Vol.7 No.2 (2024)

Journal of Applied Learning & Teaching

ISSN : 2591-801X

Content Available at : http://journals.sfu.ca/jalt/index.php/jalt/index

Effective online material development: A micro-model taxonomy for designing simulations to maximise tertiary students' learning

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Keywords

Articulate storyline;
higher education;
medical and health sciences;
online materials;
simulations;
STEM.

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Article Info

Received 19 February 2024
Received in revised form 30 June 2024
Accepted 24 July 2024
Available online 24 July 2024

DOI: https://doi.org/10.37074/jalt.2024.7.2.15

Abstract

Since the COVID-19 pandemic, the migration to teaching and learning using technology-enhanced activities has accelerated, especially in higher education. With this shift, teaching staff are required to either use commercial products or develop individual online teaching resources. However, commercial resources come with a cost, may not exist for the required topic(s), or may not suit the teaching requirements of a particular student cohort. In addition, it is common for most academics to have limited to no experience in making educationally effective interactive technology-enhanced learning resources. Thus, generated materials may lack critical features that maximise student learning experiences. To address this problem, we distilled over a decade's experience designing and implementing online educational materials for tertiary STEM and Medical and Health Science courses to develop a micro-model taxonomy. Our proposed model builds on the ASSURE and Design Thinking Macro models providing a detailed breakdown of important factors and justifications, where possible, for their inclusion in all resources. While our approach is based on the Articulate Storyline software platform, the taxonomy is software agnostic and can be applied to the design of any technology-enhanced learning resource for any course. Potential pitfalls and areas for enhancing student learning are also addressed.

Introduction

The fourth industrial revolution and the use of artificial intelligence (AI) and virtual reality (VR) technologies for educational purposes started in the early 2010s (Chaka, 2023). VR field trips, virtual laboratories, and simulations are some examples of useful activities. These activities and teaching materials can help overcome the limitations of didactic/descriptive and authentic/real-life education and pave the way for the implementation of reflexive and transformative pedagogies as they recreate real-world characteristics of situations (Beaubien & Baker, 2017). They also allow educators to teach their students and help them develop a variety of skills including critical thinking, problem-solving, designing, co-designing, making, and producing knowledge. Furthermore, they can approximate practice, especially if the activities comply with learners' needs and are accompanied by detailed feedback that informs students of the differences between their competency and the one that is desired (Chernikova et al., 2020).

For instance, VR field trips, virtual laboratories, and simulations have been used in teaching tertiary science, technology, engineering, and mathematics (STEM) and Medical and Health Sciences courses, especially as face-to-face laboratory classes are an expensive option for universities due to the cost of specialist infrastructure and reagents. In addition, for geographically dispersed students, the cost of commuting to university can be significant, and virtual laboratories can decrease the costs. VR field trips and simulations have also been used in other disciplines, including Education (e.g., Christou, 2010), Law (e.g., McFaul & FitzGerald, 2020), and Humanities, Art, and Social Sciences (HASS) (e.g., Hutson & Olsen, 2022).

The COVID-19 pandemic forced most educational institutions to transition from face-to-face teaching to online, which has subsequently expedited the use of the previously mentioned technologies in education in the last two years. In making use of technology-enhanced resources, educators can utilise pre-existing resources, which are either developed in-house or provided by a commercial entity (Crawford et al., 2020) if they are free, match the required topic, and suit the teaching needs of the student cohort (Costabile, 2020). Otherwise, academics, who are typically time-poor and have no or limited expertise in using advanced software, are forced to generate bespoke interactive technology-enhanced learning resources which can lead to the development of resources that may not include critical features to maximise a student's learning experience.

There are several studies in the literature which have investigated this unexpected shift and the use of technology-enhanced materials from different perspectives (e.g., Al-Kahtani, 2022; Gómez-Rey et al., 2021; Saleem et al., 2021). For example, some studies have examined the efficacy of online learning resources such as simulations and have shown both positive (Birrenbach et al., 2021; Kumar et al., 2023; Ooi et al., 2022; Pryor & Park, 2024) and negative (Watermeyer et al., 2021) impacts of the use of these technologies on student's learning. Other studies have introduced macro-model taxonomies to illustrate the broad steps in designing technology-enhanced materials for students, for example, the design thinking framework (DTF) or the ASSURE model (Smaldino et al., 2012). However, to the best of our knowledge, there are no micro-model classifications that provide specific details in this regard for use by academics.

To address this gap in the literature, we developed a micro-model taxonomy based on over ten years of experience in creating effective simulations to teach both lecture and laboratory content in tertiary STEM courses (Biochemistry, Immunology, and Microbiology) at the University of South Australia. Therefore, our research approach was a retrospective analysis of learnings from the creation of enhanced learning resources which have demonstrated impacts on student learning. These simulations were informed by continuous personal reflection and student feedback leading to iterative refinements in our approach. Our micro-model scaffolding framework identifies key points to consider when designing and developing simulation activities. To provide academics with a comprehensive approach and to make it easier to follow our micro-model taxonomy, our model is framed within the ASSURE model (Smaldino et al., 2012). While we have used Articulate Storyline, our framework is software agnostic, and it can be applied to the design of any online interactive learning resource, for any courses in STEM, Medical and Health Sciences, Education, Law, and HASS using any software platform.

The existing macro-model taxonomies

Both the DTF and ASSURE macro-model taxonomies are typically used by educators to design and integrate technology into education. The DTF, which originated from the early works of design methodologists in the 1960s, was originally an approach to problem-solving and identified the tools and methods that could be used to solve management problems in organisations (Elsbach & Stigliani, 2018). However, later, the related strategies were adapted and used in education to introduce a human-centric scaffolding model for planning content that can develop a student's critical thinking, collaboration, and problem-solving skills. The DTF is thus a suitable support for tertiary educators in 21st-century classrooms, especially when implementing constructivist and technology-enhanced learning (Dorji et al., 2020; Hennessey & Mueller, 2020; Scheer et al., 2012). The model consists of five stages: Empathise: research your users' needs; Define: state your users' needs and problems; Ideate: challenge assumptions and create ideas; Prototype: start to create solutions; Test: try your solutions out (Wolniak, 2017).

Similarly, the ASSURE model was designed to aid educators with their technology choice and integration. Students and their needs are the main points of focus. The model consists of six steps: Analyse learners; state standards and objectives; select strategies, technology, media, and materials; utilise technology, media, and materials; require learner participation; and evaluate and revise (See Table 1 for more details of each step). Both the DTF and ASSURE frameworks propose similar stages and have been widely used by educators and material developers (e.g., Bajracharya, 2019; Karakış et al., 2016; Listiani, 2017), with the ASSURE model being more comprehensive, introducing an evaluation and revision step. Hence, we framed our micro model taxonomy within the ASSURE macro model. Framing a micro model in a macro model classification allows us to bridge the gap between a model that has a high-level overview and introduces general steps and a model that is more focused and proposes detailed steps in designing and preparing technology-enhanced materials. This approach provides academics with a comprehensive approach that facilitates the adoption of our micro-model taxonomy. Our model builds on the ASSURE model by including an additional stage, as well as fine-level details and rationalisation of each inclusion to the model.

Table 1. Steps outlined in the ASSURE model (Smaldino et al., 2012, p. 39).

Step	Steps	Descriptions
1	Analyse learners	Analyse learners in terms of their general characteristics, entry competencies (e.g., skills and attitudes) and learning styles.
2	State standards and objectives	Define the learning standards and objectives and make them as specific as possible by including the learners' names and their related objectives, the action, and conditions (use of technology and media) that need to be taken into account, and the mastery level of the knowledge degree to which the new knowledge or skill must be mastered.
3	Select strategies, technology, media, and materials	Build a bridge between the first and second stages "by choosing appropriate instructional strategies, technology, media, and materials to achieve the objectives".
4	Utilise technology, media, and materials	Plan your teaching role by following the "5 Ps" process: "Preview the technology, media, and materials; Prepare the technology, media, and materials; Prepare the environment, Prepare the learners; and Provide the learning experience".
5	Require learner participation	Prepare activities that let them practice the new knowledge or skills and receive feedback before being formally assessed.
6	Evaluate and revise	Evaluate the lesson by examining the students' level of achievement as well as the instructional process and the use of technology and media and revise the lesson plan to address the discrepancies.

Simulations

Our micro model taxonomy was derived from over ten years of experience in developing, assessing, and disseminating the impact of interactive simulations to demonstrate key principles, processes, and practices to undergraduate STEM students (Costabile & Timms, 2020; Costabile & Birbeck, 2023; Costabile & Turkanovic, 2022; O'Flaherty & Costabile, 2020). Simulations can range from computer-generated programs that replicate key processes and lecture topics to highly authentic hospital mannequins. The technology enables learners to engage in realistic and immersive scenarios by replicating some or all aspects of a clinical situation which creates a safe educational setting for students to practice and improve their skills (Burton & Hope, 2018; Hill et al., 2024). The choice of simulation will depend on the target skill(s) and the learning context. For example, role play can be used to improve communication skills, images can be employed to instruct radiologists, or simulations and images can be combined (Chernikova et al., 2020). Simulations have also been used in educating prospective teachers on how to teach in class and communicate effectively with students (Aebersold et al., 2012).

While commercial packages can be purchased to teach students, there are great benefits for academics in developing student and content-specific simulations. These include creating custom products, focusing on specific details, adding multiple-choice questions (MCQs), and providing immediate feedback, which can be readily modified and adapted for future changes or used in different contexts by colleagues. In addition, when properly designed, a simulation can provide background content to help guide students through fundamental principles and can question them throughout to assess their learning. Therefore, negative consequences of lecture and laboratory misalignment of content will not impact a student's learning (Costabile & Timms, 2020).

Furthermore, simulations can be deployed across different learning management systems (LMS), such as Moodle or Canvas, for effective integration into a university setting. This allows academics to collect key analytic data, including the number of times the simulation has been accessed, the responses to the MCQs, and any written feedback entered into the simulation. Student assessment results can then be recorded either in a summative or formative manner through the LMS. Academics and teaching assistants can thus track the performance of individual students and provide additional assistance when necessary. However, while there are clear advantages to this approach, most academics will lack the required knowledge of all the elements required to generate effective technology-enhanced resources. This will also include choosing the technology appropriate for the desired activity, how to use the software, and ensuring the inclusion of the complete suite of required components for effective student learning. These critical elements led to our creation of a micromodel taxonomy and checklist.

Micro-model taxonomy to design simulations

As explained, to give a better structure to our micro-model taxonomy and to facilitate inclusion of critical learning elements, for academics when designing technology-enhanced activities, our micro-model was framed within the ASSURE model. Our model is diagrammatically shown in Figure 1. A checklist outlining each of the key features that facilitate the creation of an effective learning resource is provided in the Appendix.

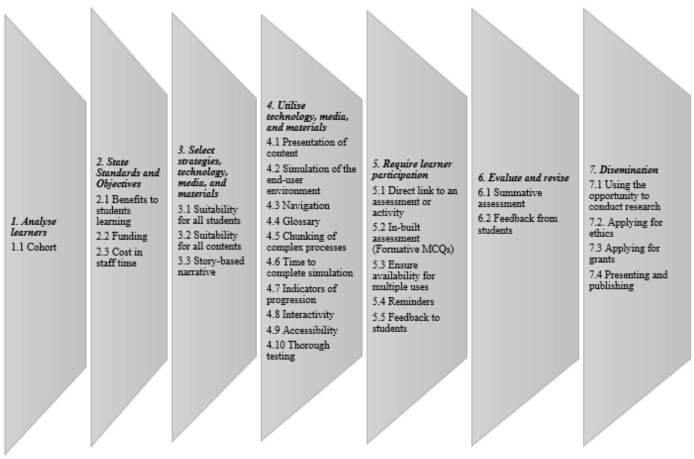

Figure 1. A diagram illustrating our proposed Micro-model taxonomy placed within the ASSURE model.

Detailed explanation of the proposed micro-model stages

Analyse learners

Cohort

Each learning resource should be designed based on a clear understanding of the cohort's learning needs and the educator's objectives based on discipline or end-user needs. Academics should identify the year level of students for which their material(s) will be used, i.e., 1st, 2nd, 3rd, etc. This will define their cohort's competencies and hence determine the level of required details. If all cohorts will be accessing the activities, they should be designed in a way that each cohort can access individual sections, and this can be distinguished within the materials using tabs, buttons, icons, etc., that allow students to select their level-related content. The learning resources can also be duplicated for use by senior students, with advanced content hidden or removed for first-year students. In addition, sufficient and appropriate background knowledge should be provided to ensure learning and progression through the simulation for all students.

State standards and objectives

Benefits to students learning

What are the benefits to student learning through the provision of an interactive learning resource, such as a simulation? Learning resources, such as simulations should be designed to be interactive, with the students required to participate in as many stages as possible. This learning can occur both inside and outside of classrooms, allowing students to control when and where the learning takes place, an opportunity most students value highly. In alignment with this idea, technology-enhanced materials are accessible anywhere, at any time, and should be able to be completed in under 30 minutes. Given the online nature of the teaching, a stable internet connection is required, which may not be true in all cases.

The provision of background information or a case study can make the activity more engaging. The inclusion of this background information is particularly useful when content is delivered out of sequence with other didactic teaching methods. For example, due to timetabling constraints, we typically teach the experimental principles of enzyme kinetics in a laboratory session before the content is presented in lectures midway through the semester. Therefore, students may be under-prepared for this learning opportunity. In this case, the use of a simulation proved to be an effective way to deliver the content to students who undertook their laboratory course early in the semester yet were not able to listen to the lecture content (Costabile & Timms, 2020).

Once generated, the activities can be used by students in related fields (e.g., immunology, nursing, pharmacy, midwifery). This can help to distribute the initial cost, as well as time requirements from the staff member. In addition, more students can benefit from each learning resource. Once generated, the activities can also be modified to deliver content that is related but different from the initial activity. This can reduce the costs and time that is needed for the development of future activities.

The activity can also augment situations where 'real-world' testing is not possible. This is particularly true when time is limited, and the required resources are not available within an institution. In addition, for example, it could be argued that using a simulation can replicate the key stages authentically so that direct interaction in a laboratory setting may not be necessary to ensure students' understanding and full learning experience. This can help with safety and costs and can cover the limited availability of equipment or specialist skills in the laboratory.

Funding

There will be a cost in generating simulations using a commercial platform. However, in many cases, an institution may already have a license for this software or have educational designers who have expertise and access to the software. If not, academics can seek funding through the institution, granting bodies, or other philanthropic means. We have noted that an educationally effective simulation that takes a student approximately 15 minutes to complete will cost approximately 2,000 to 3,000 USD to generate. In addition, there is longevity in the simulations that are generated, particularly when they are focused on a topic or content that is central to student learning, for example, monoclonal antibody production (Costabile & Turkanovic, 2022). In this example, the fundamentals of the approach have not changed since its discovery in 1975 and continue to be used, so the learning resource will remain valid for many years without detriment to the student experience.

Cost in staff time

There is also a cost associated with staff time. There are two feasible options for academics; they can learn to use the software and develop their materials and activities. This has been our experience, and it can be a rewarding approach. However, with the constraints on academic time and productivity, the other option is to use an educational designer. Most universities will have an educational designer who can generate the materials faster and with fewer issues than an academic staff member learning to use the software. In addition, since they are employed by a university, the cost may be absorbed by the unit or faculty.

Select strategies, technology, media, and materials

The traditional presentation of content via lectures can be viewed as boring and disengaging for students. For some academics, the shift from face-to-face to online means converting their written material to PowerPoint, leading to "death by PowerPoint" (Sharp et al., 2019). Thus, when an educator wishes to try a new learning approach such as an interactive simulation, for the resource to be effective, it must be designed to achieve its learning objectives.

Suitability for all students

Students learn through multiple modalities and may have a preference for visual, auditory, writing, or kinaesthetic approaches (Fleming, 1995). In practice, students will make use of multiple aspects as part of their learning approach. The materials and activities should be designed to include as many activities as possible to ensure an active learning approach. For example, images can be added for visuals, audio can be used to provide instructions through the online characters, students can enter responses by typing into a simulation, and kinaesthetic requires them to use the mouse to engage with the simulation prompts.

Suitability for all content

A key question when embarking on developing interactive learning resources relates to the suitability of the content for the chosen approach. Based on our experience, we would argue that most, if not all, content can be taught using a simulation; however, for some content, the approach may not be immediately apparent and may require lateral thinking. But the question is: Are there any better options? In some instances, the use of a simulation and how best to engage students may not be immediately identifiable. This can be challenging, but at the same time, it can be highly rewarding with the development of an approach that is novel yet highly targeted to the content and the student population. One approach that we have used effectively is generating a simulation that is relevant to the topic being covered with a strong, relevant narrative. For example, when teaching hemolytic disease of the newborn (HDN), we placed the student in the role of a gynaecologist dealing with a first-time mother (Costabile & Birbeck, 2023). Doing so clearly defines the role of the student, establishes the content area in the discipline, highlights the importance of the subject matter, and facilitates the linking of content previously presented in class. As suggested by the name, linking the concept to be demonstrated/taught to a story provides relevance to the topic and enhances student engagement. This can be aided by using animated characters, which can be utilised to develop the context of the situation.

Choice of platforms

An academic's choice of platform should be based on the content of the lesson which will be covered. Articulate Storyline (more recently, Storyline 360) is a commonly used software platform designed to generate interactive learning resources, such as simulations. This software is popular due to its simple learning curve and interface based on Microsoft PowerPoint, as well as its large user support community. The software can generate simulations that range from simple to complex, covering all aspects of student learning. However, if the content is simple and more text-based, the use of alternative platforms, such as H5P, may be suitable. If the process is more procedural, such as demonstrating a principle or steps in a laboratory setting, then an Articulate Storyline or Unity-based simulation can be used. If a situational topic needs to be covered, then VR/AR interactions can make the learning even more tangible for students. Each approach will also have cost, time, and resource implications that should be considered.

Utilise technology, media, and material

According to Smaldino et al. (2012, p. 39), it is important to follow the "5 Ps" process: "Preview the technology, media, and materials; Prepare the technology, media, and materials; Prepare the environment, Prepare the learners; and Provide the learning experience", in other words, implement it/them.

Presentation of content (vary for engagement)

Information should be presented in more than one way. For example, use a combination of written text, audio explanations, video files, graphs, and diagrams, as well as more visually stimulating approaches such as whiteboard animations. The diversity of material presentation can make the learning resource more engaging and cater to diverse learning styles.

Simulate the end-user environment

A simple approach that can be used to embed the content within the simulation and enhance the relationship with the students is using a visual background relevant to the topic. Depending on the end-user environment, the visual interaction of the simulation should be developed to mirror that environment. For example, for STEM students, the use of a laboratory notebook (Figure 2) or laboratory setting (Figure 3) can help make the simulation appear more realistic, allowing students to place the theory of the process into a realistic virtual setting. Therefore, after choosing the story-based narrative simulation as the technology in the case of the HDN, to keep the graphics that relate to the story highly relevant, we used a hospital setting.

Navigation

Once a narrative and its related visual representation have been developed, it is important to design a simple and clear mode of navigation. Most students will not have encountered interactive simulations as a learning aid previously. Hence, clear instructions must be provided as to how the materials and activities behave and how the students should navigate the simulation. These instructions should be in both written and audio/video format. The audio can be either a computer-generated voice or a human voice recording. With the recent advances in artificial intelligence, realistic computer-generated voices can be readily generated and modified. They vary in their quality, but great strides have been made in the degree to which the audio now matches a human voice. Delays in timing can be introduced to help make the audio sound more human-like. Key aspects in navigating a simulation include how to advance and return to a previous slide in the simulation, how to restart the simulation, and how to skip to a certain section (if a purposeful part of the design). It can be useful to use tabs, buttons, or visual icons on the home page to allow the student to skip to a

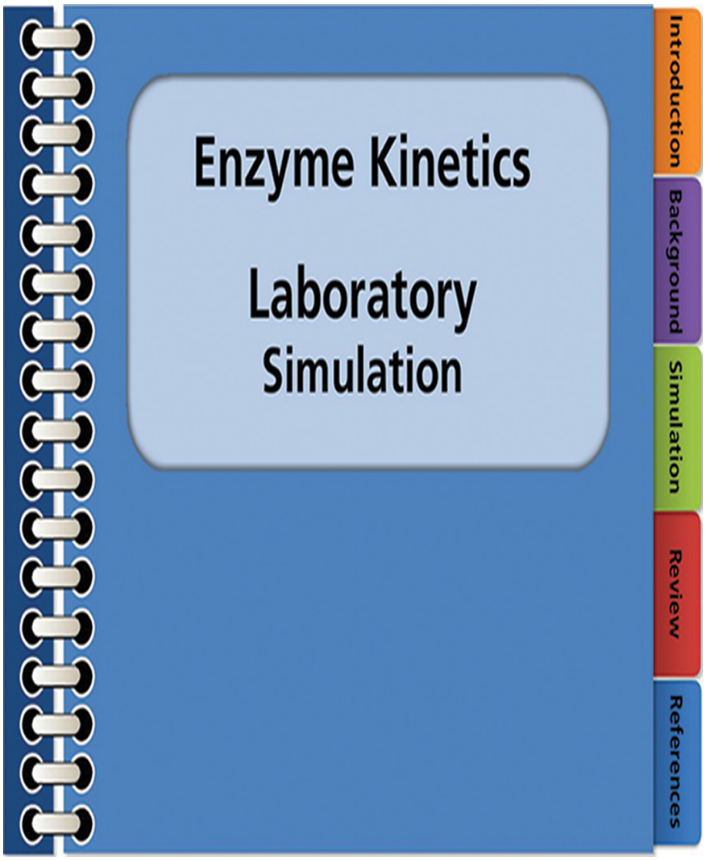

Figure 2. Simulation making use of a laboratory notebook graphic for a Biochemistry topic.

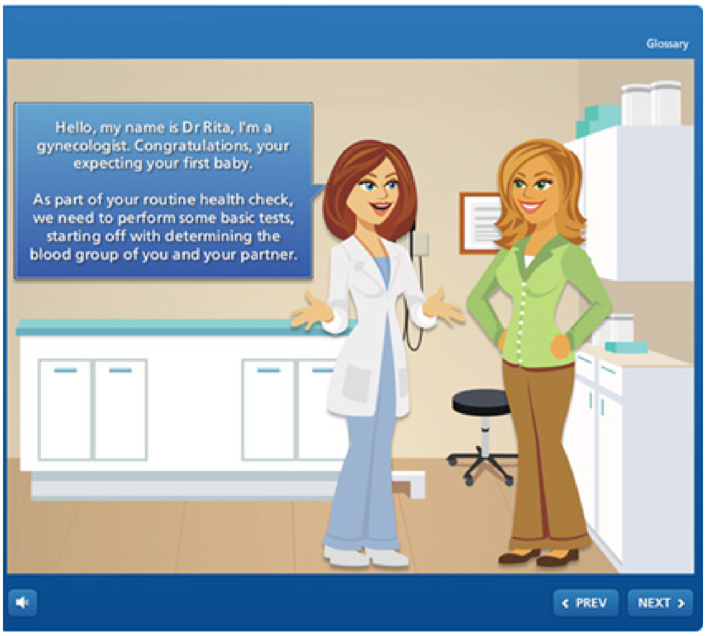

Figure 3. Simulation making use of a laboratory setting for an Immunology topic (O'Flaherty & Costabile, 2020; Costabile, 2020).

particular section. This approach is particularly useful when background information is provided in a simulation, such as in a laboratory setting. However, this approach may not be required for all simulations.

Glossary

In most disciplines, and especially in STEM, there will be terminologies that will be unfamiliar to students and hence pose a learning hurdle. For example, the diverse terminology used in immunology is a major learning challenge for medical students (Haidaris & Frelinger, 2019). As a result, the introduction of unfamiliar terms or terms that students have only heard once or twice previously can pose a learning challenge. A straightforward way to overcome this issue is to include a glossary of common terms. Students can use this glossary throughout the simulation to better understand the meaning of key terms. It is important to only include the terms that are relevant to the materials or the content and to resist the temptation to include more than is required. To summarise, it is imperative to consider the relevance of the terms to the particular situation when determining which terms to include or exclude.

Chunking of complex processes

The principal consideration for using interactive simulations is to teach a single concept to students. In most cases, this concept will be challenging to understand, cannot be readily demonstrated in class through interactions, or is a new idea or topic being taught to senior students. Given that the content will be complex, it is important to divide the content into smaller topics or manageable stages, referred to as "chunking" (Thalmann et al., 2019; Van de Pol et al., 2010). Chunking "reduces the load on working memory via retrieval of a compact chunk representation from long-term memory [...] and frees up capacity for subsequently encoded material" (Thalmann et al., 2019, p. 37). For example, the process of making monoclonal antibodies (mAb) includes seven discrete stages. Each stage can be a "chunk" and covered in the required level of detail. Within each stage, material can be cut into even smaller chunks, as required. In our example, these steps follow the same steps seen in a real laboratory setting by reinforcing the content further and aligning it to real-world practice. This practice is key when a student enters the work environment.

Time to complete a simulation

With the shift to online education, it has become more apparent that we are all time-poor, and there are multiple sources of distractions for students, such as the Internet, social media, mobile phones, etc. Thus, academics must treat student time as precious and make a simulation only if required. Academics must resist the temptation to include all elements of a topic in a single online material and activity. From a practical point of view, materials that are too long, require more time to develop, are more expensive to develop, and have more potential interactions that need to be checked. From a student perspective, students can and do lose focus if the simulation is too long, and this will affect their level of engagement (Chamberlain et al., 2014). Therefore, if a large amount of information is to be presented, it is preferable to generate several smaller learning resources as opposed to one large unit. From our experience, each learning resource and its activities should take approximately 20 minutes to be completed by a well-prepared, competent student. Students with a better grasp of the content will require less time, while unprepared students can still complete while maintaining engagement.

Indicators of progression

As explained earlier, consistent with the idea of chunking (addressing a single concept and topic in each material) and the necessity of avoiding including additional and irrelevant content, each resource should take approximately 15-20 minutes (maximum) to complete by a student following the instructions and understanding the content. For the student to know how far they have progressed through the activities, indicators of progression, such as a simple timeline, a time clock indicating the slide number, or a series of dots that progressively are filled until the end of the simulation is reached, can be effective in communicating this information. This approach can help enhance student engagement and ensure they complete the work.

Interactivity

When academics use materials that are available online, they may not cover the exact topic required, they may not cover it at the same depth required by the academic, nor can it be readily modified by the user. When considering video presentations as a substitute, one major disadvantage to this approach is the "passive" nature of any learning. Students are not tasked to be "actively" involved in the learning activity, which has been widely demonstrated to be key to learning (Freeman et al., 2014). In contrast, user-developed materials and activities (e.g., simulations) inherently require the involvement of the student, making it a much more engaging and active process (Costabile et al., 2024). Ensuring student engagement and learning of content in this way is challenging hence making the approach interactive and more academically engaging. Making the materials interactive allows the academic to ask students to make choices that are related to the content as often as required throughout the interaction. This places the students in charge of their learning, and they will be active rather than passive participants, such as when watching a video. As we will discuss later, this also provides the opportunity for immediate or delayed feedback to the students as they progress through the simulation.

Accessibility

We have recently argued that simulations are effective pedagogical tools for courses with a significant amount of content typically delivered in a didactic manner (Costabile et al., 2024). We argue that concepts that impose a high cognitive load or are threshold learning concepts need to be taught using active learning strategies, such as a simulation. Given that these topics are likely to be conceptually difficult for students, the content must be presented in a simple-to-understand manner, yet still retain the rigour required within the discipline. Thus, any materials and activities that are generated must be easy for the student to use. Issues with navigating new learning technologies are known to reduce student engagement (Bourgonjon et al., 2010).

Thorough testing

For an optimal end-user experience, all materials and activities must undergo thorough testing to ensure that all connections, links, and actions occur as expected. We suggest that the author(s) include testing, which is undertaken by someone from outside the field and/or less familiar with the content since they are likely to make interactions that might not be expected. This approach can be highly effective in identifying outcomes that may not be predicted by the educational designer. Otherwise, erroneous outcomes can confuse students, lead to their dissatisfaction with the materials and activities, and distract them from their learning.

Require learner participation

According to Smaldino et al. (2012), it is important that educators prepare activities that let students practice the new knowledge or skills and receive feedback before being formally assessed. For example, in a simulation, students should be provided with choices and have consequences for these choices. In addition, presenting immediate feedback following a choice is highly beneficial to student learning as it immediately strengthens the concept under investigation.

Direct link to a particular topic or activity (e.g., laboratory session)

Interactive learning resources should be designed around a particular topic. Doing so provides context and assists the student in focusing on a single idea or theme. It also validates that the simulation is focussed on student learning and not being developed only for an academic's interest. Ensure the link is clear to a lecture topic and/or an assessment item for best engagement. This can also then be used as a means of assessing the impact of the simulation on student learning, as explained previously.

In-built assessment (Formative MCQs)

Upon completion of the material, it is useful for students to evaluate their knowledge and understanding of the content. One approach that can be used effectively is the inclusion of MCQs. The opportunity for students to assess their understanding via MCQs is highly valued (Balasubramanian et al., 2006; Grossman & Conelius, 2015). MCQs allow students to determine whether they have fully understood the content and to identify aspects that may require further clarification and determine if they should repeat the simulation. MCQs are particularly useful when used in a formative manner, as this can encourage students to attempt multiple times with no impact on their final grade. It is suggested that between ten to 20 MCQs are included, as too few are unlikely to cover all the content.

Ensure availability for multiple uses (unless for an assessment)
As noted above, MCQs are important for students to assess their understanding of the content. But it is also important that they are allowed to undertake multiple attempts at a question, as this allows the student to gain feedback on all the possible answers. This is a valuable learning opportunity for the student during the initial phases of teaching and learning. The only time where this might not be an option is if the questions are part of a formal assessment. In our experience, we have observed that students use our simulations multiple times during a study period, ranging from two accessions up to even sixteen accessions per student.

Feedback to students

Within a simulation setting, two major forms of feedback should be provided to students. Feedback, such as MCQs, numerical answers, or any other forms of selection, is encouraged while a student is engaging with an interactive element. This feedback guides the user in determining the correct answer to a question. After the students have selected an option in the simulation, immediate detailed feedback should be provided. Studies have shown that learning is enhanced by immediate feedback (Dihoff et al., 2004; Pardo et al., 2019). Importantly, feedback should be provided for both correct and incorrect choices. Feedback for a correct choice allows for further validation of the rationale for the choice, while feedback after an incorrect choice provides the opportunity for clarification of the common errors in the content. It has been our experience that when students are given the opportunity of unlimited attempts, they purposely select incorrect answers to be able to view all the possible feedback options; further highlighting this as an excellent learning opportunity.

Reminders

The teaching staff need to be proactive in informing students about the rationale for the benefits of using a simulation for their learning. In most cases, this requires multiple reminders, which can be either verbal or automated via email. Hence, academics should encourage students to make use of the materials and activities.

Evaluate and revise

Once the simulation has been introduced, its impact on student learning objectives must be assessed. This can be achieved through a mixed-methods approach that uses quantitative measures of student performance in an assessable component, as well as qualitative student feedback. This information can be used to modify the content and ensure that it meets the student end user's needs.

Summative assessment

MCQs can be used in a summative manner, as they facilitate capturing student marks. When the content is being delivered to students, MCQs should be asked in a staged manner. That is, the concept of the term is delivered, and then a follow-up question is used to delve deeper into the understanding of the concept/terminology.

Feedback from students

While academics and educational developers can develop a simulation that operates as expected, they cannot predict all the possible interactions and feedback from the students' perspectives. Hence, student end users should be provided with the opportunity to provide feedback to the academic on all aspects of the simulation, such as ease of use, presentation of concepts, effectiveness in explaining key concepts, and formative MCQs. This feedback can and should be used to refine the simulation. Aspects that may not be clear to the students will be readily relayed back to the academic, and these can then be improved in future iterations. Feedback can come in multiple forms, including Likert scale and questionnaire-based feedback. In addition, focus groups can be used to delve deeper into the students' perspective of the simulation's benefits. Students' feedback can also be used to identify other areas that may benefit from a similar intervention that may not be immediately recognised by the teaching academics.

Dissemination

Using the opportunity to conduct research

As is true for all educational activities, it is unlikely that every student will engage in this alternative teaching approach. While this might be discouraging for academics, it does provide an alternative opportunity to assess the impact of these types of educational activities on student learning, i.e., to assess the efficacy of the simulation. Students who do not use the learning resource can be considered a default, control group to which the assessments of the students who engaged with the simulation can be compared. The necessary data can be collected after the first iteration of materials and activities, and it can be used to validate their use for future student cohorts. In one of our cases with the design and use of simulations, our data has been included in a laboratory manual as further evidence of the benefit of the technology for student learning.

Applying for ethics

With all research, institutional approval is required for all planned activities. At the University of South Australia, activities that are designed for the improvement of the course and will not be published can occur without formal human research ethical clearance. However, the inclusion of a dissemination strategy moves the work into the realm of scholarship of teaching and learning and hence requires full human ethics clearance.

Applying for grants

The outcome of the learning research can be used as the basis for applying for institutional and external grant funding to support the activities of the educator and their discipline area. This is beneficial to the scholarly profile of the individual and/or team, contributing to future promotion applications and recognition within the University and more widely.

Presenting and publishing

Lastly, the staff members can disseminate their findings at local, national, and international levels through poster or conference presentations, and publish their work in conference proceedings and peer-reviewed publications. How to undertake this process is beyond the scope of this manuscript; however, the reader should look for educational-focused publications within their discipline to provide advice on education-focused research. In the Biochemistry and Immunology disciplines, the reader can access journals including CBE-Life Sciences, Biochemistry and Molecular Biology Education, Immunology and Cell Biology, Journal of Microbiology and Biology Education, and Journal of Physiology Education.

Conclusion

Within the last two decades, the use of technology-enhanced materials that advance both face-to-face and online learning has been in high demand due to its benefits. In this manuscript, we shared our ten years of experience in creating interactive, online simulations for teaching undergraduate lecture and laboratory content by developing a micro-model taxonomy. The taxonomy was framed within the ASSURE macro model for better classification and more effective use by educators. Our model provides a comprehensive approach to developing effective online/face-to-face technology-enhanced resources and simulations. Each stage in our taxonomy was the result of hard-earned experience and while this paper discussed those stages, the real learning and benefit of this paper is for others to learn from this experience, avoiding potential errors while developing future learning resources.

Therefore, we wish to also share three key learnings that we identified beyond our micro-model taxonomy:

Learning 1: Do not make it about the teaching or the teacher

Our early ventures into simulations were well-intentioned but they focussed on trying to encourage students to access content, albeit in more interesting and interactive ways. However, without being explicit about why a learner should engage and how the simulation motivates a learner, the technical quality of the simulation was irrelevant. Without establishing personal and learning relevance, particularly around assessment, you create a simulation that looks professional, but students do not use to facilitate their learning.

Learning 2: It is not about the technology

The proliferation of educational or technological applications with their diverse features can be enticing. There have been instances where colleagues have spent an immense amount of time developing VR simulations that are engaging. However, without access to the required headsets, students in rural and remote locations could not access the learning resource. Therefore, academics should choose the simplest technological tool that fits their purpose and enables learning to occur. In short, developed technological tools that are inappropriate can function as barriers to successful learning.

Learning 3: It must be sustainable

The budget for creating an online learning application or simulation is commonly small; however, academics should consider what will happen when funding is unavailable. Sustainability is critical in a university setting and can be manifested in diverse ways, such as by prioritising efficient processes and improving time and money management. For example, colleagues developed a third-party simulation that allowed students to practice and access realistic laboratory experiments. A budget was allocated for two years and there was an institutional appetite to continue funding this development well beyond two years. However, following a change in leadership, funding was no longer readily available, and all the data that had been generated was confined to the third-party application. This action required re-generating all learning resources in an "open" platform, which required a large investment of staff time and associated costs.

Overall, creating effective technology-enhanced learning activities is complex and time-consuming; therefore, we recommend that academics use our proposed taxonomy along with the preparation checklist to make sure that they have followed the necessary procedures in their work. Finally, our micro-model taxonomy contributes to the body of knowledge concerning online/face-to-face technology-enhanced education not only in STEM and Health and Medical Sciences but also in Education, Law, and HASS as there are great benefits to using our taxonomy for both tertiary educators and students. It can ensure educators meet the highest possible standards with the design and use of the materials and activities, which in turn means enhancing students' learning. It also creates SoTL opportunities as staff can then disseminate their findings to colleagues.

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Appendix (Preparation checklist)

This checklist is designed to aid educators in designing their active simulation approach. Not all boxes will be ticked, but the provision of boxes will aid in the design and implementation of an active learning approach that uses most if not all best practices identified in our manuscript.

- ☐ Identification of Cohort(s)
- ☐ Funding identified
  - ☐ Grants (Institutional or External)
  - ☐ Individual scholarship
- ☐ Simple design
  - ☐ Designed to be suitable for all students
  - ☐ Designed to be suitable for required content
- ☐ Choice of material Story-based narrative identified
  - ☐ Relevant to chosen narrative
- ☐ Choice of application to use
  - ☐ H5P
  - ☐ Storyline 360
  - ☐ Unity
  - ☐ Other
- ☐ Presentation of content
- ☐ Simulate the end-user environment
- ☐ Clear navigation approach
- ☐ Includes Glossary for relevant terms
- ☐ Complex processes are presented in smaller chunks
- ☐ Estimated student time for completion has been determined
- ☐ Visual indicators of progression included
- ☐ Interactive elements included throughout
- ☐ Accessible via LMS
- ☐ All permutations tested before implementation
- ☐ Assessment activities included
  - ☐ Formative
  - ☐ Summative
- ☐ Feedback included throughout
- ☐ Ensure availability for multiple uses
- ☐ Communication strategy identified
  - ☐ Verbal Reminder
  - ☐ Email Reminder
- ☐ Feedback from students
- ☐ Dissemination strategy in place
  - ☐ Using the opportunity to conduct research
  - ☐ Applying for grants
  - ☐ Applying for ethics
  - ☐ Local unit level
  - ☐ Poster
  - ☐ Conference presentation
  - ☐ Publication