Current and Future Uses of Augmented Reality in Higher Education

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Abstract
Augmented-reality (AR) technology, and its impacts on teaching and learning, have already made their way into elementary, secondary, and higher-education classrooms. The authors discuss why AR matters in the higher-education context, and they describe current examples of AR use that can enhance teaching and learning across multiple fields in higher education, including but not limited to medical education, language learning, and science. They also review AR's pedagogical benefits as well as its challenges and conclude by offering tips for implementing AR in higher education. Although some may be hesitant to adjust their curriculum to accommodate AR, higher-education professionals should at least be aware of how augmented reality can shape teaching and learning, especially as current elementary and secondary students become accustomed to using similar technology in the classroom.

Keywords: Augmented reality, higher education, teaching and learning, benefits and challenges

Imagine trying to facilitate a question-and-answer session in a class of 200 students. As one student raises their hand, that student's name pops up in front of you in text-based form. As you call on the student by name and they begin to ask their question, more information about that student appears in front of you, such as their most recent exam score and their course attendance record. If you were to wear "smart glasses," a technology that offers an augmented-reality experience via a special pair of spectacles, this kind of assistance in engaging with your students could be a regular feature of your classroom. It would not only allow you to seamlessly call students by name but would also enable you to see additional data about each student that could aid in addressing that student's needs. For example, if a student asked a complex question, but you could instantly see that they had performed poorly on a previous exam, you might consider reviewing the fundamentals of the topic before addressing their specific question. This is just one of many possible uses of augmented reality (AR) in the higher-education classroom. Because the specific AR technologies (such as smart glasses in this example) are continually and quickly evolving, instructors should familiarize and prepare themselves for the future use of augmented reality in higher education.

What Is Augmented Reality?

When you think about the phrase *augmented reality*, it sounds a bit futuristic—maybe even a little like science fiction. However, AR is now integrated into our day-to-day lives in many ways. If you have used social-media filters on platforms such as Instagram or

Snapchat; visualized IKEA furniture in your home before buying, using their app (Joseph, 2017); or played Pokémon Go (Carbonell-Carrera, Saorín, & Hess Medler, 2018), you have engaged in AR. A simple definition of AR is digital data layered onto real-world environments. In other words, AR allows you to see your actual environment on your computer or television screen, as well as additional digital elements. For example, in the game Pokémon Go, an app on your phone allows you to see digital images of Pokémon characters in your real-world environment projected on your screen and play a game based on their location.

The term *Augmented Reality* was coined in 1990, but the idea has been around for quite a bit longer. L. Frank Baum (1901) imagined a version of AR in his science-fiction writing, and we saw a glimpse of the possibilities of AR in the 1964 Disney film *Mary Poppins,* in which real-life actors danced and sang with animated animals. Early explorations of AR also included potential military applications (e.g., Azuma, 1997), before AR appeared in more public settings. A good example that most people have encountered is the meteorologist on a local or national television station; often this person is interacting with projected images in real time to illustrate weather patterns for a larger audience. Another common example is the Quick Response (QR) code, which, when scanned with an application on a tablet or mobile device, allows you to access more information, open a link, or view an image that is not provided in the original document.

You can contrast this definition of AR with that of virtual reality. In AR, the digital is being locked into precise locations in your real-world environment; in virtual reality, on the other hand, the digital is completely replacing your real-world environment. A key difference between the two technologies is that in AR you can still see the real world. While virtual reality completely immerses you in the digital, AR allows you to keep one foot in the real world while experiencing a reality that is heightened by the digital.[1]

In this paper, we describe some of the uses and potential of AR environments for higher education. We start with a brief literature review of AR and explain how research on the topic has developed over time. Then we discuss some of the benefits and challenges of AR for higher education generally and for student learning specifically. We offer specific examples throughout of how AR is being used in higher education and also explore the future of AR for engaging students in online, blended, and face-to-face learning environments.

Why Does Augmented Reality Matter for Higher Education?

As augmented reality is becoming more prevalent in society in general, it has also become part of the cutting edge of education specifically—and not just higher education. Students are entering higher education having been exposed to AR in K–12 environments in a range of ways (see, e.g., Cai, Wang, & Chiang, 2014; Hsu, 2017; Huang, Chen, & Chou, 2016; Kerawalla, Luckin, Seljeflot, & Woolard, 2006; and Radu, 2014). Indeed, as the technology becomes easier to use, instructors at all levels are now creating their own AR experiences for their students (Crews, 2018).

In a recent metastudy of the K–12 literature, Radu (2014) found a range of educational benefits stemming from AR use in the classroom, including increased content understanding, long-term retention, improved physical task performance, improved collaboration, and increased student motivation. Wei, Weng, Liu, and Wang (2015) also found increases in student creativity. The literature on AR use in K–12 environments has identified difficulties with this technology as well, such as attention tunneling (students becoming so engrossed in the AR activity that they are not paying attention to the correct elements of the learning experience), usability challenges, ineffective classroom integration, and insufficient adaptability to different learners' needs (Radu). Usability challenges in particular were also highlighted in a literature review by Akçayır and Akçayır (2017); the authors also found that "a notable gap exists for AR studies focused on students with

[1] An additional term that has recently emerged is *mixed reality*, which allows the physical and digital to interact in real time. This can be contrasted with AR, which generally lays content over reality without interaction. However, some may consider this distinction between AR and mixed reality to be debatable.

special needs" (p. 4). Additionally, Akçayır and Akçayır point out conflicting results in the literature: "while some studies reported that AR decreases cognitive load, others reported that it causes cognitive overload" (p. 9); they call for at least a dozen additional areas for further study of AR in education environments.

As the use of AR increases in K–12 classrooms, students may begin to expect these same technological innovations in higher education as well. Although Akçayır and Akçayır (2017) found that more than half the research studies on AR focused on K–12 populations, whereas only 29% and 7% focused on university and adult learners respectively, we can expect studies of AR in higher education to increase as the technology evolves and becomes less expensive to implement. Current studies of the use of AR in higher education, similar to their K–12 study counterparts, have also shown benefits and challenges of this technology. Some of the benefits include decreased time for students to learn new material (Rizov & Rizova, 2015) and increased development of spatial thinking (Carbonell-Carrera & Bermejo Asensio, 2017).

Current Examples

Augmented reality is currently being used in classrooms in a variety of disciplines. Here are a few examples that demonstrate the range of AR's applications:

- An AR childbirth simulator allows medical students to practice components of labor and delivery using a HoloLens simulator (Nafarrete, 2018; for other examples of AR in medical education, see also Kamphuis, Barsom, Schijven, & Christoph, 2014).

- Using the Pokémon Go phenomenon to encourage English language learning (Godwin-Jones, 2016) or to develop spatial skills (Carbonell-Carrera, Saorin, et al., 2018);

- Utilizing AR to train welders to save time in preparing materials and enable "a reduction in material consumption and the risk of accident in the training phase" (Okimoto, Okimoto, & Goldbach, 2015, p. 6225).

As AR becomes more a part of our everyday environments, and as we learn more about how to leverage this technology and integrate it into different aspects of our lives, we are also expanding its definition. We next explore some of the potential benefits of AR for higher education and for student learning.

How Does Augmented Reality Enhance Learning?

There are several potential benefits of AR, and we are recognizing more benefits as the technology matures. In this section, we will offer an overview of the ways that AR can benefit learning. Here are a few categories of the ways in which AR engagement can expand the learner experience, across a range of disciplines within higher education.

Learners Can Access Dangerous Situations
Example. Show learners the impact of corrosive chemicals on a real-world environment.

For pretty obvious reasons—including risk management, health and safety, and expense, to name just a few—we try not to expose our students to dangerous situations in the classroom. This means that students may not get a firsthand view of how, for example, certain chemicals actually work when combined with others. AR allows students to see what *could* happen, without danger to themselves, which would be impossible in a real-world environment.

Learners Can Gain Time with Unique Specimens
Example. Let learners explore for an extended time the characteristics of a fish, which in the real world would begin to rot after two minutes.

Some of the objects that we would like to share with students are either unique or too delicate or rare for us to offer a large amount of time with them. Moreover, some of these objects are not immediately accessible and may be housed in archives on the other side of the world. AR can allow students to engage with these objects in real time, and for longer amounts of time than would be possible otherwise.

The Dog Skull Augmented Reality Interactive: An Example from Oregon State University Ecampus

The dog skull augmented-reality interactive is currently being used in an Oregon State University Ecampus Morphology of Canines course. This AR application has allowed an instructor to digitize borrowed materials so that a larger group of students can view and manipulate 3-D images of canine skulls. It links marker graphics to models via the Vuforia app, which allows users to teach devices (e.g., iPads or other mobile technology) to recognize markers and place models into a camera overlay. Thus, students can interact with the 3-D images of canine skulls through an app. Click here to see the dog skull augmented-reality interactive in action.

Learners Can Manipulate Rare Objects or Places

Example. Let learners explore the skull of an extinct animal or show learners the true size of the Mona Lisa.

In addition to being able to view rare or unique objects for longer periods, students often have the ability to manipulate objects through AR. For example, they might be able to pick something up, rotate it, and look at it from all angles. These objects might be ones that students would not be allowed to touch or to which real-world access is not feasible. When students learn about places or objects in the abstract, it can also be difficult to convey a sense of scale to them. However, AR allows students to view objects at scale within real-world environments.

Learners Can See with Increased Capability

Example. Offer learners an at-scale view of a historic building from another country.

Time travel is one of the most amazing benefits of AR. In addition to being able to view objects at scale, students also have the opportunity to view historical objects or places as they would have appeared originally. This possibility works well for situations such as study-abroad trips, where students can simultaneously view historic versions of the buildings that are right in front of them.

Example. Show learners what a tree sapling will look like as it grows over time and across different seasons.

In AR, time travel works both ways, allowing students to see into the past *and* into the future. In situations where students need to learn how something changes over time, AR offers the benefits of viewing an object's future self, and the process that it would go through to get there.

Example. Show learners what airflow in a room looks like, what a color spectrum beyond normal eyesight looks like, or the level of natural radiation in the dirt below.

In addition to depicting the future and the past, AR can help visualize phenomena that could not be seen without superhuman capabilities—those that are otherwise invisible to the human eye.

The Augmented Reality Sandbox: An Example from Oregon State University Ecampus

The augmented-reality sandbox was originally developed by the University of California, Davis, and is currently being used in an Oregon State University Ecampus Permaculture Design and Theory course. This tool uses a 3-D camera to project a dynamic topographic map onto sand. Because the map reacts in real time when changes are made to the landscape, it has allowed an instructor to demonstrate how flowing water responds to natural and design elements, such as in ponds and during earthquakes. Click here to see the augmented-reality sandbox in action.

Learners Can Obtain More and Better Data
Example. Offer students measurement data for lab specimens as they view an object using AR or offer learners different views of a garden and how it will be impacted by changing seasons so that they can make data-driven decisions about permaculture.

Embedded metadata within AR objects allow students to gather information more quickly. Rather than viewing an object and then researching that object on the internet, students can use AR to view the data with the object at the same time. In many cases, instructors also might want students to be able to imagine different outcomes for the same event, or to envision what-if scenarios. With AR, learners are able to see a range of different options acted out or displayed alongside one another so that they can make more-informed decisions about how to move forward.

Example. An AR application can be programmed to display certain colors for a user who is colorblind, or to rearrange the layout of presented numbers for a user who has dyslexia. Besides helping students see additional data about the content displayed, AR can also be utilized to tailor the way content is presented. Depending on the technology used, an application can be programmed to make information accessible to a specific user. The individualized-augmenting AR has the potential to screen out distractions and help students with specific needs focus on the relevant content.

Learners Can Be Motivated
Example. Rather than a traditional scavenger-hunt model, ask students to use an AR application to explore metadata from books within a library setting to enhance their experience.

Empirical research has found that students experience cognitive benefits when learning through AR, compared to traditional teaching methods (e.g., Carbonell-Carrera, Jaeger, & Shipley, 2018; Diegmann, Schmidt-Kraepelin, Eynden, & Basten, 2015). These benefits include increased motivation, attention, concentration, and satisfaction. In general, student subjects of past research have been eager to learn through technology and have demonstrated and reported satisfaction with the task at hand, possibly because AR can facilitate engagement by involving students physically in the learning task. Students may find AR more fun and immersive than traditional teaching methods, which can increase their motivation to learn.

Learners Can Experience More Student-Centered and Personalized Education
Example. Ask students to use an AR application to see the relative size of a person or object (e.g., compare the size of an average Neanderthal to a family member), rotate it, and click on various parts to read information.

Diegmann et al. (2015) found that AR can facilitate learning and pedagogical techniques relating to processes and course content. For example, AR can be a great tool when instructors wish to use student-centered learning, or a method that allows students to learn at their own pace, with instructor facilitation. This can individualize the learning process, and, as students use the technology to explore the content, instructors can be freed to provide feedback tailored to individual needs and questions. Additionally, this experience can give students practice in immersing themselves in the technology and content and can push them beyond the passive learning that can occur when instruction is less individualized (e.g., lecture).

The individualized nature of AR can also help students learn content more efficiently. Research has found several benefits of AR in content knowledge, including improved spatial awareness, memory, and faster learning compared to non-AR applications (Diegmann et al., 2015). Additionally, users of AR have shown better understanding of how the content could be applied, because AR can help students see everything in context (Dede, 2012). This makes AR a great tool for certain pedagogical techniques that seek to help students understand systems and interrelations between concepts, such as constructivist methods (Miller & Dousay, 2015). Students can also use AR to see things in specific physical spaces, such as in their own home. This can make the learning experience more memorable and rewarding, because students can connect and compare new content with familiar elements.

To take full advantage of many of these benefits of AR, higher education will see an increased use of metadata, or the descriptive information that can be embedded into virtual objects. Rather than storing an object and its data in separate digital or physical locations, AR offers the possibility of combining them. This landscape increases the possible uses of those data, which may increase what information the brain can access. Additionally, this use of data in AR may allow learners to discern connections between information that were not possible before. For many of us, the internet has been a first step in this process; AR is another step on that journey.

Challenges of Augmented Reality for Higher Education Implementation

Although AR has the potential to benefit learning environments, instructors might find it challenging to implement this kind of technology in the classroom, perhaps partially because of a hesitancy some instructors feel about using relationship-enhancing technology in the classroom generally (e.g., phones, tablets, social media; see Fonseca, Martí, Redondo, Navarro, & Sánchez, 2014). The literature has also noted several limitations of AR use specifically. For example, instructors need certain abilities to effectively implement AR, and developing these abilities can take time and effort for the instructor and possibly resources from the institution. Additionally, some learning outcomes and projects might lend themselves to AR use more than others; for example, Fonseca et al. (2014) found that AR tended to work better for simple architectural models than for models that were more complex in structure or volume. The following is a discussion of challenges instructors can face as they try to implement AR in higher education.

Instructors Need Training

Instructors in higher education have a lot on their plate: They often balance teaching multiple courses with other responsibilities such as institutional service and research. One way that instructors tend to lessen their load is by designing courses that can be taught similarly over multiple terms. Integrating AR into a course requires instructors to (a) understand what AR is and how it can be used, (b) re-evaluate their lesson plans and identify ways that AR can help them teach, and (c) go through the process of incorporating the technology in the classroom. This process can take a lot of time, effort, and investment, and experienced instructors with established courses and many other duties may be less motivated to take such steps.

Instructors Need Institutional Support

Due to the time and effort it takes to understand and implement AR, institutions may find that additional time and resources (including grants and hiring facilitating staff) would help in the implementation process. However, extending these resources can require additional financial investment from institutions. For example, some universities currently employ multimedia teams to design and develop AR applications and instructional design teams to help instructors use the technology in their teaching. Although it may not be feasible for all institutions to do this, administrators who wish to implement AR at an institutional level may need to provide instructors with additional support.

Some past literature has suggested that using technology such as AR may present challenges to privacy and the security of student information (e.g., Miller & Dousay, 2015). For example, if an application collects user data, such as information about eye tracking, instructors will need to ensure that they are taking appropriate responsibility as data stewards. Similar to how instructors who use social media in teaching need to be aware of student privacy on the platforms they are using, instructors using AR may need to take precautions to ensure that student data isn't misused or stored incorrectly. This can be an added time and technology investment for instructors and institutions if they are new to AR implementation.

Augmented Reality Stretches Technical Thresholds

Because AR is a technology that can be used on both the instructor and student end, even pedagogically effective uses of AR require certain technical skills. As discussed previously, instructors can be trained in the skills needed to lead the use of AR for their particular needs. However, instructors may find it difficult to manage the varying levels of technical skill in their classrooms. In the past, some academics have suggested that today's students are "digital natives" and that they will pick up new technologies easily (Prensky, 2001, p. 1). However, research on digital natives, or individuals who were born after 1984 and grew up using digital technologies, has suggested that although these individuals do frequently use digital technologies, their knowledge and ability to fully utilize technology for learning can be limited (e.g., Kirschner & De Bruyckere, 2017). Therefore, it is important for instructors to avoid making assumptions about the ability of their students to use and learn the technology. Instructors may find it challenging to anticipate how much effort it will take each of their students to learn and fully utilize AR in the classroom.

Implementing Augmented Reality Can Seem Risky

Teaching a new course or trying a new teaching method can be an iterative process, where techniques are evaluated and refined each term. If AR has not previously been implemented, it may take some trial and error for institutions and instructors to learn how to best use it. This is one drawback to implementing AR in the classroom, because it may be perceived as risky, particularly among instructors who have already established a "tried and true" way of teaching concepts. Additionally, as instructors experiment to find the best ways to utilize AR in the classroom, students may not learn as much as they would under a more established method of teaching. Therefore, instructors may feel that developing AR in their classrooms jeopardizes student outcomes, instructor evaluations, and student goals.

Augmented Reality Can Pose Cognitive Challenges

Recall the example we offered earlier of the instructor using smart glasses to receive student names and information during lecture. Although it demonstrates the benefits of incorporating AR into the higher-education classroom, it also highlights one of the challenges: managing multiple tasks such as lecturing, operating the technology, reading, and answering student questions. Although some believe that when individuals multitask, they are carrying out multiple operations simultaneously, research in this area suggests that the appearance of multitasking usually involves switching back and forth between tasks instead (Kirschner & De Bruyckere, 2017). Thus, instructors who are navigating using AR may have to switch back and forth between technology use and other processing tasks such as leading discussions and synthesizing content. Even if someone has plenty of experience using AR, this process can be draining, and professionals who intend to multitask can show less productive learning and greater numbers of errors (e.g., Kirschner & De Bruyckere). Therefore, instructors may find that AR applications inhibit their ability to teach effectively if the AR app was poorly designed to support them.

Although using the technology in general may contribute to cognitive load, research on multitasking suggests that individuals can effectively multitask if all but one of the behaviors is automated (Sweller, Ayres, & Kalyuga, 2011). This suggests that instructors who choose to implement AR in the classroom could benefit from using the technology often enough to become fully acclimated to it. If their use of the application can become an automatic process, instructors may feel less drained as they teach using the technology.

In some types of AR applications, instructors may be the primary individual operating the technology. However, others may require students to be more involved in using and manipulating the AR. In the past, the conversation surrounding digital natives has suggested that today's students would show an increased ability to multitask in addition to technology propensity (e.g., Prensky, 2001). However, research has challenged these claims and suggested that current students do not show an increased ability to perform multiple tasks at once (Kirschner & De Bruyckere, 2017). This suggests that handling AR, particularly when first learning how to operate the technology, while performing other cognitive tasks may be challenging for students. Therefore, it is not only instructors who may feel drained when adding AR to the classroom, but students as well. Yet students can also benefit from using the AR technology often enough for the behavior to become automatic (Sweller et al., 2011), because it will allow students to direct more cognitive resources toward the content taught in the application.

However, it is important to note that AR technology has the potential to perform certain cognitive tasks *for* the individual, such as in the example cited earlier, where the application assisted the instructor in recalling students' names. This could reduce the cognitive load inherent in certain tasks that individuals might try to perform without the technology. Similarly, AR technology could also reduce unnecessary data in a task, which could also reduce cognitive load. For example, an AR application may be able to blur the background behind an object that a student is examining, which could eliminate unnecessary input and help the student view the content more clearly. This suggests that although using certain AR applications may add to cognitive load, the same technology could reduce it as well. The concern about increased cognitive load may become less pronounced as AR applications continue to improve and become increasingly user-friendly.

Getting Started with Augmented Reality in the Higher-Education Classroom

A major benefit of using technology such as AR is that it can immerse students in an interactive experience that requires them to push beyond passive learning. If the information in our paper has intrigued you and you are interested in dipping your toe in the AR waters, here are some recommendations for getting started with current AR technologies and tools.

Step 1: Know Your Learning Goal

Just as you would when incorporating any other new assignment or technology tool into your classroom, you should identify the learning goals and objectives that you wish to accomplish by implementing AR. For example, is there a particular piece of course content that you want students to understand better? Will you be using AR to test a particular disciplinary skill or ability? Will you restrict the AR implementation to a specific assignment, or will you include it throughout the course in a more general way? Understanding definitively *why* you are incorporating this new technology will help you ensure that the rationale is clear to both you and your students.

Step 2: Experiment with Different AR Tools

Augmented-reality tools come in many shapes and sizes, so you should experiment to see which tools will best fit your learning goal and be the easiest for your students to use. You may find that certain smart phone apps, for example, are easier to use than others or are less expensive than other tools. Experimenting with certain hardware (e.g., Google Glass) can also show you the range of possibilities offered by AR, even if you are not ready to invest in more complicated technologies. On the other hand, you may decide through experimentation that your ideas for incorporating AR in the abstract may be too difficult to implement, given the reality of your classroom. Experimenting with the different ways that you might imagine incorporating AR into your teaching will help you decide whether you want to invest the time to actually do it.

As you look for ways to experiment with AR, you should also explore the support structures within your institution. For example, if you have instructional designers or multimedia specialists on your campus, they may have AR hardware and software recommendations, as well as samples of different pedagogical activities that you can view or experience. There are also many smart-phone applications available through Apple's App Store and the Google Play Store, and some offer free trials, allowing you to test different technologies economically. Online reviews by other higher-education instructors who are engaging in AR can also point you toward tools or technologies to try. Even after you incorporate AR into your teaching, it may be beneficial to continue to try new devices as they are released, because the hardware is evolving quickly. New hardware may leverage a more ideal combination of strengths, which may make using AR in the classroom easier than before.

Step 3: Decide the Scale or Amount of AR to Implement

Based on your experimentation, you may have a better sense of the kinds of tools and technologies that you want to implement into your classroom. Even if you are especially tech savvy, you should also consider the level of technology implementation that your students will be comfortable with. This question of scale or amount of implementation can also be influenced by the learning goal that you have identified for the AR integration, as well as the discipline-specific AR tools that may already be available for you to use out of the box. Additionally, your budget for implementing AR in your classroom might determine whether you can utilize hardware such as Google Glass, for example. These tools are becoming more affordable all the time but still require monetary investment if not readily available on your campus for loan.

Step 4: Choose Your AR Tools

Once you have a sense of the kinds of AR that would best fit your learning goals and your student population, you will need to choose your AR tools. First, identify the primary audience for the AR implementation. If you want to experiment with AR as an instructor, that is different than asking all your students to partake in AR experiences. For example, you may want to test smart glasses as you accept student questions during your lecture. In this case, students might use a software application to submit questions, but you as the instructor would experience the more direct AR engagement.

For instructor engagement in AR, consider the following regarding hardware and software choices.

Hardware. Smart glasses are a popular choice for instructor-based AR engagement. This category of hardware has several different options to choose from and can be used for classroom activities such as soliciting student questions and feedback during lecture.

Software. Your goals for your AR implementation may require that students use particular applications or software to communicate with the hardware device you are using.

For student engagement in AR, consider the following regarding hardware and software choices.

Hardware. For students to engage with AR, they will most likely need a smart phone or tablet to access the AR application for your course. Many AR programs are designed to be used with hand-held devices, so this is something to consider when integrating AR into any course environment.

Software. Depending on the AR tools you choose to integrate into your course, students will potentially need to download an application to their device in order to utilize the AR technology. Many of these applications are free for educational purposes, but you should consider whether AR implementation will impose any additional financial burden on your students. Additionally, you may need to alert your students to other practical concerns, such as the app draining their smart-phone batteries.

Many factors impact the success of AR implementation, so as you experiment with different tools and technologies and test the tools that you plan to use, we recommend that you have a backup plan, in case the technology does not work the way that you expect. This is particularly useful if you are hoping to integrate AR into your classroom for a larger assignment. If you are just beginning to use AR in your classroom, more discrete and controlled implementations with students may be prudent, so that you can quickly identify areas that need frequent troubleshooting or that present challenges to students who may not be familiar with the technology.

Step 5: Create a Tutorial for Students

Whatever level of AR that you choose to implement in your classroom, you will need to ensure that students know *why* it is there as well as *how* to engage with it. Creating a tutorial or demonstration for students that shows them how to use the technology will help prevent a negative user experience from compromising their learning. Depending on the modality of your course (face-to-face, online, etc.), this tutorial or demonstration could be delivered live or be recorded in advance and posted online. Even if a class is taking place fully face-to-face, online resources for students to access on their own time regarding AR can be helpful if they are using the technology for homework or when you are otherwise not present to assist them with questions or troubleshooting.

Step 6: Measure Success of Implementation

Knowing whether the implementation of AR in your classroom has been effective will help you determine whether it has been a worthwhile investment or whether you should continue to use it in the future. Treating your AR implementation as a pilot, and asking for frequent student feedback, will help you learn more about students' engagement with this new technology and whether they believe that it had an impact on their learning. For example, you could use an instrument such as the Intrinsic Motivation Inventory (e.g., McAuley, Duncan, & Tammen, 1989) to measure students' interest and enjoyment, as well as their perceived competence, effort, and the usefulness of the AR over time. Additionally, as your teaching methods and technology evolve, you may find it useful to continue to track efficacy and embrace the idea of ongoing adjustments to the technology and your teaching methods. You might also consider designing a more formal Scholarship of Teaching and Learning (SoTL) research project for the AR implementation. For example, a more intentionally designed SoTL project might offer the opportunity to compare course outcomes in a control environment without AR integration to those in an intervention environment that included the new technology.

Conclusion

In addition to helping students master subject matter, the experience of using AR technology may benefit institutional learning outcomes. Many higher-education institutions aim to prepare students to continue to learn and excel after graduation through information and technological literacy (Cydis, 2015). Using AR can help students develop skills such as troubleshooting and tinkering, as they navigate new technologies. Implementing AR will pose challenges, but it may be worth the investment if the technology facilitates increased mastery of course content and technological literacy that students will need after graduation.

Although some may be hesitant to implement AR in the higher-education classroom, the technology and the applications that support it are developing at a rapid rate. Although little evidence suggests that younger students exhibit a greater ability to learn technology, students who experience AR in their early educational years may become disillusioned if higher education does not follow suit. As discussed earlier, AR as a pedagogical tool could significantly change how students learn. Just as many other technologies that we interact with in our day-to-day lives have found their way into the higher-education environment, we should also expect to see AR appear in our classrooms in the coming years. Additional research will be needed to explore the relationship between AR and more specific student learning outcomes.

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