Promote student and employee public engagement and outreach activities

comparison of their pre-pandemic (July 2019–March 2020) and pandemic depression scores. The report (106) highlighted 12.9% of respondents went from a pre-pandemic depression score <10 to a score >10 during the pandemic. Furthermore, of the 19.2% responders that reported some form of depression (score >10), 80% stated their wellbeing had been affected by the pandemic, with 84.9% reporting feelings of stress and/or anxiety (105). Although no details regarding professional/job status were collected, sickness rate data from NHS Digital suggests that healthcare professionals are vulnerable to mental health difficulties, demonstrated by this repeatedly being the most common cause of absence for NHS employees (18). However, this is generated from NHS Electronic Staff Record (ESR) data, thus largely depends on NHS Trust's self-reporting, and has many limitations, e.g., variations in how Trust's report their absence rates, under reporting, or not reporting reasons for illness.

A group particularly vulnerable to mental health and wellbeing impacts are apprentice trainee Biomedical Scientists as they would face an accumulation of both student and employee challenges, worsened by the pandemic, with a hectic academic and laboratory workload, in addition to their personal lives. They are often required to invest a large proportion of their personal time to catching up with assignments, which leaves little time for rest, increasing their risk of burnout (109). With the increased uptake of apprentices into Biomedical science, also indicated in the NHS Diagnostics and Recovery plan (86), further research, resources, and effective signposting to support apprentices is warranted. The recognition of the impact of mental health and wellbeing has been recognised through its inclusion in the

updated HCPC standards of proficiency for Biomedical Scientists summarised in **Table 1** (66, 111).

CONCLUSION

A realisation of this review is that the impact of the pandemic on training and assessment in the clinical laboratory is multifaceted and cannot simply be summarised. Every level of trainee, from undergraduate, apprentice, staff pursuing further education and those looking to develop their practice, experienced unique challenges. In addition, the impact on different pathology disciplines varied enormously, however all experienced a very different way of working and adapted to novel and stressful situations. Effective workplace planning will require reliable data on the current state of the clinical laboratory workforce (85, 86). Strategies moving forward should address the long-standing concerns regarding staffing and investment in all disciplines relevant to future workloads and testing demands, not only those that were hit worst during the pandemic. Collaboration between HEIs and industry are vital to ensure training is fit for purpose from the very beginning. A common theme throughout this review is that there is limited research published regarding the impact of major change on the clinical laboratory workforce in multiple areas, including their training and development. With the vital contribution this group has on the patient pathway and in national crises, as highlighted by the pandemic, this warrants further attention. Subsequent research is required in relation to the clinical laboratory workforce, barriers to their training, and how the service can be shaped to provide better care for patients.

The outlook is promising as demonstrated by the IBMS corporate strategic plan (87). HEIs are innovating their teaching practices, learning from the transition to ERT, which provided many insights and opportunities that can be harnessed to improve the quality of teaching for the future. A fundamental impact of the pandemic on clinical laboratory training and assessment is highlighted through the recognition of the importance of a quality service for patients and in developing a workforce that is fit to respond to changing patient needs and future crises. Despite the challenges imposed by the pandemic, pathology departments have maintained a quality service and implemented innovative practices that will have a long-lasting impact on the quality of care for the future. Ultimately, this review has aimed to highlight the plethora of challenges faced by the clinical laboratory workforce, pre- and post-pandemic, with special attention on the impact of training at all levels. This may serve as a starting point for what will inevitably be a growing area of research for the future as a result of the workforce's newfound visibility and subsequent recognition of the vital contribution they make to healthcare and wider society. Furthermore, the 2023 revised QAA benchmark statement for Biomedical Sciences will ensure key knowledge, skills and competences including equality, diversity and inclusion, resilience, leadership and sustainability, will become embedded into higher education courses in the near future (68, 112).

A summary of the main findings from this review can be found in **Figure 4**, with final recommendations in **Table 4**.

LIMITATIONS

Limited primary resources available in this area, as identified by review, requires further research.

AUTHOR CONTRIBUTIONS

Review produced in partial fulfilment of MSc Biomedical Science by CP, corresponding author. SS as dissertation supervisor and mentor, contributed to revisions and provided the original title "Critically Evaluate the Impact of COVID-19 on Clinical Laboratory Training and Assessment" to which this work was based.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ACKNOWLEDGMENTS

The authors would like to thank the IBMS for continuous updates regarding the clinical laboratory workforce *via* various means. We also thank NTU Applied Biomed apprentices, their employer mentors, and the Biomed community that reached out on twitter in response to this dissertation title, for their valuable insights into their laboratories during the pandemic. These discussions aided understanding of the challenges faced and the evolving situation as primary resources were limited. The corresponding author would also like to thank Mark Cioni from Nottingham Trent University, and David Wells from the IBMS, for their feedback and support.

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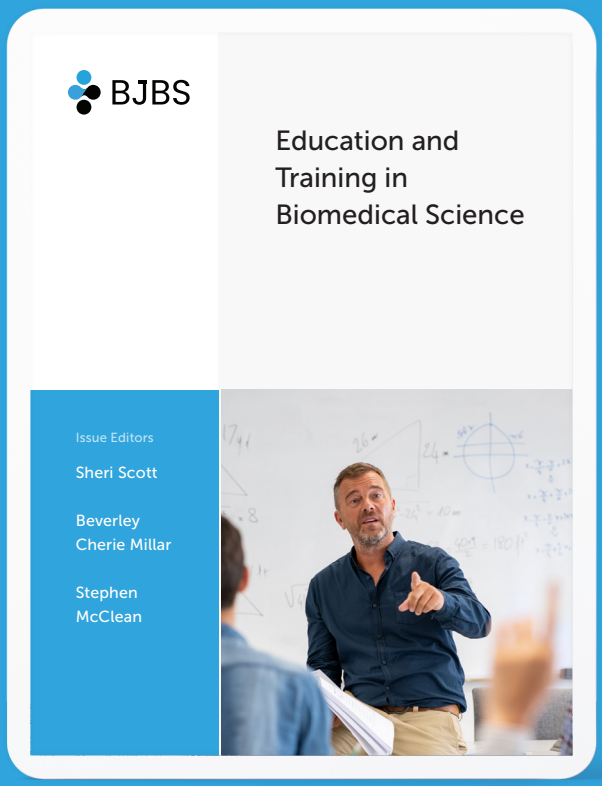

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