The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #44150

Board 127: Work in Progress: Strategizing the Integration of VR and AR in STEM Education: Aligning Educational, Organizational, and Technological Strategies

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WIP: Strategizing the Integration of VR and AR in STEM Education: Aligning Educational, Organizational, and Technological Strategies

Abstract:

This paper will be presented in a poster format.

The integration of STEM education with Virtual Reality (VR) and Augmented Reality (AR) technologies offers opportunities to enhance students' learning experiences by connecting theoretical knowledge with real-world applications. STEM courses, including a range of concepts in mathematics, physics, and engineering, become more perceptible and meaningful when visualized in 3D mediums. Moreover, these learning experiences are enriched when 3D visualization incorporates interactive elements within the virtual environment, allowing students to unleash their curiosity, manipulate concepts, and practice critical thinking skills through an immersive experience. However, applying AR and VR in education is not without its challenges such as the need for infrastructure investment, the steep learning curve for educators, the development of effective pedagogies, and effective resource allocation. Consequently, the adoption process necessitates a strategic alignment among educational, organizational, and technological strategies within institutions. This paper discusses the essential requirements, opportunities, and challenges of adopting VR and AR technologies and developing effective pedagogies in STEM education. With the continuous advancement and increasing accessibility of these tools and training resources, some challenges will be addressed in the future, and this paper aims to discuss the challenges of adopting specific emerging technologies in STEM education and offer a strategy framework that helps faculty lead or contribute to technology adoption initiatives by understanding the alignment of organizational, technological, and educational requirements in adopting such technologies.

Introduction

The landscape of higher education is undergoing a transition from the educational needs of Millennials to the distinct preferences of Generation Z and Generation Alpha. The newer generations maintain unique learning styles due to their exposure to technologies [1], [2]. This may necessitate an integration of innovative tools and teaching methods to enhance learning experiences, particularly in the fields of Science, Technology, and Mathematics (STEM). The innovative tools and teaching methods should include the adoption of technologies that support multimodal learning experiences through high levels of perception [3], highlight social connections [1], and support experiential learning [2]. The technologies should engage and enhance students' learning and offer flexibility for a necessary shift toward remote education.

To navigate the complexities of the evolving educational landscape and address potential challenges, this paper proposes an appropriate approach to the incorporation of emerging technologies in teaching and learning by introducing a strategic framework to faculty members, empowering those who wish to lead or contribute to current or future technology adoption initiatives within their institutions. Additionally, we aim to share insights from our ongoing efforts to integrate teaching and learning with emerging technologies, including lessons learned and challenges faced.

In particular, this paper discusses the current challenges in adopting technologies such as Virtual Reality, Augmented Reality, or Mixed Reality, in STEM and encourages further discussions and collaboration on this topic to understand and strategize solutions to the challenges. In this paper, we use Extended Reality (XR) as the main term to refer to the technology which encompasses several forms of technologies including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). This paper does not provide recommendations on adopting XR in higher education institutions. Instead, the goal is to discuss the opportunities and challenges of adopting XR in teaching and learning and use a strategy alignment framework to assist faculty in assessing these opportunities and challenges from a comprehensive perspective.

This paper is a collaboration of three faculty members and a multimedia specialist. The initiative is currently being developed by one of the faculty members at a small-sized private STEM school. The motivation for submitting this work to FDD is twofold: to discuss the challenges of adopting XR technologies and to share practices, strategies, and mindsets for faculty-led projects in STEM education, emphasizing a bottom-up rather than a top-down organizational approach. The implication of this ongoing project is to utilize an approach by which all faculty, staff, students, and administrators collaborate to understand more about all stakeholders' needs before adopting technologies for teaching and learning. The paper outlines a framework for requirement gathering in the adoption of technologies such as XR applications for teaching and learning in STEM fields. This framework aims to assist faculty members interested in either leading or contributing to technology adoption initiatives at their institutions.

Opportunities

Several studies discuss that the XR applications can offer immersive and interactive experiences that would leverage student learning by offering additional modalities to interact with STEM concepts. For example, studies have shown that VR can help improve student experience when interacting with 3-dimensional atoms, and molecules in chemistry [4], physics [5], and calculus concepts [6]. VR can also enhance learning, motivation, curiosity, cognitive abilities, and reflective thinking in art and design students [7]. Moreover, VR can simulate complex environments that are impossible for students to experience in the real world. For example, to train students in manufacturing processes, a simulated manufacturing environment can be used to alleviate concerns about any undesirable impacts on the process [8]. Experiencing representative real-world environments through VR is likely to sharpen their problem-solving skills and unleash their creativity. AR can also enhance students' learning without sacrificing the context of the physical environment by overlaying digital information or objects onto real-world environments. AR has shown its effectiveness in the science, mathematics, technology, and engineering components [9]. Mixed reality allows users to interact with digital information or objects and manipulate the objects multimodally. These technologies, through immersive experiences, can help students engage with complex concepts more visually and perceptually.

Challenges

While the adoption of XR technologies can offer opportunities for immersive teaching and learning, this adoption process is not without its challenges. For example, faculty members as primary adopters face several challenges in developing and experimenting with pedagogies within individual courses and across curricula. The challenges include insufficient experience using or teaching with XR technologies, lack of training resources, lack of professional development support, and resistance to changing teaching methods. In addition, the potential side-effects of using XR for faculty and students such as simulation sickness and accessibility concerns have yet to be fully addressed. Moreover, there are infrastructure challenges that the adopted tools must be compatible with the institution's learning management systems, and there must be adequate technical support available for both faculty and students to ensure a smooth and effective integration of XR into the educational framework.

In the following sections, we provide two examples of adopting XR: 1) the integration of XR technologies to enhance the teaching of safety practices within the industrial and systems engineering curriculum, and 2) the application of XR to fulfill a safety training requirement. These case studies discuss the opportunities, challenges, and specific requirements involved in incorporating XR technology into educational practices, illustrating a bottom-up approach to technology integration. Subsequently, we introduce a strategy alignment framework designed to broaden the perspective of faculty members. This framework encourages them to consider additional, organizational-level requirements for technology adoption initiatives, following a top-down organizational approach. By practicing these approaches in parallel, we aim to offer a comprehensive overview that not only highlights the immediate educational benefits and challenges of using XR but also aligns these efforts with broader institutional strategies and objectives.

An Adoption into the Industrial and Systems Curriculum

Case: Safety Engineering

Risk assessment using safety engineering analysis techniques often involves assessing real industrial settings with hazards with the scope to impact design, process, or safety practices. However, when teaching these concepts in a classroom, the challenge is to make students understand the challenge of recognizing hazards in real industrial settings only with traditional pedagogical methods such as lectures, videos, etc., due to constraints in time, availability of actual industrial settings to immerse students in within the scope of a class project, and the practical and safety challenges in "creating and showing" what hazards are. We think that simulating a hazardous physical environment is a much more realistic, fun, and immersive approach to engaging students in safety engineering assessments. To address this goal, we are working on a VR project to create artificial physical environments with embedded hazards. Students will engage with the virtual environment to recognize and identify hazards and assess their risk. We plan to use a wall-to-wall immersive VR system to be as representative as possible for simulating actual industrial environments. In the future, we also plan to implement AR-based hazard recognition by embedding virtual hazards within academic buildings to constrain the scope and time needed for students to engage in this activity. The AR-based project will also be used to introduce students to industrial engineering and safety concepts as part of engineering recruiting events. While both the VR and AR projects require effort and time to build and implement, they can be readily adopted by other institutions and scale it down if needed.

Some of the challenges encountered in developing this project include (1) setup of VR space (2) connecting with industry to create realistic scenarios (3) training requirements (4) time, effort, and performance assessment. First, the setup of a wall-to-wall VR space is expensive and may not provide returns if used only for teaching purposes for a few classes. But we also know that VR and simulation setups could yield benefits in the long term – for example, in the healthcare domain, VR and other simulation environments are used extensively for teaching, and they are found to be beneficial in student learning. In this case, the faculty is using this VR setup for both research and teaching and was able to invest in it through institutional funding support. It is important to note that there are many low-cost, affordable VR equipment available for classroom adoption, which might be a more feasible approach for individual faculty to experiment with VR technologies in teaching. Second, in order to create realistic VR scenarios for teaching, industry connections, and support might be important. This instructor found it challenging to connect with industry to provide support for this goal given the time and effort it might require from the industry partner. One strategy is to initially integrate this as part of capstone design, where industry support is already available. Third, creating VR scenarios and models would require some programming and development. This necessitates the faculty teaching the course to train themselves in VR and develop the application or train students to support development. In either situation, training in emerging technologies becomes a professional development need, which an organization may or may not recognize and support. Fourth, extensive time and effort are needed to develop different scenarios for classroom purposes, but it is unclear from a faculty perspective how these efforts will be assessed and rewarded. For example, depending on the institution, course development efforts may not be considered as a contribution to faculty performance in annual or tenure evaluations. This might discourage faculty, especially junior faculty, from pursuing such efforts. Additionally, given the significant effort and time, and evolving evidence on student learning benefits, faculty may not find it rewarding in the short-term.

An Adoption into the Practice

Case: Safety Training

To earn access to a machine shop on campus, students must complete a safety quiz successfully beforehand. The current process requires students to watch a 12-minute-long PowerPoint presentation. While the current training method prepares students to avoid unsafe practices, the goal is to incorporate active learning approaches in a simulated environment to increase students' engagement with the content and help them retain safety practices when necessary. One approach is to create a digital twin of the machine shop and train students in a safe virtual environment before practicing machinery operations to reduce the risk of accidents in the shop. To implement this method, a virtual tour was developed by the school’s multimedia specialist. The development process included location selections of the physical environment where the digital twin will be developed based on, using 360-degree cameras to take high-fidelity panoramic photographs, importing photos into a virtual tour software package (i.e., 3DVista), and integrating quizzes on the virtual environment into the school’s LMS for assessment purposes.

The image below shows a sample photo of the virtual tour at the shop entrance location. Students can navigate the virtual environment, walk through the entire shop, and train with several safety instructions interacting with shop items such as the first aid kit, emergency power disconnect, fire extinguisher, lathe, CNC machine, drill, lockers, and saws. Instructions include manuals, safety videos, and mini quizzes. Students take the safety quiz in the virtual environment and their score will be synced with the school’s LMS. Adopting this method is considered easy and inexpensive with a high impact on learning. For such an application and similar virtual environments, tools such as Insta360 Titan Pro 360-degree camera and 3DVista software can be used. However, several inexpensive virtual tour software applications and almost any camera, including smartphone cameras can be used. Although the current practice is considered easy to pursue in all STEM campuses, there needs to be a few hours of training and learning how to implement such an environment by a faculty or technologist. This case was developed by the school’s multimedia specialist who is one of the employees of the school’s learning and technology center. The mission of learning and technology is to provide instructional technology services including training and technical support to faculty, students, and staff using educational technologies.
One of the challenges of initiating and developing the safety case is that it relies on the availability of a specialist with relevant technical skills. Also, with the expansion of the current case or initiation of similar projects by faculty or the learning and technology center, there may be challenges with insufficient human resources with relevant skills to assign to projects and meet the goals. Moreover, currently, the center maintains and provides equipment loans sufficient for the size and the current use requests to faculty, students, and staff. This may require higher investment in a mid- and large school as there may be higher demands for developing similar cases.

This safety training virtual environment example is a recent development and is still under final expert testing before deploying to a larger audience. While this one and other use cases will progress, we will discuss the effective measures of such practices, and expenses in future papers.

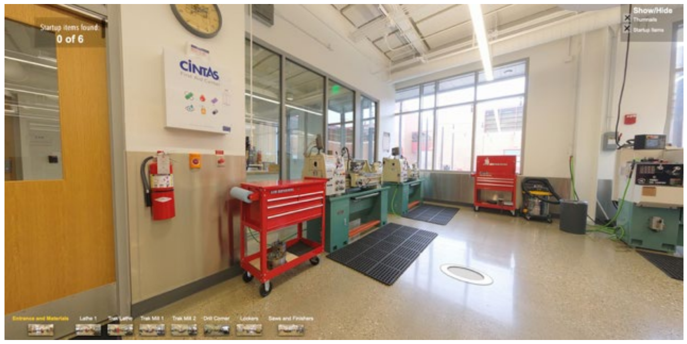
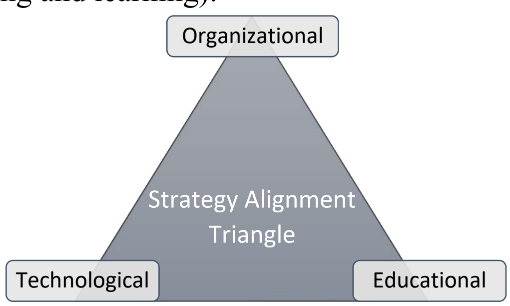


Figure 1. A sample photo of the virtual tour at the shop entrance location

In the following section, we introduce a strategy framework to assist faculty leaders in cultivating a mindset oriented toward strategy alignment. This framework assists in understanding stakeholder needs, effective collaboration, and communication across the institution, and facilitates the strategic navigation of challenges. This framework helps ensure that educational efforts in adopting XR are aligned with broader institutional objectives and stakeholder expectations.

The Information Systems Triangle

Pearlson, et al. introduced the Information Systems Strategy Triangle framework that emphasizes the alignment between organizational strategy, information systems strategy, and business strategy [10]. The framework is applied in the context of business information systems and strategic planning purposes. We adopted the information systems strategy triangle to discuss the necessary components of strategic planning and alignment between each component in integrating XR with higher education for next-generation STEM students. In this adopted model for higher education, we emphasize the impact of adopting XR and the necessary alignment between organizational (the institution), technological (capacities, and infrastructure), and educational strategies (teaching and learning).



Organizational Strategy*:* At the organizational level, higher education institutions, and STEM programs should consider the adoption of any technologies such as XR as a strategic tool that should enhance the learning experience for the applicable programs and majors. Not all STEM subjects or majors may benefit from incorporating emerging technologies such as XR into teaching and learning. Therefore, the identification of potential target users (faculty and students in specific majors, and subjects) should be advised by faculty and students at the educational level before being discussed and considered at the organizational level. Upon identifying appropriate majors or subjects, at the organizational level, the institute administration in collaboration with faculty should define clear educational objectives that adopting XR technology can help achieve for identified subjects. The objectives should also be aligned with the institutional strategic planning and overall mission. For example, for a medium-sized engineering school, the objectives may include increasing student engagement, and in a small engineering school the objectives may include practical engineering skills through innovative teaching. Moreover, supporting faculty and staff with their efforts (through incentives, or performance assessment plans), supporting professional development, training resources, and partnership opportunities with industry should be discussed and strategized at the organizational level.

Technological Strategy: Institutions' faculty and administration must understand their organization's capacities in adopting new technologies. It can include decisions in selecting and implementing the right XR technologies that are aligned with the educational goals. It also involves investing in a suitable path toward the necessary integration of these technologies with existing educational technologies and platforms including the Learning Management Systems (LMS) in the future, ensuring a cohesive and seamless technological ecosystem that supports both educators and students. It is also necessary to include alternative plans in the strategies to address some of the challenges in using XR applications such as users' simulation sickness, general safety, and accessibility concerns [11].

Educational Strategy: At the instructor level, strategies involve considering requirements for developing effective pedagogical practices including new instructions, materials, assessment methods, and pedagogies adoption framework, professional development, and training resources for faculty, staff, and students. Strategies should also involve user requirement analysis to understand the educational capacities by collecting user feedback from faculty, staff, and students. For instance, seeking feedback from faculty, students, or staff about their learning curve adapting to the new educational logistics, their perceived usefulness of such technologies in teaching and learning, potential sickness, and side effects can provide valuable insights to align educational needs with technological requirements. This framework can help planning with a more structured approach to understand the requirements for considering adopting XR for teaching and learning.

Discussion and Conclusion:

In the process of developing and aligning educational and technological strategies for XR technology adoption, we have identified several challenges. From an educational standpoint, the main challenge is the limited availability of pedagogical frameworks and practices that extend beyond isolated use cases to broader curricular applications. The absence of universally applicable learning objectives, outcomes, and assessment methods presents another educational challenge. Additionally, even faculty members who recognize the potential benefits of XR technologies for their teaching often lack the necessary experience in using or teaching with these tools. Addressing this requires standardized training, access to professional development resources, and the establishment of discipline-specific communities for sharing resources and discussing best practices. Such communities could also engage faculty members who are skeptical of the value of educational technologies, facilitating a broader dialogue about potential benefits and concerns.

Similarly, in technological strategies, challenges include ensuring infrastructure readiness and the absence of a clear roadmap for the adoption of hardware and software that meets all requirements, including training, maintenance, and compatibility with existing institutional technology ecosystems. A short-term solution could involve investing in a limited set of hardware and software to pilot pedagogical developments and faculty-led testing, which may inform more refined long-term strategies.

Moving forward, the strategies and some of the challenges we've discussed will be addressed further through practical application, pedagogical development, and the assessment strategies that are currently in progress. This will initially focus on industrial and systems engineering and engineering management, with parallel efforts aimed at disseminating lessons learned to other disciplines. We recognize that the challenges outlined here may not encompass all those encountered across various campuses. The diversity of experiences and strategies among faculty members who are considering adopting such tools, currently using them, have stopped using them, or see no value in them remains a rich area for exploration. Our goal is to establish a network of faculty members to exchange concerns, challenges, strategies, lessons learned, and best practices in teaching and leadership related to the adoption of XR technologies. By creating a network that includes faculty members from different disciplines and institutions, we aim to facilitate further research into the long-term impacts of XR technologies on learning outcomes in STEM education. Investigating the effectiveness of specific VR and AR applications in diverse educational settings will yield valuable insights into best practices, pedagogical development, and strategies. Moreover, developing accessible and inclusive XR content that meets the needs of all learners, including those susceptible to VR sickness, remains a critical area for future exploration within this network.

Acknowledgement:
One of the authors developed the strategies based on the knowledge gained through participation in the *"Unleashing Academic Change,* a faculty development national workshop from the Engineering Unleashed network [10].

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