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Enhancing students' digital skills through a *Biotechnology & Bioprocessing* module designed for chemical engineers

Alfred Fernandez-Castane

Department of Chemical Engineering and Applied Chemistry, Aston University, Birmingham, UK

ABSTRACT
The transformation of the chemical engineering profession is occurring in response to the industry needs of the rapidly-developing bioeconomy and biosector across Europe. To meet these requirements, a new Biotechnology and Bioprocessing module has been designed and offered to Chemical Engineering undergraduates at Aston University, UK. This module bridges chemical engineering and biosciences disciplines, providing students with new skills and knowledge to better understand the opportunities available to chemical engineering professionals within the biosector. Here, we evaluate how the use of digital technologies enhances the student's learning experience using a range of innovative learning activities delivered in a digital environment. The student's and author's perceptions are evaluated, and future improvements identified. This module will contribute to preparing graduates for a successful career in the highly competitive landscape of the bioeconomy and biosector. This pedagogical approach prepares graduates for, hybrid and remote study and working patterns and; changing industrial and digital learning demands.

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1. Introduction

The rapidly-developing bioeconomy and the biosector require that chemical engineers gain a range of new skills that prepare them for a greater diversity of roles available. The role and opportunities for chemical engineers in the bioeconomy and biotechnology have been analysed extensively (National Research Council, 2004; Shott et al., 2015; Webb & Atkinson, 1992). Recently, the BioFutures Programme was set in the United Kingdom to help shape the Institution of Chemical Engineers (IChemE) strategy and ensure that the transformation of the chemical engineer profession includes learning new and more diverse skills that will meet the requirement of the bioeconomy growth. According to the UK Government's published report *Growing the bioeconomy: A national strategy to 2030* (HM Government, 2018), the UK aims to double the size of the impact of the bioeconomy to £440 billion by 2030. On the other hand, it is expected that the bioeconomy will represent up to 10% of the total industrial production globally by 2050 (European Commission, Joint Research Centre M'barek et al., 2019). To this end, harnessing the power of biosciences by producing innovative products and processes that rely on renewable biological resources instead of fossil fuel alternatives will be key in the aim for at least a 68% reduction in greenhouse gas emissions by 2030 (BEIS, 2020) toward a net zero target by 2050 (BEIS, 2019) in the UK and to support the sustainability development goals as set by the United Nations (United Nations, 2018).

Therefore, the growth of the bioeconomy will be underpinned for example, by advances in industrial biotechnology (IB) (Donohoue et al., 2018), synthetic biology (Vickers et al., 2017), and; artificial intelligence and digital technologies (Niazi et al., 2019) whilst developing sustainable products and processes (Straathof et al., 2019; Hierro-Iglesias et al., 2021; Hierro-Iglesias et al., 2022).

CONTACT Alfred Fernandez-Castane a.fernandez-castane1@aston.ac.uk Department of Chemical Engineering and Applied Chemistry, Aston University, Aston Triangle, B4 7ET, Birmingham, UK.

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According to the report published by BioFutures (IChemE BioFutures, 2018), it was found that the industry responders to a survey (62.5% of all responders and 83% of those that employ chemical engineers) believe that there was a common lack of biosciences skills and knowledge provision among chemical engineers working in industrial biotechnology and the bioeconomy. The results from the survey also suggested that industry would like chemical engineering graduates to have a deeper knowledge of biotechnology-related topics particularly, those that fall under the discipline of engineering such as bioprocessing (i.e., fermentation, bioreactor design and downstream processing). Therefore, several Universities across the UK, including Aston University, are in the process of expanding the chemical engineering curriculum to increase the biosciences-related content ("biocontent") in their programmes. A recent report from the THYME Project presents the action plans for employers and universities to collaboratively enhance graduate employability for bioeconomy roles, thereby benefiting both universities and employers (Peasland et al., 2021). Nonetheless, some challenges that may hinder the implementation of the aforementioned changes such as, but not limited to:

- Need for Institution-level investment and fit with the University's long-term strategic aspirations
- Expertise by existing staff in the biosector
- Time and willingness for staff to implement changes
- Additional laboratory space when students are exposed to practicals
- Risk of diluting the core chemical engineering content

Acknowledging that the introduction of biocontent (or other addition to the curriculum) would necessitate trimming elsewhere in the core chemical engineering curriculum, there is an outstanding question of whether these extra materials are to be added in existing modules or whether new specific "bio" modules need to be created.

On the other hand, the recent COVID-19 pandemic and the government-imposed restrictions have caused significant changes in many aspects of our lives, including economic and social impacts. Universities were affected by additional economic pressures (London Economics, 2020) and increased demands to ensure a high-quality student learning experience (Higson, 2020; Dumont et al., 2021). Students and academics have faced additional challenges to deal with, such as managing the use of new technologies, attending on-campus sessions with social distancing or moving the delivery of modules using an online environment entirely due to university closure. The recent pandemic accelerated the deployment of digital technologies, suggesting multiple ways to communicate, learn, correspond, cooperate, and collaborate (Rahman, 2020). This is key to developing positive relationships between digital technologies and education to effectively contribute to educational institutions to remain a long-term response. Online learning needs far more purposeful, thoughtful design, with attention to those active learning principles, but done in a more flexible fashion (Clay, 2020). In this context, and to broaden the biosciences skills and knowledge of chemical engineers to enable them to enter the biosector, the Department of Chemical Engineering and Applied Chemistry (CEAC) at Aston University has developed a third-year optional module in "Bioprocessing and Biotechnology" as an online teaching and learning experience. Here, the author presents the development of learning activities in this new module offered to BEng/MEng Chemical Engineering students. Implementation of the learning materials, methodology and good practices is discussed. Finally, the implementation and limitations of this study are discussed; as well as changes to implementation in future years are proposed.

2. Implementation of the innovation

Technology-enhanced learning (TEL) or digital learning encompasses a wide range of learning approaches, digital technologies, and services. In essence, the academic engages digitally with the student in the context of a pedagogic framework and the outcomes are monitored and measured using an assessment strategy. The potential of TEL can (i) enhance the student experience, (ii) potentially improve student outcomes, (iii) widen participation) and (iv) improve accessibility and inclusion. In contrast, adding a digital element to learning could result in (i) challenges reconciling the inconsistent experience, (ii) impact on connectivity and bandwidth on the experience, (iii) technology displacing effective practice and (iv) poor experience due to insufficient skills and capabilities across staff and students (Clay, 2020). The adjustment of the curriculum to fit with the needs of the chemical engineering profession and the changes in the higher education landscape, therefore, represents an opportunity to effectively use digital technologies to design and deliver a new module subject of this study, *Biotechnology and Bioprocessing*. The author never taught an online class before the COVID-19 pandemic other than using virtual learning environments (VLEs) to support traditional teaching and therefore, the design of the new *Biotechnology and Bioprocessing* module for online delivery required many hours of work including, learning the technology and identifying the best teaching approach to deliver biocontent to third-year chemical engineering students. With the technological help from the Technology-Enhanced Learning (TEL) team and a working group within the CEAC Department that emerged as a result of the pandemic situation, the author acquired the necessary IT skills for teaching remotely. The strategy to include biocontent in the chemical engineering curriculum was incubated for around three years including discussions with internal and external academics along with the CEAC Industrial Advisory Board, in coordination with the Head of the Department and Programme Director.

Subsequently, a few core chemical engineering first- and second-year modules have incorporated now biocontent (not the subject of discussion in this work) and a dedicated "bio" optional module sitting in the interface between the biosciences, biotechnologies and engineering disciplines, has been created.

2.1. Structure and learning activities

Biotechnology and Bioprocessing, developed by the author (module owner) and an additional module tutor is a 15-credit module. With online teaching, the developers sought to achieve two aims: (1) develop a set of biocontent tailored to chemical engineering students and (2) effectively use interaction methods that stimulate the student's learning experience despite the restrictions resulting from the COVID-19 pandemic to promote active learning. A variety of learning approaches were implemented to enable widening participation and improve accessibility and inclusion in a newly developed module (Al-Sholi et al., 2021).

To this end, the developers divided the module content into three blocks. First, a block of content was dedicated to fundamentals in biology, which would help chemical engineering students to familiarize themselves with common terms and concepts used in the biological sciences. Having this basic knowledge will in turn enable students to communicate with professionals with diverse backgrounds in the biosciences. The second block of content was dedicated to core biochemical engineering topics where students will be able to apply their knowledge and skills in chemical engineering and adapt these within the context of dealing with biological entities. The third block was dedicated to biotechnological processes and applications where the learning materials from blocks one and two were consolidated by learning from case studies and examples of integrated bioprocesses.

On the other hand, the developers used a hybrid online format (Sener, 2015) to deliver the module content through asynchronous online flexible learning activities (i.e. pre-recorded lectures) and synchronous online live and interactive activities (i.e. tutorials). In addition, and order to provide a practical element to the module, virtual labs were conducted. Table 1 summarises the types of learning activities

Table 1. Learning activities developed for teaching the Biotechnology and Bioprocessing module.

Learning Activity	Timetabled component	Type of activity	Students role	Duration (min)
Recorded lectures	Asynchronous	Individual	Passive	15–30
Problem-based tutorials	Synchronous	Individual/group	Active	60
Seminar: Case study of a biotechnological process	Synchronous	Individual	Passive/active	60
Round table: Discussion about a relevant hot topic	Synchronous	Individual/group	Active	30
Tutorials in support to the preparation of group presentations	Synchronous	Group	Active	120

Asynchronous: Online Flexible Learning Activity; Synchronous: Online Live and Interactive Activity.

developed for teaching the *Biotechnology and Bioprocessing* module and these are further discussed below.

2.1.1. Recorded lectures

The development of asynchronous lectures through sections between 15 and 30 min duration ensured that issues related to internet connectivity that may affect live sessions were avoided and enabled students to learn at their own pace and flexibly. The pre-recorded sessions enabled the lecturer to incorporate theoretical concepts as well as "well thought" examples into the lecture sections that were prepared using Microsoft Office PowerPoint and recorded using Panopto Recorder. Subsequently, video recordings were uploaded onto the Blackboard module course, which is the VLE used at Aston University. As an example, Figure 1 depicts a screen capture of the video recording of the *Bioreactors* session as part of the asynchronous component.

2.1.2. Problem-based learning tutorials

The problem-based learning (PBL) tutorials were introduced in this module as part of the synchronous sessions with the expectation that students become competent in applying knowledge learnt through the asynchronous sessions in the context of solving a given problem. A list of problems was made available to students at least 2–3 days before the tutorial. This list combined a mixture of relatively short problems with long and complex problems with different levels of difficulty and students were able to select those to be solved during the tutorial. To provide active learning opportunities, students were given time to solve the problem individually, followed by a discussion and solution provided by the lecturer. As an example, Figure 2 shows one of the problems solved during one of the PBL activities by sharing a PowerPoint document through Blackboard Collaborate and solved using handwriting with the aid of the XP-Pen Deco01 Professional Graphic Drawing Tablet with 8192 levels Stylus. The use of the drawing tablet and the stylus facilitated the implementation of this activity thus, mimicking traditional handwriting on white/blackboards that are typically utilised in face-to-face PBL tutorials. This type of activity helped in bridging the theory-practice gap and promoted learning effectively whilst providing an accessible environment to widen student participation and inclusion. The sessions also included reflection on the tasks and revision of previously taught content. Therefore, critical thinking, problem-solving and teamwork skills were particularly emphasized (Barr & Tagg, 1995; Wood, 2004).

2.1.3. Virtual labs

The addition of laboratory practicals is an important component in STEM disciplines. Lab work allows students not only to put the theoretical concepts taught in lectures into practical use but also, to improve their understanding of a particular process (Brown et al., 2019). The delivery of a practical

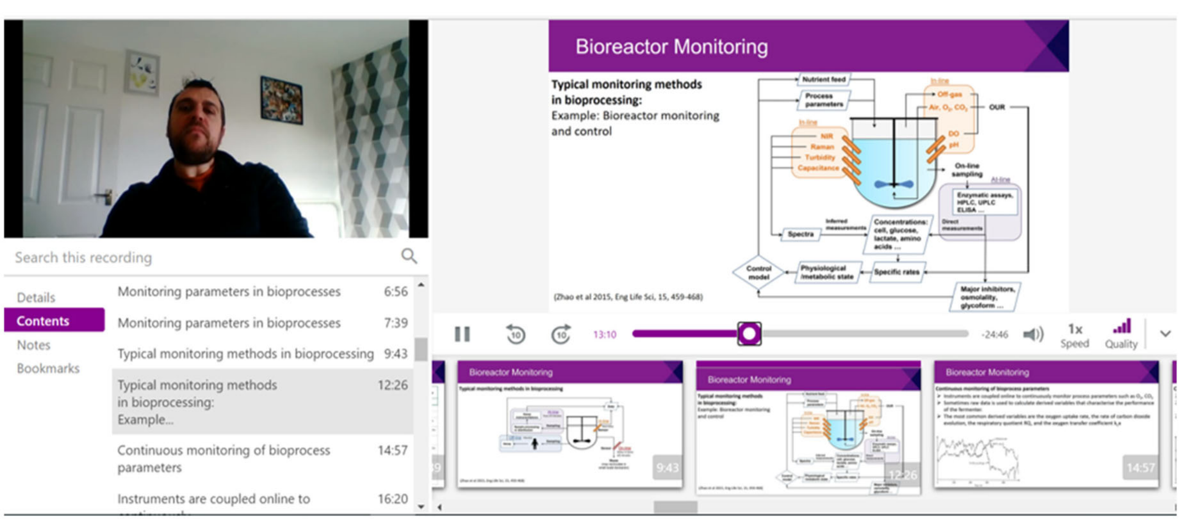

Figure 1. Screen capture showing a video recording of the *Bioreactors* session as part of the asynchronous component of the *Biotechnology and Bioprocessing* module.

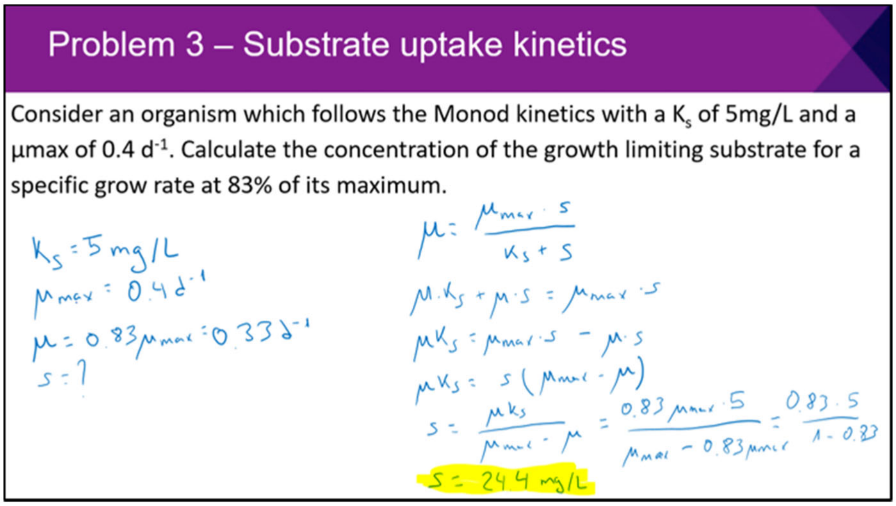

Figure 2. PowerPoint slide that included free-hand written text to a problem-based activity with the aid of the XP-Pen Deco01 Professional Graphic Drawing Tablet with 8192 levels Stylus.

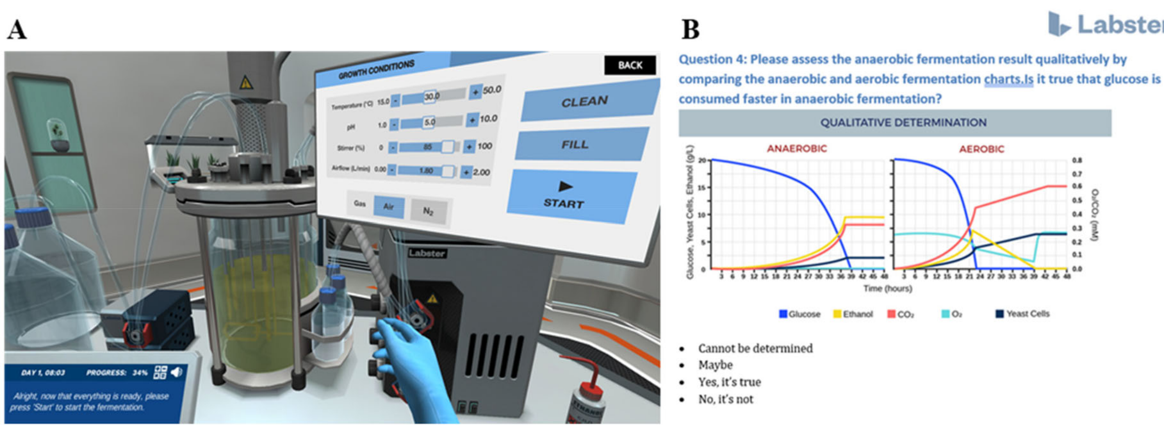

Figure 3. Screenshot of Labster 3D virtual environment of the simulation (A) "Fermentation: Optimize bio-ethanol production" and (B) example quiz question related to the virtual practical.

component in a digital environment can be achieved by using, for example, virtual lab simulations that allow students to complete laboratory experiments online and explore abstract concepts and complex theories without stepping into a physical science lab. Labster was used for the delivery of virtual labs that aligned with the contents taught in synchronous/asynchronous through the three teaching blocks of the module. This software has been effectively used in a range of STEM subjects including biotechnology and biochemical engineering (Kumar et al., 2021; Wismer et al., 2021). Labster consists of a 3D learning virtual environment (i.e., may be a laboratory, a forest or the desert plains) that combines storytelling and a scoring system. One of the advantages of this platform is that it can be integrated into Blackboard so that students' engagement and performance data can be kept and recorded easily. Figure 3 shows as an example the virtual lab environment of the simulation named "Fermentation: Optimize bio-ethanol production." In this experiment, students evaluate, how changing the fermentation parameters (temperature, pH, stirring, air flow rate) affects cell growth, bio-ethanol production, O_2 consumption and CO_2 emissions.

2.1.4. Seminar

Chemical engineering students enrolled on the *Biotechnology and Bioprocessing* module needed to develop a deep understanding of engineering principles, basic knowledge of fundamentals in biology and problem-solving skills. To achieve this, three key areas needed to be studied: theory,

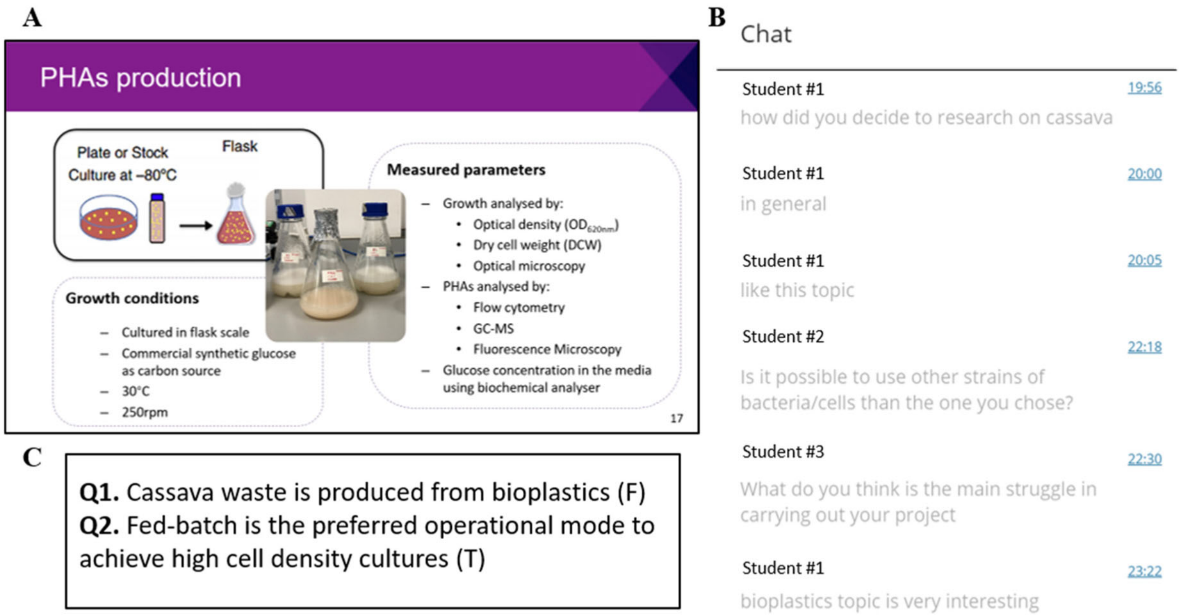

Figure 4. Learning activity. Seminar on the *Production of polyhydroxyalkanoates from cassava waste using biological routes.* (A) PowerPoint slide presented in the seminar that relates theoretical concepts with their application, (B) screen capture of the questions posted in the chat by students to the presenter and (C) example questions that were asked to students using Blackboard Collaborate Poll. F, False; T, True.

implementation and application. Deep theoretical understanding gives the basis for the two latter areas and this was achieved through the recorded lectures and PBL activities.

The seminar *Production of polyhydroxyalkanoates from cassava waste using biological routes* was given by an Aston University PhD student. This learning activity enabled students to (i) better understand the context of the topics that were being taught in this module and (ii) make the connections between engineering and biotechnological disciplines. Moreover, the topic of the seminar enabled students to recognise what they were studying and its significance in the context of real-world research. The activity was structured in three parts: First, the presentation given by the PhD student followed by Q&As and a poll at the end of the session. Figure 4 shows as an example a PowerPoint slide which connects some of the theoretical concepts e.g. cultivation conditions and calculation of cell growth) with their application in the context of a research project presented in the seminar (Figure 4(A)). This seminar can be classified as research-led teaching where students are taught research findings in their field of study (Higher Education Academy, 2017). Many authors have already highlighted the benefits of such practice. For example, it facilitates a deep understanding of the teaching material; it allows students to develop their intellect by experiencing independent and/or collaborative research and by letting them become a creative and critical thinkers; it increases students' engagement in their studies and helps them become independent learner (Brew, 2006; Healey, 2005; McLean & Barker, 2004). The Q&A part of the session was done through the use of the chat function on Blackboard Collaborate so that students could ask questions to the presenter (Figure 4(B)). In this way, students posted several questions and the presenter was answering using the microphone. Interestingly, and from the authors' perception, the use of the chat function seemed to enhance student engagement in asking questions compared to Q&As after face-to-face seminars. This observation is in line with previous studies where teaching with technology and the use of online chat fostered student engagement and effective discussions and interaction in in-class and online environments (Cameron, 2006). The last part of the session consisted in asking questions directly linked to the content of the seminar to students using Blackboard Collaborate Poll. Figure 4(B) shows as an example, two questions that were formulated by students. The post-seminar poll aimed to evaluate the effectiveness of the communication and whether students could recall important information. To achieve this purpose, True/False questions and MCQ (multi-choice questions) were articulated. The results of each question were revealed and a short discussion followed to consolidate the acquired knowledge and benefit the participants' experience (Zueger et al., 2014).

Overall, the seminar resulted in an enjoyable session for both, the presenter and the audience and stimulated the active engagement of students. The post-seminar poll successfully measured the impact of the seminar.

2.1.5. Round table

A practical, engaging alternative to the traditional classroom (or virtual room) for small group teaching is the use of round tables. The lecturer had the chairing role in the session and students debated around the selected topic: an article that was recently published in *The Guardian* "What's the point of lab-grown meat when we can simply eat more vegetables?" (Kleeman, 2020). Topical news stories are a great source of teaching material and the above news article was selected according to the appropriateness of the topic, length, language content and task suitability (Ree, n.d.). Lab-grown meat is an emerging biotechnology in food manufacturing that is expected to impact the food system making a "net zero" contribution to climate change in 2040 according to the National Farmers Union (National Farmers Union, 2001); the news article was of the adequate length (< 1000 words) to ensure the most attention; news articles are written to communicate with a non-specialist reader and; the session was designed to empower critical thinking and interaction between students. The article was made available to students in advance of the session to read it flexibly. They were tasked to critically read it so that they would come up with an "opinion made." The following questions prepared by the lecturer were used to drive the structured discussion among students:

1. What are the ethical implications of eating meat cultivated in the lab?
2. Is meat cultivated in the lab a solution to greenhouse gas emissions?
3. What are the regulatory implications of producing meat in the lab? What are the potential hazards? How lab-grown meat can be produced safely?
4. What is the role of chemical engineers in this sector?
5. Would you eat cultivated meat in the lab? Justify your response.

The above questions were formulated to understand the opinions of the students. Throughout the course of the activity carried out after distribution students randomly in groups of four out using the Breakout room function on Blackboard Collaborate, students presented their arguments to sustain their opinions within the group for a period of 20 min. The use of a microphone was encouraged rather than using the chat function. This enabled them to develop their communication skills and improve their confidence when engaging in conversations with peers. The lecturer moved through the different "rooms" to oversee the course of the discussions and assist students where needed. Students were doing the majority of the speaking throughout the session after the 20 min breakout room session, all students came back to the "main room" whereby one representative of each group summarised the discussion and different views on the topic. As a result of the activity, students developed their self-expression and built an authentic voice on a hot topic that was linked to the theoretical and practical learning materials (Roberts & Cooke, 2009).

2.1.6. Tutorials in support of the preparation of oral group presentations

An oral group presentation was one of the assessment components for this module (Table 2). Details of the assessment and feedback methodology are presented in Section 2.2. To support students with the preparation of the oral group presentations, two tutorial sessions were organised. The activity initially was designed and delivered through Blackboard Collaborate to the 2020–2021 cohort which worked very well. However, feedback received by students and their willingness to have an "on campus" activity

Table 2. Assessment methodology.

Assessment component	Type	Class	Assessment system	Weight (%)
Quiz 1	Individual	Formative	Points based grading	20
Quiz 2	Individual	Formative	Points based grading	30
LABSTER virtual labs	Individual	Formative	Points based grading	20
Oral Presentation	Group	Summative	Grading through rubric	30

in this module, actioned the academic team to move tutorials and the group presentations to face-to-face sessions from the 2021 to 2022 cohort onwards. Tutorial 1 and Tutorial 2 occurred three and one weeks before the assessment date, respectively. Students were instructed to read the selected research article and annotate questions before attending the first tutorial. In Tutorial 1, the description and aims of the task, advice on the structure and additional resources were provided by the tutors. Students were allowed to ask questions related to the content of the research paper (e.g. clarification of technical concepts or terminology) and by the end of the session, all groups had distributed the work among the team and decided what to include in their presentation. Students had two weeks to work on the preparation of their oral presentation before attending Tutorial 2 in which they had the opportunity to ask questions and receive further support on the preparation of their presentation. Tutors provided informal feedback on the content of the slides.

As part of this assignment, reading and understanding the literature around a specific subject was an important task that is also applicable in roles such as researcher, consultant and process/product engineer. By preparing for the oral group presentations, students developed skills that enabled them to recognise the typical structure of research articles and understand important aspects of scientific writing. Students learnt about how research data is presented to high standards and needed to demonstrate the ability to explain and discuss results from research findings. Additionally, students were able to apply their critical thinking to understand the relevance and contribution of a research article within the field of biochemical engineering. Teamwork was another important aspect of the group oral presentations. The introduction of the tutorials in support of oral presentations enhanced the learner's awareness of oral presentation delivery skills which are useful beyond the academic environment (Živković, 2014) such as in job interviews and communication with clients and colleagues in the workplace (Tsang, 2020).

2.2. Assessment and feedback approach

The digital assessment was conducted via Aston's VLS Blackboard which supports a range of assessment processes for marking and providing feedback on assessment. The assessment methodology is summarised in Table 2 which includes individual Blackboard quizzes and LABSTER quizzes embedded on Blackboard and. a group oral presentation.

The use of online quizzes was selected as an assessment strategy thus, enabling the delivery of formative and summative assessments. This has several benefits such as speeding the marking process and delivery of feedback to students; automated archiving of assessments, grades and feedback and immediate feedback for quiz questions. Grades and feedback are gathered in each student's "My Grades and Feedback" on the Blackboard module. The report helps students to reflect on their performance and feedback to see how they can improve in future assessments. Blackboard's Quiz tool has a rich feature set that enables the creation and delivery of sophisticated online effective assessments. A range of questions including Multiple Choice, Multiple Answer, True/False, missing blanks, ordering and calculated formulas were designed to effectively test higher-order learning outcomes (Scully, 2017). Three quizzes were designed as formative assessments corresponding to the three separate blocks of this module (fundamentals in biology, biochemical engineering and biotechnology applications). All quizzes included at least one question related to the Labster virtual labs. The assessment aimed to evaluate students' (i) understanding of concepts in biotechnology and bioprocessing that allowed them to effectively communicate with professionals from other disciplines such as biochemists, bioengineers and biotechnologists and (ii) technical background and understanding of the key factors involved in the production of biological products/materials within the "biosector."

The group oral presentation assignment consisted of the presentation of a research article related to the broad area of biochemical engineering and aimed to evaluate the (i) understanding of concepts in biotechnology and bioprocessing that will allow the student to effectively communicate with professionals from other disciplines such as biochemists, bioengineers and biotechnologists; (ii) technical background and understanding of the key factors involved in the production of biological products/materials within the "biosector" and; (iii) communication skills. Students were allowed to freely form groups of 3 or 4 and select one of the research articles shortlisted by the lecturer or present a paper of their choice as long as it fulfilled the requirements as specified in the assessment brief. Group components and the

Table 3. Feedback strategy.

Type of assessment	Type of feedback	Release of feedback
Individual Blackboard quiz	• Specific Feedback to each quiz question • Additional individual feedback	• Three days after completing the quiz • On student's demand within teaching term
Group oral presentation	• General "informal" group feedback • Formal group feedback • Additional individual feedback	• Immediately after the presentation • Three days after completing the presentation • On student's demand within teaching term

article subject of presentation were notified to the lecturer no later than four weeks before the assessment date. For the 2020–2021 cohort, Blackboard Collaborate Ultra was used for the live delivery of the oral group presentations timetabled on the last teaching week of the term. The oral group presentations were delivered face-to-face for the 2021–2022 cohort onwards to introduce an element of "on-campus" activity for this module. Feedback prepared for students intended to benefit their learning experience by being constructive, timely and meaningful following principles of good feedback (Higher Education Academy, 2013). The feedback strategy is summarised in Table 3.

3. Discussion of the impact

3.1 Reflection

Based on the informal feedback gathered by the module owner from students and the end-of-term anonymous survey, the *Biotechnology and Bioprocessing* module was very well received with a 4.3 in "Overall module satisfaction" (based on a 5-point Likert scale, where 1 corresponds to *Strongly Disagree* and 5, *Strongly agree*). The average values for questions related to the module and the lecturer were 4.2 and 4.0, respectively. Figure 5 represents the average values of the questions responded to by the students ($n = 57$, 90.5% response rate). Interestingly, all questions achieved > 4 average values except for the three statements "*I have received helpful feedback on my work (verbal or written), "I have received sufficient support with my studies" and "An appropriate reading list was made available for this module*" which scored 3.8, 3.8 and 3.9, respectively. Despite such results were not dramatic, these can be explained by the student's expectations in terms of support in the Higher Education, a landscape which is less controlled and the environment is less structured compared to pre-University settings (Money et al., 2017). In contrast, feedback on the effectiveness of digital technologies was rather positive, "*Blackboard has been used effectively to support the module*" and *"Labster virtual labs have been used effectively to support the module*" scored 4.3 and 4.4, respectively. Therefore, it is clear from the student's views that the digital delivery was well received, leading to a satisfactory student's learning experience and enhancing their digital skills. From the authors' perception on the effectiveness of Labster, it seems that the majority of the simulations selected for this module (6 in total) were well balanced, including practicals directly linked to the taught materials (e.g. Polymerase Chain reaction, Bacterial Growth Curves) and others on more applied experiments (e.g. Fermentation to optimise bio-ethanol production, From Algae to Bioenergy) the alter, bridging biological with engineering disciplines which are more relevant and appealing to chemical engineering students.

The student perception of the impact of this module was very positive from their responses to the question "*What did you like best about this module?*" with comments such as "*how structured the module was and the layout of the lectures that were easy to follow*" or "*The insight to biological process and technology. How a chemical engineer can relate to this in industry*". The module feedback form can be found as Supplementary File (Figure S1) and anonymous responses are available from the author upon reasonable request. On the other hand, the time required for recording and designing assessments, particularly the quizzes, increased the preparation load. However, the authors' view is that this is an investment of time as the recorded lectures or parts of them can be reused and thus, reduce the time commitment in future years. The creation of new quiz questions in the next 2 -3 years will produce a bank of questions that can be also reused hence, representing a further investment of time. Improving accessibility to enhance students' experience is key. Blackboard VLE includes a very useful feature, the "accessibility scores" that checks accessibility for the new and existing course content. To measure accessibility, it

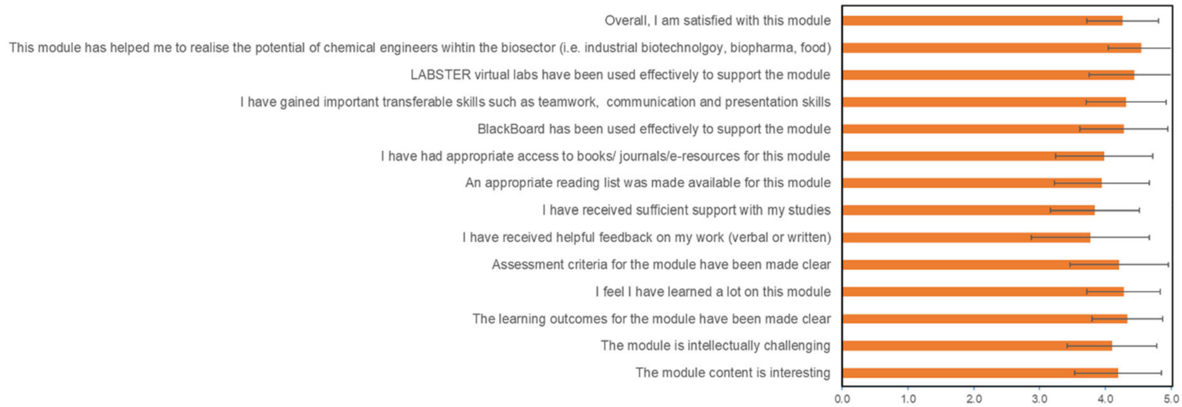

Figure 5. Feedback on the "End-of-term" survey for the *Biotechnology and Bioprocessing* module given by the 2022–2023 cohort ($n = 57$, 95% response rate) based on a 5-point Likert scale. Error bars correspond to standard deviation.

assigns the content an accessibility score. Each score is composed of both a numerical number and a coloured gauge that reflects the number (low/medium/high). For accessibility scores less than 100%, Blackboard gives suggestions for improving the accessibility of the file. The author ensured that where possible, the course content had high accessibility scores (> 67%) to provide a positive learning experience.

The greatest challenges in implementing the delivery of this new module were (i) the lack of extensive experience in using digital technologies for teaching and assessment; (ii) creating quiz questions that could effectively identify the areas where students were struggling and (iii) ensure the appropriateness of the teaching strategy to deliver "biocontent" to chemical engineering students that were not familiar with this subject before enrolling in this module. The author plans to overcome these three challenges of this module in future academic years by re-designing and/or replacing teaching materials as necessary as well as to continue improving the assessment methodology (agreed student marks can be seen in Figure S2). On the other hand, student attendance was 40–80% in synchronous activities—except for the group oral presentations session—which is endemic in many UK higher education institutions. The author will seek appealing formulae to revert the relatively poor attendance in a few sessions and thus, positively impact student learning. Moving forward and in line with the benefits of academia-industry collaboration for the curriculum co-development, the author will seek to engage with regional and national industrial players in the biosector to help improve the content and teaching delivery approaches in this module. For example, by bringing industrial speakers to give a seminar or to help re-defining the module content where needed.

3.2. Limitations of this study

The present work evaluates the effectiveness of using digital technologies to enhance the student's learning experience upon introducing biosciences-related subjects to chemical engineering undergraduates. Here, we reflect on the experience of designing and implementing a new module in *Biotechnology and Bioprocessing* not only using a digital delivery approach but also expanding the curriculum of the Chemical Engineering program at Aston University. This was done in response to the disruptions in face-to-face teaching caused by the pandemic and the need to provide skills and knowledge to chemical engineering graduates to increase their employability prospects within the "biosector." The student views and learning outcomes of this innovation were evaluated. However, some limitations of the study can be identified. It is not possible to evaluate how the use of digital technologies enhanced the learning experience compared to more traditional teaching approaches as this is a new module. Nonetheless, after running this module for three years, it is clear, as evidenced by the student's feedback (see supplemental Figures S3 and S4), that the objectives of the module are achieved; on one side, to expand the technical skills of the rapidly changing chemical engineering profession and the other hand to develop digital skills enhancing the students' experience. Despite no particular issues being raised by students, the capacity of the module to provide insights into practical aspects of biotechnology and bioprocessing (i.e. laboratory-based activities) is limited. Labster simulations were introduced as a practical component. However, as acknowledged by the creators, Labster virtual labs are not intended to replace real labs, they are designed as an addition—to understand, practice and repeat more deeply. The technology helps to reinforce concepts from lectures and gives students the next best thing to a real-world, hands-on lab experiment. One addition to this module would be the incorporation of real biotechnology/bio-processing labs and the use of Labster as a pre-lab component. This approach has shown in other UK institutions that Labster significantly boosted outcomes in terms of exam and coursework results (*UCL Increases Test Scores by Using Labster as a Pre-Lab*, n.d.), A longer study will provide more robust results and compare differences between cohorts. Nonetheless, the student experience accumulated for three years since this module was first taught, seems to be steadily highly positive. Moreover, it will be interesting to evaluate whether students enrolling on this module increase their opportunities to be employed in roles within the biosector or continue their postgraduate studies (i.e. MEng, MSc or PhD) in the interface between chemical and biological engineering disciplines.

4. Conclusion

This work presents how technology-enhanced learning is effectively used to enhance the student's digital skills and expand the knowledge in "biotechnology and bioprocessing" in the fast-changing chemical engineering profession. The "Digital learning in higher education" guide from Jisc, the UK's digital body for tertiary education has been considered in the design and implementation of the recently created *Biotechnology and Bioprocessing* module. A variety of learning approaches were implemented to enable widening participation and improve accessibility and inclusion in a newly developed *Biotechnology and Bioprocessing* module. This is a third-year option available to BEng/MEng Chemical Engineering students at the Chemical Engineering and Applied Chemistry Department (CEAC) at Aston University, UK. The module has been designed and delivered using digital technologies within Blackboard, the virtual learning environment employed at Aston University. This new module along with the addition of biocontent in existing core chemical engineering modules showcases the Department of CEAC's commitment providing new and important skills to Chemical Engineering graduates to expand the student's employability prospects within the biosector whilst contributing to the long-term response of the higher education in adapting digital technologies effectively.

Author's contribution

AFC contributed to all aspects of the manuscript.

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ORCID

Alfred Fernandez-Castane http://orcid.org/0000-0002-2572-7797

Data availability statement

The data that support the findings of this study are available from the corresponding author upon request.

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