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Decision support model to leverage extended reality technologies to augment manufacturing education

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Abstract
Extended reality devices and applications are being utilized to augment training and education within engineering and beyond. Their innovative and powerful ways to engage with numerous senses of the learner are making several educators explore and experiment within classrooms and makerspaces. The authors have implemented training using these technologies at a large public institution of higher education, and the paper will present experience reports and anecdotal student feedback. This paper aims to present a decision support model that could map the educational learning outcomes to the current state-of-the-art of Extended Reality technology. Such a framework could help educators make better decisions on how to effectively integrate these new technologies within the curriculum to enhance and augment the learning of engineering concepts for students.

Introduction

Extended Reality (XR) is an umbrella term for various types of electronically enabled realities like Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) [1]. Extended reality (XR) devices and applications are being utilized to augment training and education within engineering and beyond. These include a broad spectrum of devices ranging from immersive virtual reality headsets with handheld controllers to augmented reality headsets with finger tracking and smartphones with intelligent machine vision. Fig. 1 shows the continuum of XR training applications.

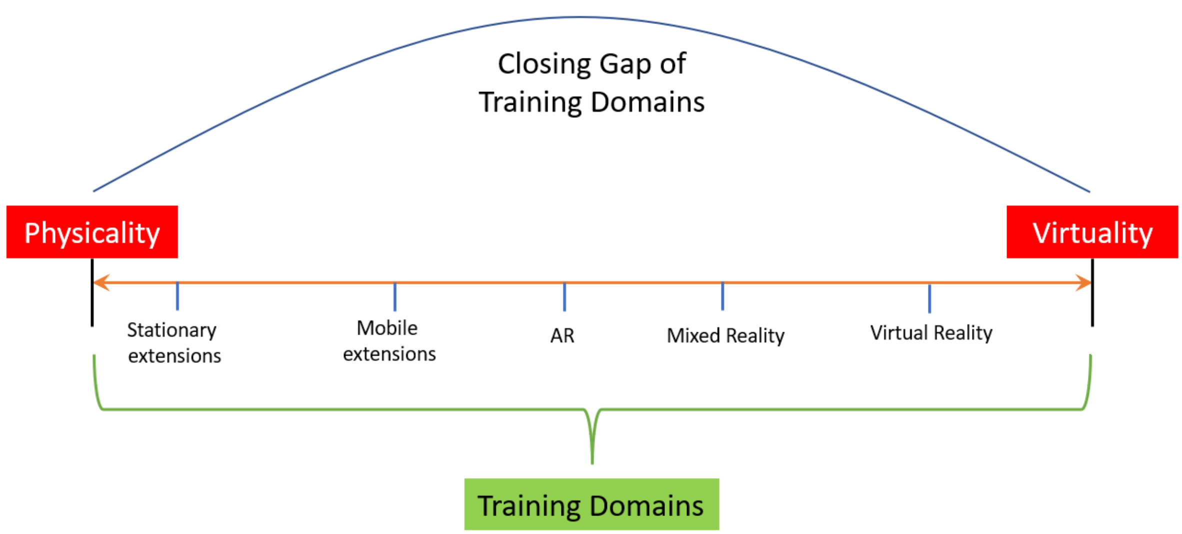

Figure 1 Continuum of XR Training Application based upon [1]

For faculty, these technologies are, in addition to the already existing and diverse content delivery and educational technology tools like multimedia, photos, voice-over instructional video, presentation slides, handouts, etc. This variety of tools can overwhelm faculty when deciding how to best leverage these tools for creating the most effective teaching and learning environment. For example, numerous possible formats exist in instructional videos itself [2], such as animations, using blackboard, showing live demonstrations, or talking heads in front of slides. Researchers [3], [4] have tried to develop evidence-based techniques to design instructional videos. However, there is a need to establish clear guidelines for implementing mixed reality techniques to augment training and education for design and manufacturing education. Faculty might also face cognitive dissonance when being pressured to utilize novel technologies within their pedagogy to implement the teaching curriculum. Cognitive dissonance can also occur when a person holds two or more contradictory beliefs or attitudes. For example, faculty believing in the value of hands-on learning might question the efficacy of AR/VR tools. Still, they might also value exposing future engineers to the latest technology. Hence, we propose a framework that faculty could use to develop a systematic transition plan for bringing innovative learning support technologies to the classroom.

Literature Review

A systematic literature review was conducted using several online databases with search keywords including "mixed reality", "engineering education", "virtual reality", and "augmented reality". The articles identified several XR applications in engineering education that fall into three categories: (1) Design and Prototyping, (2) Training and Assessment, and (3) Visualization and Communication.

Soliman et al. [5] studied passive teaching methods (only instructor lectures) and compared them to active teaching methods (student input added) by reviewing multiple databases of prior research. The study revealed that active teaching methods had cognitive and pedagogical benefits for students' learning and development.

Vlah et al. [6] did a group study on a set of students. The students were first asked to design basic models in CAD software on desktop computers. The second part of the study included these students using VR tools to create the same models using freeform tools and dimensional parametric tools. The study found that CAD tools on the desktop are better for students to model dimensional modeling, while freeform tools available in VR are much more intuitive and efficient in desktop CAD tools for organic geometry.

Emily et al. [7] discuss a case study in which a team of faculty members developed a faculty-led, student-centered, and interdisciplinary project-based learning approach to teaching engineering design. The authors found that this approach allowed students to transfer knowledge across disciplines and apply it to real-world problems. Project-based learning encouraged students to work collaboratively in teams, enhancing their problem-solving and communication skills. Additionally, the authors emphasize the importance of faculty support and collaboration in developing and implementing practical interdisciplinary project-based courses.

H.-K [8] explores the potential of augmented Reality (AR) in education. Their approach includes discussing AR's current status, opportunities, and challenges in education. A few highlighted benefits of AR in education include increased engagement, motivation, and knowledge retention. Comparatively, the challenges include the high cost of technology, the need for specialized training for instructors and students, and the limited availability of AR content. The article concluded with an emphasis on further research and development of AR technology in education. A few suggestions made by the authors include designing effective AR learning environments, creating AR content that aligns with educational objectives, and evaluating the impact of AR on student learning outcomes.

Overall, these papers demonstrate the potential of Mixed Reality in engineering education and highlight the benefits of using these technologies for teaching and learning. They also identify challenges that must be addressed to fully realize the potential of Extended Reality in education, such as technical limitations, implementation cost, time, and the need for effective pedagogical strategies.

Model Development

The approach undertaken in this study was first to develop experimental training modules to teach hands-on manufacturing skills for makerspace tools using mixed reality techniques. Secondly, a technology inventory table was created to compare, contrast and assess the capabilities of various mixed reality techniques. Finally, a preliminary multi-criteria decision-making model was developed to balance the faculty's expected learning outcomes, the student's learning styles, and the capabilities and limitations of the technology.

Experimental Demos

The authors and their collaborators utilized Microsoft Hololens 2 units with Dynamics 365 guides to develop a step-by-step training guide to emphasize safety when using laser cutters and to thread the needle in a sewing machine. Both of these training modules are currently covered as part of the in-person training supplemented with printed handouts and an asynchronous video. These specific hardware and software tools were chosen because they were made readily available as part of the exploratory project funded by the School. The step-by-step process used to create the guides was very similar to the one reported in the literature by Lavric et al. [9]. The primary benefit of using the Dynamics 365 guides tool was that the skills needed for creating the instructional guide were very similar to building MS PowerPoint slides, and no coding skills were necessary.

The first case study was an AR instruction guide for helping the user thread the needle on a sewing machine without human intervention. The instructional guide can be viewed at: https://youtu.be/bRjRcxKyC8g.

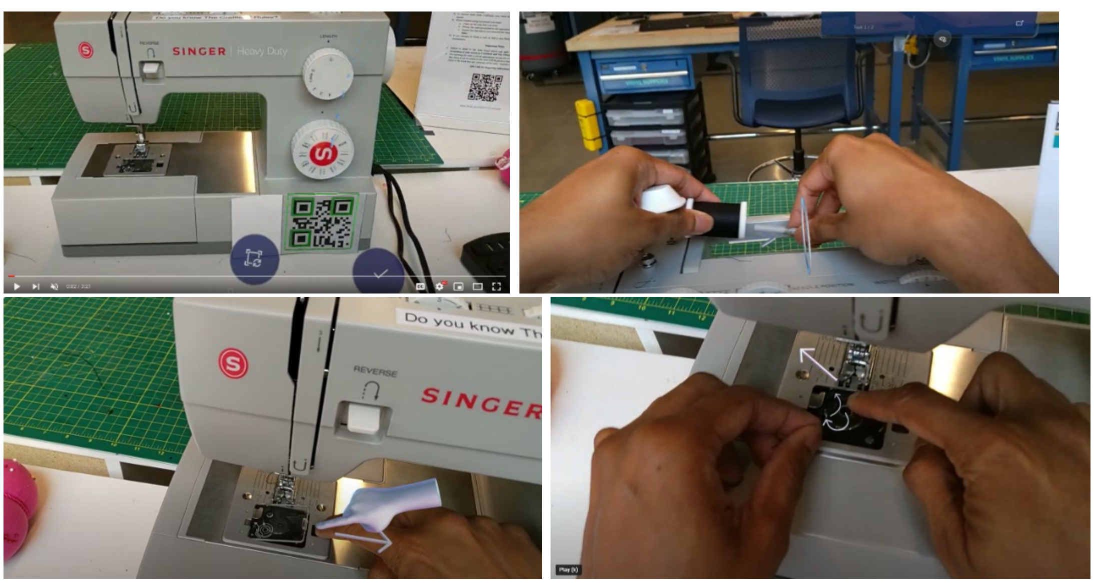

Figure 2 Screenshots taken from the AR head-mounted device for the Dynamics 365 Guide for Sewing machine

Fig. 2 shows the screenshots taken from the head-mounted device while the trainee was trained on using the sewing machine in the makerspace. The various locations for the annotations were anchored in the virtual environment with help of a QR code physically placed at a pre-determined orientation and location on the equipment. In this exercise, the trainee could read the instructions, hear them read out loud, and see arrows and other symbols as annotations superimposed in real-time relative to where the trainee was seeing.

The second case study was to walk through the user with the key safety aspects of the laser cutter. Improper use of safety procedures could damage the equipment (like using a fire extinguisher inside a laser cutter for small fires) and poor recognition of hazards could impair the ability to the user to take corrective action (for example, large fires with unventilated smoke causing the user to be left unconscious). The instructional guide for Laser cutter can be viewed at: https://youtu.be/dFVuOFDhu80.

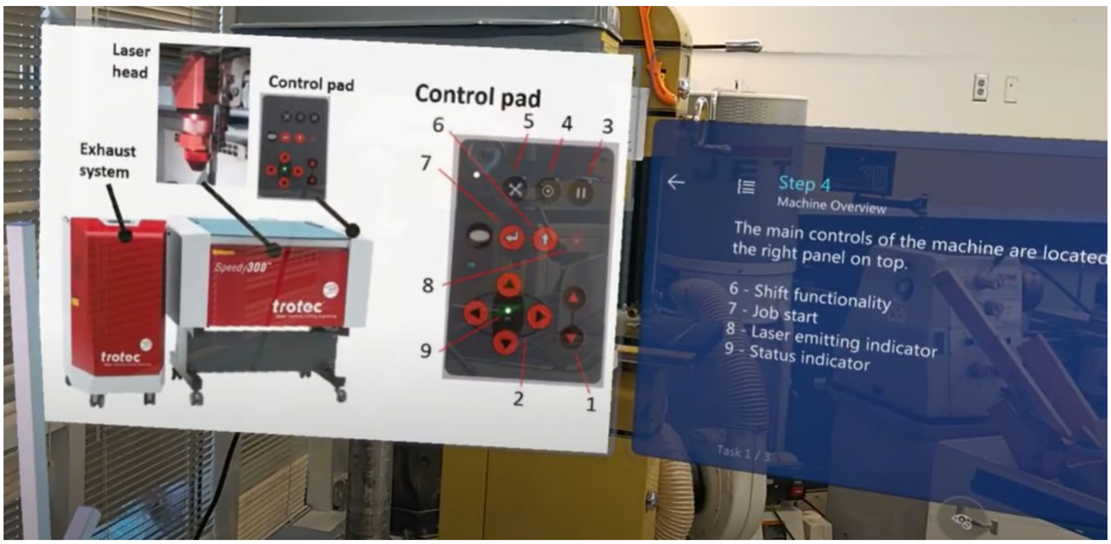

Figure 3 Screenshot from the head mounted device for laser cutter safety training showing the labeled control panel in users' view

Fig. 3 shows a screenshot from the head-mounted device (HMD), which was the MS HoloLens 2 for laser cutter safety training. It shows the ability to place a labeled control panel in the users' view so that they can compare it with the actual panel and familiarize themselves without the need for human intervention. Fig. 4 shows yet another screenshot from the HMD showing a video that the user can play on demand as well as be guided to interact with the appropriate physical interfaces with help from superimposed annotations on the actual laser cutter. Detailed studies on the efficacy of the two AR tutorials were not conducted. However, these experimental demos helped explore the barriers and opportunities available when leveraging mixed reality techniques to augment user training.

Figure 4 Screenshot from the head mounted device showing superimposed annotations along with a brief video demonstrating the specific steps

The authors hosted a campus-wide event to engage with students from across various majors and years and to expose them to the latest state of the art in XR technologies. They invited speakers from the industry to share real-world case studies on the implementation of XR technologies to solve training and business challenges. This talk was followed by a hands-on demo of the various of the XR technologies. The team setup several workstations within the School's makerspaces with various XR technologies pre-loaded with specific software along with large displays showing the live feed from the various headsets. They were as follows:

1. Mixed Reality gaming
   a. MS HoloLens 2 with software for gaming applications like Roboraid, Fragments and Playground
2. Virtual Reality gaming
   a. Oculus Quest 2 units with gaming applications like Beatsaber and Superhot VR
3. Mixed Reality engineering work instructions
   a. MS HoloLens 2 with Dynamics 365 guides for laser cutters
4. Mixed Reality remote collaboration
   a. MS HoloLens 2 with Dynamics 365 Remote Assist
5. Mixed Reality Collaborative Design in low fidelity
   a. MS HoloLens 2 with Microsoft Mesh
6. Mixed Reality Collaborative Design in high fidelity
   a. Varjo XR3 unit with AutoDesk VRED software
7. Virtual Reality immersive CAD
   a. Oculus Quest 2 units with Gravity Sketch software

Fig. 5 shows the pictures taken from the campus wide student engagement event.The top right photo shows a student using gravity sketch to sketch in virtual space, and his virtual view is broadcast on a display TV for onlookers. It is interesting to note that the student is bent close to the ground and immersed in the sketching activity. The top right photo shows a student helper acclimating to the finger-tracking controls of the MS HoloLens 2 device. It took roughly 10 minutes per user to calibrate the headset to their iris and for them to acclimate to the novel user interface. The bottom left photo shows two students co-creating designs by collaborating virtually using AR headsets. The bottom right photo shows a student staff helping the user navigate through the virtual user interface. It was interesting to observe that the student staff had to rely on their memory, assume what the end user might be seeing, and guide them through the virtual navigation steps within the users' own Reality. This limitation was easily overcome on other workstations where the headsets were tethered to physical 2D display devices. However, this experience highlights the barrier/obstacle an instructional team might face when getting their students to follow the correct steps when navigating an immersive virtual environment.

Figure 5 Photos from the Campus-wide Extended Reality event

Comparison of state-of-the-art XR technologies:

Having tested with a range of XR technologies, the team conducted an ad hoc survey to list the desired features from an ideal training technology tool. We then conducted a holistic review of the current state of the art for the various XR technologies and compared the features and limitations, in contrast with conventional training methods like instructional videos and in-person training. Palmas and Klinker [1] define the various XR technologies as follows:

- VR is a computer-generated virtual environment that allows users to interact with, move around in and be completely immersed in a virtual environment. By combining different types of hardware, immersive experiences with entirely computer-simulated sensory reception can be achieved. We utilized the Oculus Quest 2 headset to study the applications of VR.

- AR is an overlay of digital content onto a physical reality. It cannot directly interact with the environment, and it is rendered by a medium that displays both the real world and digital content simultaneously, enabling the user to experience both simultaneously.
- MR is a hybrid form of XR, created by combining virtual and augmented Reality. It employs an overlay of virtual content that can interact with the actual environment and therefore facilitates the interaction between realities as a result of the blending of the physical and digital world. For the sake of this study, we utilized the MS HoloLens 2 headset and Varjyo XR2 units.

Table 1 summarizes the features and limitations of the various training delivery modes from an instructor's perspective, and Table 2 lists similar assessments from an end-user perspective. The first column lists the various needs or features from an ideal XR technology. For example, faculty prefer to use an instructional medium that offers lower barriers to use (like a smartphone since everyone has one) and also a lower developmental barrier (like typing notes or creating slides since most faculty have these skills as against video editing or coding skills).

Table 1: Comparison of training delivery modes from the instructor's perspective

Features/Needs	**VR**	**AR**	**MR**	**Videos**	**In-person**
Examples →	(Quest 2)	(Smartphone)	(MS HL2)		
Show on-demand animations	Y	Y	Y	Y	N
Show video with vision/head tracking	Y, immersive	Y	Y, immersive	N	N
Draw/annotate on real objects	N	Y	Y	N	N
Track or identify real objects	N	Need QR codes	Needs prior CAD of object	N	Y
Allows interaction with Reality	N	Y	Y	N	Y
Developmental barrier for interactive **design/CAD** tools	Limited set of available apps		Limited set of available apps	NA	NA
Developmental barrier for **training/instructional** tools	Require skills using Unity or other VR dev. Platform	Needs custom design and maintenance of apps	Only some device platforms offer low code software dev. tools	Could utilize slides but need video editing	Lowest barrier since instruction can be verbal/text
Developmental barrier for **collaboration** tools	Several low-cost apps available		Several low-cost apps available	NA	NA
Ability to edit/change instructions	Possible but needs to be considered during instructional design	Could be easier than editing an entire instructional video	Could be easier than editing an entire instructional video	Non trivial unless original video was designed in modules	Easy

Table 2: Comparison of training delivery modes from the user's perspective

Features/Needs	**VR**	**AR**	**MR**	**Videos**	**In-person**
Examples →	(Quest 2)	(Smartphone)	(MS HL2)		
Barriers for end user	HW and SW license cost	Relatively low cost if works on user's device but might need SW license	HW and SW license cost	Universally available anytime through internet	Requires access to equipment and trained personnel
Ability to scale to many users	Limited by HW units and SW licenses	Limited by SW licenses	Limited by HW and SW licenses	Most scalable	Most restrictive and limited by space, equipment and people.
Precision of user inputs	Depends on controller	Limited	Varies. Limited with finger tracking and better with handheld controllers	N	NA

Learning Styles

One of the striking anecdotal feedback that the team received from the trails conducted was that not all students who tested the XR tools were eager to see their future training materials transformed using XR. While there was lot of excitement at the start of the trials, a few students did report that they felt disoriented after using the devices whereas others preferred conventional techniques like written instructions or demonstration videos. This difference in feedback could be a result of various reasons like their past experiences with technology, their personal level of anxiety with new technology as well as their preference of learning styles. Coffield [10] argues that there are 13 major models of learning styles. They remark that, "fortunes are being made as instruments, manuals, videotapes, in-service packages, overhead transparencies, publications and workshops are all commercially advertised and promoted vigorously by some of the leading figures in the field. In short, the financial incentives are more likely to encourage further proliferation than sensible integration. It also needs to be said that there are other, distinguished contributors to research on learning styles who work in order to enhance the learning capabilities of individuals and firms and not in order to make money". Financial motives also seem to play a major role by XR development companies when they prescribe specific tools and technologies to faculty to integrate within the curriculum. There are several different models of learning styles, but the most widely recognized are:

1. Visual learners: Visual learners prefer to learn through visual aids such as pictures, diagrams, and videos. They benefit from seeing information in a graphical or visual format. While XR technology with its immersive reality benefits can engage with the learner, not all XR platforms provide a high-resolution visual learning environment and immature adoption of XR technology can lead to severe disappointment and loss of interest among students. A recent news article [11] on the poor rendering capabilities of a VR platform is a reminder to ensure that the technology is capable before launching to end users.

2. Auditory learners: Auditory learners prefer to learn through listening and hearing information. They benefit from lectures, discussions, and spoken explanations. While XR technology is not limited to serving auditory learners, creative use of reading out instructions to mimic real world engagement could be used effectively.
3. Kinesthetic learners: Kinesthetic learners prefer to learn through hands-on experiences and physical activities. They benefit from activities such as role-playing, simulations, and experiments. MR technologies are best suited for these followed by VR exercises with user inputs. However, as shown in first case study, it could be challenging for the end user if the activity require fine dexterity and the learned would end up getting challenged and frustrated by having to do fine motions while wearing a heavy headset and viewing through narrow field of view optics.
4. Reading/writing learners: Reading/writing learners prefer to learn through reading and writing. They benefit from written explanations, note-taking, and reading texts. Learners with these preferences could be engaged using AR or MR (not VR) by allowing them to take physical notes, as well as providing them with written handouts.
5. Social learners: Social learners prefer to learn through interaction with others. They benefit from group activities, discussion, and collaboration. VR is probably the cheapest (in the current state-of-the-art) and most immersive method to engage with these learners.

It is important to note that these learning styles are not mutually exclusive, and individuals may have a preference for more than one learning style. Understanding learning styles can be useful for educators in designing XR instruction that is accessible and engaging for all learners. Bloom's Taxonomy [12] and learning styles are two different frameworks that are commonly used in education to help teachers design effective instructional strategies and assessments for their students. Bloom's Taxonomy is a framework that categorizes learning objectives into six hierarchical levels, ranging from lower-order thinking skills such as remembering and understanding to higher-order thinking skills such as analyzing, evaluating, and creating. The taxonomy provides a systematic way to structure and organize learning objectives and to ensure that learning activities and assessments are aligned with the intended learning outcomes. While there is no direct relationship between Bloom's Taxonomy and learning styles, as they address different aspects of learning, we propose that instructors use Bloom's Taxonomy to design instructional strategies and assessments that accommodate different learning styles. For example, teachers can design various XR learning activities that incorporate different modalities to cater to visual, auditory, and kinesthetic learners, while also ensuring that the activities target different levels of Bloom's Taxonomy to promote higher-order thinking skills.

XR technologies allow learners to ***remember*** content by presenting information in an immersive environment which can be practiced over and over through repetition. The interaction ability of the XR tools can provide the learner to recognize the limits and boundaries of a concept leading to greater ***understanding***. The learner can follow instructions steps in a safe environment without the risk of hurting oneself or damaging physical equipment leading to creative methods to gain ***application*** skills. Virtual tear down exercises, once modeled and implemented on XR tools can help the learner ***analyze*** complex abstract concepts and physical mechanical systems and sub-systems without incurring the cost of physical breakdown, disassembly and assembly. Virtual scenarios and exercises can be developed to help the learner hone their ***evaluation*** skills by being able to model and extrapolate results and see them in an immersive reality. Finally, with help from real-time XR collaboration and co-creation CAD design tools, the learner can ***create***, design, and build in virtual or real environment with augmentation from XR tools. Overall XR tools can play a very important role at all levels of Bloom's Taxonomy of learning. It is critical that the instructors are intentional and deliberate in selecting the appropriate XR technology and designing relevant learning exercises to support the learner's growth to a greater level of learning and engagement.

Conclusion

It is important that instructors consider all delivery and engagement modes within their pedagogy when designing effective learning environments. XR technologies can be one tool in the arsenal of tools but will probably not replace any of the conventional tools in the near future. When deciding which XR (Extended Reality) tool to augment an existing course outcome, an instructor should consider several factors such as:

1. Learning objectives: The XR tool should align with the learning objectives of the course. As presented in this paper, XR tools currently provide immersive experiences to enhance collaborative design and prototyping skills, tool training and visualization skills. The instructor should consider how the XR tool can enhance the learning outcomes for their respective course and help students achieve the intended outcomes.
2. Accessibility: The XR tool should be accessible and inclusive for all students. We list a few barriers associated with the current state of the art of XR technology. As this field develops, the instructor should consider any potential barriers to access and ensure that all students have the opportunity to participate. Barriers could be obvious, like training time, cost to acquire the tool but can also be non-obvious like the devices not physically fitting the user or users' skepticism about having numerous tracking cameras.
3. Student engagement: Like any mode of content delivery, the XR tool should be engaging and motivating for students. XR tools tend to provide a greater degree to immersion and the instructor should carefully consider the learning styles and preferences of their students when selecting an XR tool.
4. Cost: The XR domain is still in its nascent phases of development and so instructors should consider the budget constraints of the course and select an XR tool that fits within the available resources.
5. Technical requirements: The XR tool should be compatible with the technology and infrastructure of the course and that of the institute. Certain XR device platforms require individual student login credentials. Managing software licenses on a large scale could soon become challenging if instructors utilize a specific device ecosystem without working closely with the Institute's IT team. The instructor should consider any necessary hardware or software requirements and ensure that students have access to the necessary equipment.

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