STEM crisis teaching: Curriculum design with e-learning tools

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Abstract
The COVID-19 pandemic and subsequent social distancing protocols have accelerated the shift to online teaching across the globe. In Science, Technology, Engineering, and Mathematics (STEM) programs this means a shift from face-to-face laboratory instruction to self-directed learning with e-learning tools. Unfortunately, selecting and integrating an e-learning tool into a curriculum can be daunting. This article highlights key questions and practical suggestions instructors should consider in choosing the most effective option for their course and learners.

KEYWORDS
computer-assisted instruction, COVID-19, curriculum, distance education

1 | INTRODUCTION

On March 11, 2020 the World Health Organization (WHO) declared the novel coronavirus (COVID-19) outbreak a global pandemic.¹ In the weeks that followed, educational institutions worldwide closed brick and mortar classrooms and made a rapid transformation to online learning and remote content delivery.²–⁶ Over the past three decades online education has grown considerably and now is central to the long-term strategies of many higher educational institutions. Competing responsibilities of learners have, in part, driven the development of flexible learning opportunities, enabling learners to learn synchronously or asynchronously from a distance. The COVID-19 pandemic changed online education from an alternative to a necessity.⁷,⁸ In biomedical sciences education, this meant a shift from laboratory teaching to self-directed learning using e-learning tools.³,⁹ Now, more than ever, e-learning tools have become a valuable asset in delivering content and learning experiences.¹⁰ However, selecting an e-learning tool can be frustrating if faculty are not versed in criteria for critically evaluating the number and variety of e-learning tools.¹¹ This article highlights key principles to consider when selecting and integrating an e-learning tool into a curriculum, which may be helpful—if not essential—as educators transition to distance learning in an online environment.

2 | WHAT ARE E-LEARNING TOOLS AND APPLICATIONS?

For the purposes of this article, e-learning tools are computer applications that mediate the learner’s interaction with
educational content through an electronic interface to facilitate knowledge construction. The use of e-learning tools in the biomedical sciences prior to the COVID-19 pandemic has been well-documented in undergraduate Science, Technology, Engineering, and Mathematics (STEM) programs (e.g., zoology, physics, chemistry, engineering, nursing, medicine). STEM educators may choose from many options, and the choices are multiplying rapidly as demand increases with the switch to remote teaching and learning on virtual platforms. Many education institutions have created their own e-learning solutions or invested in commercial options over the past two decades. Some commercial examples include LabsLand© and Complete Anatomy©, while institutional creations include 360Anatomy (Western University, London, Canada; 360anatomy.uwo.ca) and SecondLook (University of Michigan; https://secondlook.med.umich.edu). Many e-learning platforms (e.g., VoiceThread, Turning Point®, Poll Everywhere) also integrate with learning management systems (e.g., Blackboard®, Desire2Learn, Moodle®, etc). The realities of educating in a socially distanced environment are likely to increase pressure to incorporate e-learning tools into STEM curricula.

3 | NAVIGATING THE SEA OF CHOICES

Introducing a new e-learning tool can be daunting when selection, implementation, and integration must happen swiftly. We outline three broad questions, based on common considerations and pitfalls (Table 1), to help educators select and integrate an e-learning tool that complements the curriculum and addresses learners’ needs.

1. What skills or content do you want learners to learn with the e-learning tool?

The dynamic nature of various STEM disciplines (physics, chemistry, engineering) may make them well-suited to using e-learning tools to enhance learning through simulation. E-learning tools that facilitate experiential learning support learners’ understanding of physical models and processes and make interactions at the particle level less abstract. E-learning tools provide opportunity for learners to conceptualize structures that cannot be seen with the naked eye, such as atoms or cellular structures, and visualize complex processes such as protein synthesis or the operation of efficient machines, processes, and systems. Research suggests e-learning tools with two- or three-dimensional animations and interactive components benefit learners who study highly dynamic subjects such as mechanical systems, computer algorithms, or geological and astronomical phenomena.

However, e-learning tool effectiveness seems to be tied to the nature of the content. In anatomy, static content (e.g., neurovascular and osteological structures) may not require highly interactive e-learning tools with animations. Instead, simpler e-learning tools that present like a textbook may depict the relevant morphology and anatomic relationships adequately and effectively. For example, take two commercial

| Consideration          | Common Pitfalls                                                                 |
|------------------------|---------------------------------------------------------------------------------|
| Skills/content         | Unclear expectations of the skills and content you want learners to learn with the e-learning tool |
|                        | Selecting a tool that does not deliver knowledge or facilitate skill development expected of the learners |
|                        | Using an unnecessarily complex e-learning tool to teach simple concepts |
| Usability              | Selecting a tool that is difficult for faculty and learners to use |
|                        | Assuming learners will be intuitive users of the e-learning tool |
|                        | Assuming commercial e-learning tools have been developed and evaluated for learning effectiveness |
|                        | Selecting a tool with a limited life span or inadequate support |
|                        | Choosing a tool that does not satisfy the budgetary or security requirements of your institution |
|                        | Selecting a tool that does not integrate with various operating systems or learning management systems |
|                        | Choosing a tool that cannot be customized to your needs |
| Curricular alignment   | Selecting a tool that does not align with the course learning objectives, assessments, or instructional methods |
|                        | Choosing a tool that does not facilitate the cognitive levels specified in the learning objectives or promote understanding and mastery of the content |
|                        | Selecting a tool that does not align with how you assess knowledge, skills, and competencies |
|                        | Underestimating the effort and time required to integrate the tool constructively into the learning experience |
anatomical e-learning tools that have dissimilar interface designs.21

1. A.D.A.M. Interactive Anatomy (Ebix, Atlanta, GA): a
two-dimensional tool that presents static anatomical im-
ages in a textbook-like fashion. This e-learning tool only
allows users to view anatomical structures from “key
views” (i.e., anterior and posterior) and has relatively
low interactivity (nine features), meaning that students
interact with the program using a limited number of
features.

2. Netter’s 3D Interactive Anatomy (Elsevier, Philadelphia,
PA): a three-dimensional appearance and provides a high
level of user interactivity (20 features). In this program
users are also able to rotate a structure along any axis
point, enabling unlimited viewing angles.

Research involving these tools suggests that the simple
e-learning tool (A.D.A.M. Interactive Anatomy) is as effective
as the more complicated e-learning tool (Netter’s 3D Interactive
Anatomy).21 Furthermore, results demonstrated that Netter’s
3D Interactive Anatomy significantly disadvantaged learners
with lower spatial ability, while A.D.A.M. Interactive Anatomy
did not academically disadvantage any learners.21 In fact, other
studies also indicate anatomical science e-learning tools that
allow learners to rotate and manipulate unfamiliar objects on a
virtual platform may hinder learning processes for learners with
lower spatial abilities.21–32 However, it is important to stress
that dynamic concepts such as muscle actions and physiological
processes (e.g., blood circulation through the heart) may be
ideally suited for highly interactive e-learning tools, rather than
simpler options. Analyzing the concepts you teach and how you
plan to assess learners on their knowledge of these concepts
will help you to decide whether a complex, highly interactive
e-learning tool versus a more simple, static tool is suitable for
learners’ needs.

2. Can you navigate the e-learning tool efficiently, effect-
ively, and satisfactorily?

Usability is the extent to which a product facilitates goals
with effectiveness, efficiency, and satisfaction.33,34 Successful
e-learning tool interaction requires learners to navigate the
platform, orient themselves to how the information is pre-
presented, and then filter and synthesize the subject matter.13,35
An e-learning tool that requires a learner to spend considerable
time learning how to navigate the program may compromise their
understanding of the educational content.26–39 Poor usability
may frustrate learners and discourage adoption.40,41 Similarly,
poor usability may aggravate educators and lead to clumsy in-
tegration of the tool into the curriculum, affecting the overall
learning experience and reducing the likelihood that learners
use the tool. To mitigate negative outcomes, educators should
demonstrate how to integrate the e-learning tool into their
learning template at the beginning of the course. This may take
the form of a short screen recording providing learners with a
basic understanding of how to navigate the program and/or an
in-class demonstration of the tool (either in person or virtually
with screen sharing). These demonstrations reduce frustration
and allow learners more time to use the e-learning tool to aid,
plan, and coordinate their learning.

Usability is a complex construct that involves more than
the learner implications discussed above. Other usability
considerations should be assessed from a course-design per-
spective including:

1. What is the “lifetime” of the e-learning tool? Will it
work for future needs or other curricular needs? Tools
with limited life span or applications may face premature
set/ting and require considerable re-design of course
assessments and delivery methods.

2. Do you require an e-learning tool that is readily imple-
mented, or one that offers creative control to customize it
to your needs? If the latter, what is the learning curve, and
do you have adequate technical support at your institution
or from the e-learning tool provider?

3. Does the tool satisfy your institution’s security require-
ments? For example, some institutions have strict
guidelines about the use of usernames and passwords to
access web-based content. Others require educators to go
through an extensive approval process to ensure the plat-
form is secure. You should consult with your Information
Technology department early in the selection process to
speed implementation.

4. Is the e-learning tool available across various operating
platforms (e.g., Windows, Mac, web-based, desktop,
mobile)? This consideration is especially important, as
learners vary in their preference for operating systems and
platforms. Prescribing a single technology platform may
disadvantage learners who are accustomed to a different
platform.

5. Is there a cost associated with the e-learning tool? If yes,
then inquire about licensing options and educator dis-
counts as well as consult the appropriate decision makers
at your institution.

3. Can the e-learning tool be aligned to your curriculum
meaningfully and constructively?

Curricular alignment is best achieved with backward de-
design, an educational planning approach that uses outcomes
to design curriculum units, performance assessments, and
classroom instruction.42 The same approach should be used to
align an e-learning tool with a curriculum, since this tool will
deliver content and, potentially, assessments. By beginning
with the end in mind, educators ensure that the e-learning
tool is aligned seamlessly and constructively with all course
components (i.e., learning objectives, instructional methods,
and assessments.43 This requires considerable time and effort
on the front end, but the pay-off and time saved on the back end are invaluable.

The backward design process involves three stages:

1. Identify desired results (i.e., learning objectives and outcomes: what the learners should know, understand, and be able to do).
2. Determine how you will assess the desired results have been achieved (e.g., formative and summative assessments).
3. Design activities that ensure learners achieve these results (e.g., lesson plans, learning events, and teaching methods that provide the knowledge and skills needed to achieve the outcomes).

Questions you should ask to ensure the e-learning tool facilitates the alignment of objectives, assessments, and instructional methods include:

1. What type of learning experience do I want to deliver (e.g., in-person lectures and/or activities, blended learning, or distance learning)? This helps you decide if the tool should be a central part of the content delivery and assessment of learner learning or an optional supplementary resource. For example, when designing an anatomy curriculum, distance learning through a technology platform may require an e-learning tool to deliver content conventionally taught with cadaveric dissection. In this instance, an e-learning anatomy application that learners consult as an atlas during dissection transitions from a supplemental reference resource to an essential means of presenting content and assessing knowledge.
2. Does the e-learning tool support the instructional method (e.g., lecture, team-based learning, problem-based learning, flipped classroom)? This will help select key features offered by the tool, such as adaptive learning, built-in quizzes, or the ability to create and deliver content asynchronously. For example, as educators flip the classroom, built-in quizzing features integrated with asynchronously delivered didactic content is significant to facilitate self-assessment of knowledge acquisition in preparation for the synchronous course session. To facilitate open discussion, application, and inquiry during a synchronous session, educators will seek e-learning tools which support small and large group formats and provide a real time, collaborative workspace.
3. What features are required to deliver content and/or assessments in your course (audio recordings, video recordings, integration with the learning management system (LMS), mobile friendly applications, etc.)? If the content is highly visual in nature, video recordings are a desirable feature. If you are replacing in-person laboratory experiences, the tool may need to offer a means to engage learners in simulated activities or experiments. If you would like learners to access it via the LMS and/or their mobile phones, the tool needs to integrate with these platforms. When replacing in-person laboratory experiences with simulated activities delivered with an e-learning tool, it is critical to revise and align assessments accordingly. For example, if laboratory dissection is replaced with a three-dimensional virtual anatomy platform with interactive models, learner knowledge of anatomic structure should be evaluated on the platform, not on images of cadaveric dissections.
4. What level of interactivity will be required for the learners to accomplish learning outcomes, and does the e-learning tool provide the appropriate level and options? Consider whether the tool is intended to be a supplementary learning resource or reference, or if it serves as a central component of content delivery, self-directed learning, and/or assessment of learning.
5. Does the e-learning tool facilitate the cognitive domain specified in the learning objectives (as ascribed by Bloom’s taxonomy)? Bloom’s taxonomy defines and distinguishes different levels of cognition using a hierarchical ordering from lower cognitive levels (e.g., memorization) to higher levels (e.g., evaluation and application). The taxonomy provides a framework for specifying expectations, or objectives, of what learners should accomplish as a result of instruction. Higher levels of cognition such as evaluating and creating may not be achievable with all e-learning tools, so special consideration should be given to aligning the e-learning tool capabilities with learning objectives.
6. Would you like to be able to track data and user performance to assess learner engagement and progress? Would you like learners to be able to track data, receive immediate feedback, and assess their own performance? If so, inquire if the tracking features integrate with your LMS and/or assessment dashboard. You may also want to investigate if the application offers adaptive learning—a data-driven approach that provides customized learning paths to address the unique needs of each learner. Adaptive learning provides learners with immediate, customized feedback to advance their learning.

The questions provided here are not exhaustive; however, they will help align an e-learning tool with your curriculum and the needs of the learners, educators, and institution. The backward design process should be used to thoughtfully incorporate an e-learning tool into any curriculum. This process is critical to achieving desired learning outcomes and fostering a positive learning environment. Figure 1 summarizes the backward design process for curricular alignment, with an emphasis on e-learning tool integration.
The authors encourage educators to challenge their assumptions about e-learning tools. Global commercial entities produce and market e-learning products and services in a competitive marketplace, and often there is no quality assurance mechanism to protect consumers or learners. As a result, extensive variability exists in the quality and usability of commercial e-learning tools, with no guarantee that they have been developed and evaluated for learning effectiveness. Similar concerns exist with e-learning tools developed by educational institutions, as tools may not rest upon sound pedagogical and cognitive principles, but instead on the aesthetics of the technology.

The COVID-19 pandemic has compelled the rapid implementation of online learning to accomplish outcomes and sustain educational programs. STEM faculty are looking to e-learning tools to facilitate what used to be face-to-face laboratory experiences in an online environment. This article highlights key principles and questions educators should consider to select and integrate e-learning tools into curricula. E-learning tool integration is complex and rarely a smooth journey; frontline educators who have committed to making innovative changes in their curricula in this time of uncertainty should be commended.

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