Digital Dinosaurs 14

Bringing Dinosaurs Back to Life with VR/AR in the College Classroom

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Course title	*Digital Dinosaurs*, BSC4454C/6932
Description	This course provides a comprehensive exploration, including some hands-on training, of the cutting-edge digital tools used in paleontology. While the subject matter focuses on dinosaurs, the techniques are applicable to a variety of disciplines. By attending lectures and labs, students gain both theoretical and practical knowledge across a variety of topics, such as surface and volume scanning, 3D reconstruction and analysis, visualization and animation, and dissemination of scientific works. Real-world exams evaluate the students' synthesis of lecture concepts and lab skills through deliverables that represent the entire scientific pipeline in professional academia: idea/hypothesis generation, research, and proposal writing (Midterm), followed by data generation/analysis, publication, and presentation (Final Project).

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Student learning outcomes	Students will demonstrate the ability to: • apply a broad array of digital technologies, such as 3D scanning, reconstruction, visualization, and animation • value the application of said techniques to paleontology and other natural sciences • write a four-page National Science Foundation pre-proposal • create their own digital and 3D-printed creatures (either real or imaginary) • optionally: submit work from these exams to student grant opportunities [links are provided in the syllabus]
Format	In-person lectures on the history, theory, and application of digital approaches to paleontology, including virtual and augmented reality (VR/AR). Nine directed labs on various hardware devices and software programs, followed by six open labs to facilitate creation of Final Projects.
Enrollment	24 students: 22 undergraduate and two graduate. Course is offered every spring semester.
Institutional context	*Digital Dinosaurs* is offered by the Department of Integrative Biology in the College of Arts & Sciences. The University of South Florida (USF) is a public R1 doctoral university and Association of American Universities member serving more than 50,000 students in the Tampa Bay area, Florida. USF is a minority-serving institution, with underrepresented students receiving 43% of all degrees awarded and comprising 51% of first time in college enrollment (USF 2022).
Overview of VR/AR usage	Through a series of integrated labs, this paleontology-themed technology course provides the unique opportunity for biology students to not just view but to also create VR/AR content. Students learn the digital techniques to create 3D assets and deploy them in VR, and then experience the content they created within the virtual environment. The motivations for using VR/AR in this pedagogical setting include student engagement as well as skills training to become more competitive in applying for jobs and graduate degree programs. Ultimately, bringing dinosaurs "back to life" with such next-generation visualization technologies enables the "gateway science" of paleontology to help further inspire the next generation of students in STEAM fields.

Virtual reality (VR) and augmented reality (AR) are rapidly developing technological tools that have increasingly been adapted for pedagogical utility in higher education, allowing students to easily visualize and interact with digital environments and objects that are not otherwise accessible in the classroom. *Digital Dinosaurs* was designed to be a paleontology-themed technology course that teaches biology students how to generate 3D data for purposes such as VR and AR deployment. Through various labs, students create their own digital scenes and use head-mounted displays (HMD) to experience them in VR. Although VR/AR are promising platforms for enhancing learning outcomes and enabling access to fossil and other geological datasets, there are multiple challenges and ethical concerns that must be overcome and addressed. Access to such technology is relatively rare, with respect to both availability of advanced hardware as well as ample knowledge of the software, and inappropriate use of the technology can hinder learning. Additionally, acquisition of appropriate digital content for teaching in a VR/AR setting may be difficult to obtain, as open-source and/or educational material for a particular topic may not be readily available. In this chapter, we discuss these ethical considerations as well as relevant content from the *Digital Dinosaurs* lectures and labs. We also synthesize perspectives from the course creator and professor (R.M.C.), graduate teaching assistant (A.M.K.), students (E.S., class survey), and VR/AR developer (H.K.) to provide inclusive insights into how we bridge the gap between the knowledge and the use of these immersive technologies in higher education.

Curriculum

Lectures

Each PowerPoint lecture begins by highlighting a "Dinosaur of the Week" and covers a specific theme, complemented by readings sourced from exclusively open-access online materials (e.g., Mori et al., 2012, Farke, 2013). The "Immersion" and "Dissemination" lectures during the tenth and twelfth weeks of the semester are the most relevant to VR/AR concepts and ethical concerns. The former lecture introduces the predecessors of VR and haptic devices, from the Sensorama (1962) and Sensorium (1984) to the Power Glove (1989), as well as VR depictions in movies such as *The Lawnmower Man* (1992) and *The Matrix* (1999). We present concepts of the technology adoption lifecycle and "crossing the chasm" (Moore, 2014), followed by class discussion on the barriers to VR/AR adoption (e.g., cost, low fidelity, cybersickness, perceived utility to consumers). We follow this with a timeline and introduction to VR devices and techniques, along with presentations of systems such as cave automatic virtual environments (C.A.V.E.) for immersive scientific visualizations. The concept of the "uncanny valley" (Mori et al., 2012)—the unsettling feeling people get from seeing artificial human-like figures such as humanoid robots—is discussed from an aesthetic and evolutionary perspective. After introducing the "virtuality continuum" (Milgram & Kishino, 1994) of mixed realities, we discuss AR technologies within the contexts of popular usage (e.g., Pokémon GO, Snapchat filters, Mexico's AR currency) and early "augmented paleontology" case studies such as a museum display of an AR *Deinonychus antirrhopus* skull (Bimber et al., 2002, 2003). Subsequent topics include various AR devices and the future of AR, followed by the development of VR/AR content using texture and normal mapping as well as game engines such as Unity Technologies' Unity. This lecture class concludes with a conversation on haptics and the computer/brain interface.

The relevant portion of the other lecture is framed by linking the dissemination of technologies (i.e., technology adoption lifecycle) to the dissemination of information and analog dinosaurs (fossils). The latter is exemplified using a case study of the famous *Tyrannosaurus rex* specimen known as "Sue," as (mis)represented in the controversial film *Dinosaur 13*, and the subsequent response by the Society of Vertebrate Paleontology (SVP). This leads into a class discussion that incorporates the SVP Ethics Code (SVP, n.d.), along with the topics of fossil collection, sale, and context—e.g., whether scientifically important or on public lands. Also discussed is the necessity of repositories such as museums for curating specimens that are kept in the public trust for display and study.

Labs

The nine directed labs each follow their respective week's lecture theme. Labs 1, 4, and 5 include photogrammetry of a replica *Velociraptor mongoliensis* skull, model modification and preparation for 3D printing, and geometric morphometric landmarking and analysis. The remaining directed labs follow a sequential pipeline, starting with a scanning lab involving a Faro Design ScanArm 8-axis laser scanner demonstration with a *Deinonychus* skull, along with training opportunities—both an in-house 27-minute video and hands-on experience—and then a separate lab in which students use 3D Systems' Geomagic Wrap software to process the *Deinonychus* skull scan (i.e., aligning, cleaning point clouds, meshing, and post-processing). Using Autodesk's Maya software, the Maya I and II labs focus on modeling and animation, respectively: creating a virtual museum exhibit of the *Deinonychus* skull on a pedestal in front of Rudolph Zallinger's 1947 mural *Age of Reptiles* from the Yale Peabody Museum of Natural History, and then adding and animating a rigged set of *Deinonychus* forelimbs (Gishlick & Carney, 2003). In the Unity lab, the students turn their Maya I scene into a VR experience (Figure 14.1: top), and then view this and other content in the VR/AR lab. The six open labs that follow are focused on the students utilizing all the skills that they have learned to image, process/post-process, and ultimately 3D print their scientific or artistic models as their Final Project, which they then present to the class in a conference-style symposium. A selection of these 3D models created by the students is available at www.sketchfab.com/digitaldinosaurs, where they can also be viewed in VR (and in AR via the Sketchfab app).

During the past two years, we conducted our typical 75-minute VR/AR lab, and we also provided an opportunity for interested students to spend an additional two hours to further engage with the technologies and participate in group discussions about their perspectives on VR/AR in the classroom. In 2023, students were split into two groups, with one using only VR devices and the other using only AR devices. Halfway through the lab, students were instructed to begin a Google Forms survey and fill out the section related to the technologies they had used. Once the appropriate portions of the survey were filled, the groups switched device types and repeated the process, returning to their online surveys afterwards to fill out the missing portion along with some additional questions relating to comparisons between AR and VR experiences. Completing the survey marked the end of the normal lab time, and from here any students interested in revisiting devices or participating in verbal discussion were allowed to do so during the additional two hours provided directly afterward. In 2022, the survey had been given only to those six students who participated in the extended lab time, which was held on a different day; the survey and how it was administered was otherwise identical. In total, the survey was completed by 25 students (24 undergraduate, 1 graduate), with 11 of those students opting for the additional time. Students' responses form the basis of several sections that follow, and parenthetical values reported in Table 14.1 and the text below are based on a 7-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Slightly Disagree, 4 = Neither Agree nor Disagree [Neutral], 5 = Slightly Agree, 6 = Agree, 7 = Strongly Agree), with values representing the average score from each response.

Table 14.1 Averages of student survey responses regarding VR/AR technologies

HESITANCY (I was hesitant to use VR/AR devices due to:)	**VR**	**AR**
Unfamiliarity with the technologies	3.2	2.9
Fear of not being able to see my surroundings	3.0	n/a
Fear of sickness or dizziness	2.2	1.9
COVID-19	2.2	1.9
UTILITY		
Would want VR/AR to be used for educational purposes	5.8	6.0
Would be useful in my future career	5.8	5.6
Would make me more productive in my other classes	5.5	5.3
Would be too distracting as a learning tool	3.5	3.0
CREATION		
I valued viewing my scene within the VR environment over viewing my scene on a computer screen	5.7	n/a
I enjoyed creating content to view in VR	5.6	n/a
Creating and viewing my own scene makes me want to create more content in VR in the future	5.6	n/a
I now have the basic knowledge necessary to create content for VR	5.5	n/a
Creating content for VR was simple and easy to understand	4.9	n/a

(1 = Strongly Disagree; 4 = Neutral; 7 = Strongly Agree; some prompts slightly modified for consistency).

Devices and Content

The VR devices used consisted of the HTC Vive, Google Cardboard, as well as the Meta (formerly Oculus) Quest 2 and Go. Presented on one of the two Vive devices was the museum scene created by the students earlier in the semester using Unity. The scene can be slowly rotated when prompted by a controller button. The second Vive hosted a virtual geology field trip to Elk Garden Ridge located at Mount Rogers (VA), which was a collaborative project made by Megan Cook and Dr. Mel Rodgers with help from USF's Advanced Visualization Center (Cook, 2021). In this simulation, students could walk around and use a hammer to mine rocks and learn more information about the different rock types present at the location. Google Cardboard was used to display the app "Human Anatomy 4D-Mixed Reality" by Irusu Technologies using an iPhone XR, with which students were able to interact with different human organ systems. The Quest 2 experience was an Egmont Key State Park (FL) virtual tour created by a team led by Dr. Laura Harrison (USF), and the Go experiences included the Jurassic World *Apatosaurus* and *Blue* (Felix and Paul Studios).

The AR devices consisted of the Microsoft HoloLens 2, HoloLens 1, and an Apple iPad (5th generation) running iOS 13.3. Presented on the HoloLens 2 was the HoloHuman app by GigXR, in which students were able to view, walk around, and interact with different human organ systems. The HoloLens 1 presented a 3D model of our *Archaeopteryx* skeleton (Figure 14.1: bottom right), which students could walk around, scale, and rotate; they could also watch a brief animation of the model being assembled. The iPad utilized our custom app ARchaeopteryx, through which 3D animated scenes depicting the *Archaeopteryx* model and other content were projected onto a flat surface using the device's camera (Cieri et al., 2021: Figure 5cd, Supporting Information Video S1).

This interactive "ARchaeopteryx holographica" model was based on our 3D reconstruction of *Archaeopteryx lithographica* (Thermopolis specimen, WDC-CSG-100), generated outside the scope of this course. The skeletal anatomy was created using customized high-resolution X-ray scanning, followed by segmentation using Thermo Fisher Scientific Inc.'s Avizo software (Carney, 2016). Photorealistic textures of the bones and limestone slab were created using tens of thousands of macro photographs coupled with photogrammetric reconstruction using Capturing Reality's RealityCapture software. This effort was led by the course's teaching assistant and former undergraduate student, A.M.K. (Kirk et al., 2018), which exemplifies how the technical skills acquired in this course can prepare students for graduate research. The wing feathers were hand modeled in Maya. Maya was also used for the skeletal assembly, rigging, and animation, with the shoulder motions derived from X-ray Reconstruction of Moving Morphology analyses of living birds and alligators, along with scientific motion transfer (Carney, 2016).

Assets were then optimized for VR/AR using Pixelogic's ZBrush (UV unwrapping) and Maya (mesh retopology, texture transfer, and atlas generation); normal maps were created with CrazyBump, xNormal, and Adobe Photoshop (NVIDIA normal map filter) (Cieri et al., 2021: Figure 5b). Using Unity, these assets were incorporated into multiple HoloLens and iOS AR apps through collaborations with USF developer H.K. and National Geographic. It is worth noting that we had developed and utilized an app prototype for HoloLens 1 in previous years, but that this was incompatible with subsequent operating system updates. As a simple solution to avoid (re)developing a custom stand-alone app, we exported the animated, non-textured skeletal model from Maya as an .fbx file, which could then be viewed using the device's native 3D Viewer Beta app (Figure 14.1: bottom right).

The processes of scanning, reconstructing, and animating this digital *Archaeopteryx* also served as an instructional through line across multiple lectures, and culminated in bringing this dinosaur "back to life"

Figure 14.1 **Top**. Screenshot of a student's VR museum scene in the Unity game engine interface. **Bottom left**. Photo of a student using the HoloLens AR headset. **Bottom right**. Mixed reality photo of our *Archaeopteryx* 3D model, as captured by the HoloLens.

in the lab. Ultimately, these immersive and interactive AR experiences allowed students to better understand the complex 3D anatomy and flight stroke, with students remarking that "It was most interesting to see the skeleton of *Archaeopteryx* come to life! The skeleton looks so realistic" and liking "The way each unit of the dino would come to life and show as a hologram-esque figure. Learning was so much more interesting especially with being able to visualize the wing flap."

Reflection on Ethics

As we have reflected on previously:

> It is intriguing to contemplate the cosmic journey of matter through its various natural and artificial transmutations. Billions-of-years-old "star stuff" makes up the genetically encoded building blocks of morphology in living organisms (*in vivo*), developing

> and evolving into 'endless forms most beautiful,' with some organic structures chemically transformed into fossils (*in situ*). By harnessing electromagnetic radiation such as X-rays, we can render such matter into the pixels and voxels of the digital world (*in silico*), including virtual reality (VR). These bits of data can then be returned to the analog world, through augmented reality (AR) (*in holo*) or 3D printing.
>
> (R.M.C. in Cieri et al., 2021)

Each of the anthropogenic steps in this grand process has its own ethical considerations—from extricating geological material from the earth and curating the physical form, to digitizing and curating the virtual form, and finally designing (Steele et al., 2020) and deploying educational VR/AR content in the local classroom or on the world stage. The following sections will provide a breakdown of each ethical consideration, with specific examples from our own experiences where applicable.

Geoethics

Geoethics is an emerging branch of ethics that relates to the interaction of humans with the Earth, and is relevant here with respect to activities such as the excavation and digital preservation of fossil specimens. Generally, geoethics "deals with the ethical, social and cultural implications of geoscience knowledge, research, practice, education and communication, and with the social role and responsibility of geoscientists in conducting their activities" (Di Capua & Peppoloni, 2019). Geoethics thus includes both abiotic and biotic considerations—such as destructive sampling (Butler, 2015) and the importance of community culture and provenance (i.e., material's origin; Nature Geoscience 2021). This interdisciplinary set of values "is shaped and informed by a strong awareness of the technical, environmental, economic, cultural and political limits existing in different socio-ecological contexts" (Peppoloni et al., 2019). Formal recommendations are guided by organizations such as the International Association for Promoting Geoethics (www.geoethics.org) and International Association for Geoethics (www.icog.es/iageth), and include engaging stakeholders, establishing best practices, minimizing environmental damage, and incorporating such ethics into university curricula and fieldwork (Di Capua et al., 2022). With respect to vertebrate paleontology in particular, the SVP Ethics Code includes mandatory and aspirational standards regarding fossil collection, collections management, working with specimens, paleontological research, and research dissemination and public engagement (SVP, n.d.).

Furthermore, ethical concerns surround even publicly held fossils in museums, as the majority of a collection is typically not out on display or accessible to the public, but is instead carefully placed in storage. Access to these specimens may be limited, as many are fragile and risk deterioration if handled, and visiting museums may be difficult because of constraints including distance, pricing, time, and personal disability. Digitizing specimens lowers the risk of damaging fossils through other replication methods such as casting, provides an easy way to preserve a copy of the specimen, and reduces the need for the items to be handled frequently (Farke, 2013). Having digital versions creates a more accessible and globally scalable means to view and study specimens, which is especially useful for rare fossils. The use of VR/AR enables such digital specimens to be more immersively available to those who are unable to physically view them, and promotes sustainability in the preservation and dissemination of scientifically important material.

During both lecture and lab, the *Digital Dinosaurs* students are asked to consider the differences between what can be done in person versus what can be accomplished using VR/AR. After having the chance to view their Unity scenes in VR, students stated that visiting their own created museum scene was "better than going to a museum," echoing the fact that many museum specimens are not out on public display, unable to be viewed closely, are fragile and/or rare, and in another country entirely. The ability of VR/AR to provide access to such specimens can also be applied to other settings and use cases, particularly as virtual field trips that would otherwise be too difficult or dangerous to travel to in person. The students all agreed that it is also challenging to arrange field trips with college students due to schedule conflicts, so quick trips in a VR setting could be a better solution.

Intellectual Property

Ethical considerations also abound during and after the digitization process—especially concerning intellectual property. For example, if a museum requests the transfer of copyright for any photos taken of their fossils, what about derivative products such as photogrammetric 3D models? Another consideration is the potential misuse, commercialization, or other unknown consequences stemming from the digitization of rare and/or monetizable materials. For example, Epic Games—which developed the online game Fortnite and game engine Unreal—acquired the photogrammetry software RealityCapture and the online 3D modeling platform Sketchfab in 2021. Both of these platforms are used in the *Digital Dinosaurs* course, potentially creating some ethical issues in the future. If, for example, Epic Games wants to capitalize on the popularity of dinosaurs in the entertainment industry, a 3D content creator in the world of education and research may face an ethical dilemma—should they prioritize financial gain and accept that there may be inaccurate derivatives that jeopardize the scientific integrity of the model?

It should be noted, however, that the current versions of these two platforms' user agreements explicitly state that the user retains ownership of the content they produce, import, and/or upload (RealityCapture, n.d.; Sketchfab, 2023). Additionally, multiple types of licenses exist that allow the creator to decide how their model is to be used, if derivatives are allowed to be created, or if the model can be commercialized (Flynn, 2019). The Sketchfab agreement also tackles the burgeoning topic of generative artificial intelligence (AI), the recent advent of which (e.g., ChatGPT) presents new ethical challenges with respect to intellectual property. In the agreement, users are required to identify redistributable content created with generative AI using the tag, "CreatedWithAI" (Sketchfab, 2023). As a protection for non-AI content, the agreement states:

> We care about protecting creators and providing the tools to protect their creations. You are able to tag your projects containing your User Content with "NoAI" if you would like such content to be prohibited from use with AI. … Sketchfab agrees, whether or not your User Content is NoAI Content, that it will not use your User Content or license your User Content to third parties for use (i) in datasets utilized by Generative AI Programs; (ii) in the development of Generative AI Programs; or (iii) as inputs to Generative AI Programs.
>
> (Sketchfab, 2023)

What might the future ramifications be for scientific specimens that are created and/or hosted by such platforms? And does an environment of uncertainty, change, and generative possibilities stifle or accelerate intellectual and artistic pursuits? These questions have no definitive answers currently, and perspectives are evolving along with the technologies themselves.

Physical

It is also important to consider from an ethics standpoint what students can physically tolerate in these digital devices, as one of the biggest complaints about VR especially is discomfort when using head-mounted displays (HMDs). This discomfort has been noted to result from the size, fit, and weight of the device, as well as "simulation sickness" aka "cybersickness"—an ill feeling with symptoms that include nausea, dizziness, headache, and eye strain (Pellas et al., 2021; Southgate et al., 2019; Young et al., 2020). These symptoms and physiological changes are similar to those of classic motion sickness (Gavgani et al., 2018), and can occur from being unable to view one's surroundings, and/or when the virtual camera moves forward in the scene but one's body does not. AR may help in alleviating much of the discomfort of wearing a HMD, by virtue of retaining visibility of one's physical environment (into which the digital content is projected). Acclimating students to such a mixed reality environment may also serve as a stepping stone prior to immersing them into a fully virtual environment. While AR may not always fit the goals meant for VR devices, one related feature that may prove useful is the recent integration of real-time passthrough views from front-facing cameras on certain VR devices, thus enabling an AR experience. Regardless of the device being used, special care should be taken when monitoring students interacting with devices to ensure that no injury results from bumping into objects. Many VR applications don't require physically standing or walking around, and in such cases, sitting is an alternative that usually helps in not only diminishing the fear and likelihood of collisions but also lessens the focus on balancing when wearing a heavy device.

In our labs, the students sit stationary when using most of the VR devices. However, if standing or moving (e.g., using the Vive), students were monitored by a teaching assistant and given plenty of open space—well beyond the arm's full reach in case the controller is extended. We also put tape on the floor so that the student has an idea of the boundary beforehand. Regardless, a couple of students still stated that "I did not like that I could not see my surroundings in VR as I was moving around, it was slightly disorienting for me" and that their virtual dinosaur skull "was really low to the ground, and I was worried about running into something." Students expressed that being able to view their surroundings in AR improved the feeling of uneasiness and sickness while using the device. For the binary survey question, "Do you feel sick or dizzy," approximately one-third of the students answered

"Yes" for each of the four VR devices, yet nearly all of the students answered "No" for each of the three AR devices. Overall, students disagreed with the statements that they were hesitant to use VR and AR devices due to fear of sickness or dizziness (2.2, 1.9) or fear of not being able to see their surroundings in VR (3.0).

A notable complication occurred while we were setting up the Vive. One of the sensors used to track the position of the user fell and hit the ground, which we believe resulted in visual glitches within the headset. Thankfully the issue was caught relatively quickly after two students stated their difficulties getting the program to perform properly, after which we were able to promptly switch the program over to a different Vive headset with new sensors. After fixing this issue there seemed to be no more complaints about the program acting odd. However, it should be noted that a couple of students may have reported increased feelings of sickness, discomfort, and difficulties learning device controls when using the Vive in our survey due to this issue.

Psychological

"Information overload," or the overuse of multiple stimuli at once, is a separate factor that can lead to discomfort in such devices (Christopoulos et al., 2021; Slater et al., 2020). Information overload can lead to confusion and distraction, which makes the use of such technology counterproductive as a learning tool (Pellas et al., 2021). Having too many pop-ups, sounds, visual stimuli, and too much text to read all at once can be very disorienting, especially in a VR environment. With such relatively new technologies being used in classrooms, it may be impossible to know beforehand (or even afterward) what effects these types of devices have on students with psychological impairments.

While our students didn't describe any of the content itself as being overwhelming, one did remark on the content creation being overwhelming:

> Learning "How to" make a scene was great. The whole process seems a bit overwhelming, especially because the software (Maya) has a lot of buttons and options. But learning some basic tools made approaching the scene a lot less intimidating.

Conversely, some beneficial psychological effects shone through in some comments. One student responded to the question of what they liked most about viewing their VR scene with "I could see the details of the skull and how the shadows moved, that made me really happy." For the ARchaeopteryx iPad experience, another student noted:

> I liked that it was interactive and very easy to begin. The narration and animation enhanced the experience of learning of the fossil. But the AR of it is the best part. Made it more tangible, like the feeling and awe of viewing fossils in museums.

Previous classroom studies have also found that VR/AR can help increase material accessibility as well as provide previously unavailable opportunities to students through virtual field trips, simulated hazardous scenarios, and unreachable scenes (Cieri et al., 2021, Cook, 2021, Pellas et al., 2021, Ramirez, 2022). Additionally, deploying a variety of scenes in classrooms has been shown to boost student engagement and motivation in learning the material (Pellas et al., 2021; Ramirez, 2022).

Hygiene

Hygienic concerns and risks over sharing devices can be mitigated by using disposable sanitation covers made for HMDs, or face-safe disinfectant wipes on the surfaces that come into contact with skin. However, it should be noted that a special lens cleaner and microfiber cloth should be used for cleaning the glass display and similar components, as a disinfectant wipe could scratch or otherwise damage the display. Ultraviolet germicidal irradiation is another method of disinfection, albeit more expensive. During the COVID-19 pandemic in spring 2020, we canceled the VR/AR lab and transitioned to remote instruction, and in spring 2021 one student opted out of sharing devices during the VR/AR lab despite us cleaning the contact surfaces with alcohol wipes between students. In spring 2022, after vaccines had been widely available for nearly a year, our observations and survey results demonstrated that students were generally not hesitant to use VR or AR devices due to COVID-19 (2.2, 1.9).

Privacy

Protecting a student's private information is crucial when implementing any new technology into a classroom. The Family Educational Rights and Privacy Act, or FERPA, is an Act of Congress that specifically protects private student information from being shared to unapproved parties and should be incorporated into the use of new teaching technology (U.S. Department of Education, 2021). The biggest factor to consider when using VR/AR devices for educational purposes is who can access that student's information. In many cases, student information and work can be stored directly on devices, but protections should be considered beforehand regarding who can access that information. Furthermore, brands such as Meta require a personal account to use their devices and are capable of collecting data relating to device use (Meta, 2022). Using private accounts on these devices reveals personally identifiable information about students such as their full name, so again it is important to consider ways to protect students from any risks that may breach their privacy (Meta, 2022). Solutions include using devices that don't require an account, or the use of an enterprise account, though these usually come with their own limitations on the material one wishes to deploy. Educators should also ensure that students aren't accessing untrustworthy sources that could compromise privacy. Such monitoring could include device logs or plugins that track activity, with the caveat that this may itself pose a privacy risk. For our classroom use, we logged into Meta devices with a single lab account, as opposed to requiring students to create or use their own accounts.

Accessibility

Relatedly, how can the effects of unseen disabilities such as PTSD or epilepsy be assessed without violating students' privacy? With this in mind, instructors should provide such disclaimers and the ability to opt-out of participating, perhaps with alternative devices or material for students who may not feel comfortable using certain devices. Thus, although VR/AR may be a helpful aid to some students with disabilities, such devices can come with their own accessibility issues. As stated above, HMDs are often noted as uncomfortable to wear, and this can be especially true for students who wear glasses (Young et al., 2020). Due to the shape of the device, some students may be impeded and not get the same experience, which could also be the case for students with other disabilities. Additionally, recent evidence suggests that VR cybersickness is more likely to affect women than men (Kelly et al., 2023). With VR HMDs completely blocking the user's vision, it also makes interacting with people very difficult. Though multiple devices can be used at once, device wearers may find difficulty communicating with other classmates due to their immersion and impeded vision. The use of VR may not be best for group work or team-building activities and studies have reported that users find HMD experiences to be very isolating (Cook, 2021; Wolfartsberger, 2019).

Access to Technology

VR and AR technologies come in a wide variety of different forms, and all devices are not created equal. The type of device that an instructor wants to use in a classroom should be carefully considered before implementing. Higher-end devices such as the Quest Pro, Vive XR Elite, HoloLens, and Apple Vision Pro have very high performance with clear graphics, though their steeper price tag limits how many devices a class may have access to. More affordable options exist for adapting a smartphone into a VR headset, such as the low-cost Google Cardboard, which could allow for every smartphone-owning student in a large classroom to have their own device. However, the tradeoff is that the graphics are variable and lower resolution, which may hinder learning or contribute to greater instances of sickness (Pellas et al., 2021). When deciding on what device is right for a course, consideration into how much time students are given to complete material may help in quantifying how many devices are needed, since having fewer devices than students means that students will need to take turns. It is also crucial to make sure that a chosen device isn't making the content more difficult to learn, as issues such as motion sickness or difficulty reading the device screen can have adverse effects on students' engagement.

Through the class discussions, the *Digital Dinosaurs* students recognized that such improper delivery of content may inhibit instead of facilitate learning, and this sentiment was explored with respect to the cost-versus-quality tradeoff of different devices. The students still placed a high value on AR experiences other than that of the costly HoloLens 1 and 2, specifically stating that the iPad ARchaeopteryx app was a great experience with high-quality visuals and text clarity. Conversely, students stated that it was very difficult to read text and clearly see everything in the Google Cardboard. They seemed to agree that if given the choice to learn using such a device, they would rather view the material on a computer screen due to the better readability and resolution. Thus, while Google Cardboard is accessible from a cost perspective, its visual capabilities may be prohibitive to learning.

In addition to hardware costs, software costs may also be an issue as devices do not always come with relevant content. Instructors need to put thought into whether they plan on purchasing content or creating their own, the latter of which depends on their technological literacy and capabilities. We would also like to note that as of printing, RealityCapture, Maya, Unity, and SketchFab are free for students and educators to use. Geomagic software is commercial; however, there are alternative options for free and open-source mesh processing software such as MeshLab.

Technological Literacy

To access opportunities and especially learning experiences in the 21st century, an individual is required to understand technology. It is therefore vital that students be exposed to and acquire the knowledge needed to use and explore modern technology. "Technological literacy" refers to an individual's ability to manage, evaluate, and understand technology, while not being intimidated or infatuated by it (International Technology Education Association, 2000). A technological literate person uses technology as a tool to explore, enhance, and experience content in a practical way. With respect to aforementioned ethical concerns, students lacking technological literacy may encounter difficulties in engaging with VR content, potentially missing out on valuable educational insights. Students who are oblivious to the privacy and security implications of their data face a greater risk of unauthorized access, putting their personal information at risk.

The appropriate use of technology can also contribute to tech literacy, whereas an instructor deploying learning material in a VR/AR headset that functions the same as on a computer is an impractical use of the technology. When using AR/VR, there should be a reason that these devices are being used over existing devices such as a computer or smartphone, as introducing needless or unfamiliar technology may lead to more confusion with students who have never used said devices. If students are unable to use the devices properly, this could impede their learning, especially if they put more energy into figuring out how to use a device than they do engaging with the course material. Indeed, tech literacy is important for not just the instructor, but for the student as well—and may play a large role in whether or which VR and AR devices should be used in a classroom. When deploying new technologies in a classroom, students should have all the resources they need to understand how to use the devices, from consistent access to support and initial guidance for how to use new devices, so that the device itself does not hinder their ability to learn. Improper execution of the right technologies is more likely to lead to frustration than to a successful learning environment, and improper preparation before the use of such technology could likely lead to less confidence and more hesitancy to using the devices.

Our team made numerous efforts to support technological literacy of the students. During content creation, the lab materials and introductions provided guidance for using Maya and Unity, and working in such 3D digital environments may have served as a convenient primer for the 3D virtual world in which the students later experienced their creations. In lecture and again in lab, we first briefed the class on things like the HoloLens hand gestures (Figure 14.1: bottom left). This repeated priming better enabled the students to communicate and reinforce the guidelines among themselves as needed during the course of the activities. We also brought in extra teaching assistants during the execution of the VR/AR labs to make sure that everything ran smoothly. Based on recent student feedback, in the future we will also provide a short printout at each station with the device name and instructions, to supplement the verbal briefings.

Students specifically voiced that *Digital Dinosaurs* had prepared them for what to expect when using these devices, and slightly disagreed with the statement that they were hesitant to use VR or AR devices due to unfamiliarity with the technologies (3.2, 2.9). Furthermore, students expressed that having proper preparation for VR/AR should be necessary for other classes that plan on implementing these devices, in the form of a prerequisite course or a set lab day to get students familiarized with the devices being used. Students compared *Digital Dinosaurs* with other classes that use VR, and mentioned that one issue they see with VR/AR being implemented in a classroom setting is the technological literacy of the instructor teaching the course. Regarding another course taken previously, one of the students stated, "My professor can't even work Canvas [the USF web-based learning management system]. I can't imagine them teaching with VR devices."

Conclusions

Through the *Digital Dinosaurs* lectures and labs, students had the opportunity to not just learn about VR/AR technologies, but to create and view their own VR content, as well as experience other materials using a variety of VR and AR devices. The 25 students who participated in the survey revealed additional insights through group discussion, free response, and survey answers, which allowed us to gain a better understanding of students' general perceptions of VR/AR. Students identified possible issues with deploying these technologies in a pedagogical setting, with these main issues being the technological literacy of the instructor, the cost accessibility versus quality of devices, physical discomfort and accessibility of different devices, and the replacement of real experiences with VR experiences. Despite these challenges and the aforementioned ethical considerations surrounding VR/AR, students championed the benefits of introducing these technologies into the classroom.

During the labs, students were able to use a wide range of different technologies—each with its own advantages and disadvantages—to further inform their opinions on the ethical issues that may arise and what types of devices are best to use in a classroom. Though students felt more comfortable using AR devices, they naturally found VR to be a more immersive experience. Students also noted that (non-immersive) AR technology is more familiar and readily accessible than VR, as AR is already prevalent on smartphones and tablets while most VR requires access to a headset and computer. Despite differences between these two types of technologies, students ranked both AR and VR devices relatively closely and expressed that their use should be based on their intended experience of the user. Students were asked to rank each device they used from best (1) to worst (7), after which the scores were assigned a weighted score with the best getting 1 point per student and the worst getting 7 points per student. The devices were ranked as follows, with lower scores representing higher preference from students: HoloLens 2 (53), Quest 2 (73), Vive (75), HoloLens 1 (88), Go (94), iPad (137), and Cardboard (152).

Despite—or perhaps because of—the fact that VR and AR devices are relatively new additions to the pedagogical scene, the students seemed excited and eager to use these technologies. Average results from the Likert survey questions (1 = Strongly Disagree to 4 = Neutral to 7 = Strongly Agree) indicate that the students would want to use VR for learning in other courses (5.8), and most agreed that they would like to see AR used more broadly for educational purposes (6.0). Students felt that VR and AR would make them more productive in other courses (5.5, 5.3) and did not feel that these technologies would be too distracting in a classroom setting (3.5 vs 3.0). Specifically, when asked their opinion on what the best application for VR/AR technologies in a classroom setting would be, students listed experiences such as training on equipment before labs, conducting labs where the materials or tools being used are especially dangerous, or virtual field trips to distant places.

Though VR/AR devices are not used to deliver primary learning material in the course, *Digital Dinosaurs* provides a unique experience wherein students create their own content for deployment in VR. By gaining this perspective on content development, students stated that they were able to better appreciate what goes into creating and deploying content in VR. After having spent many weeks learning different software programs such as Geomagic, Maya, and Unity, students ultimately had the opportunity to see and interact with the results of their hard work in an immersive 3D environment. For the students, being able to experience the content they created in VR influenced their learning of content deployment in a positive and hands-on way, and they valued viewing their scene within the VR environment over viewing their scene on a computer screen (5.7). With respect to what students liked the most, the free responses included that it was rewarding to see "The fruits of my labor," echoed by another that "Being able to see our hard work of creating a 3D model and museum scene come to life and being able to walk around in our scene like it was a real room." Unanimously, students agreed that they enjoyed creating content to view in VR, and that this process was simple and easy to understand (5.6, 4.9). They felt that they now have the basic knowledge necessary to create content for VR, and that their experience creating and viewing their own scene makes them want to create more content in VR in the future (5.5, 5.6). We were interested to learn that the students also believed that VR and AR would be useful in their future careers (5.8, 5.6).

Thus, while students have some concerns about VR/AR, they also recognize the utility of these technologies in their courses and careers. Students' emergent feedback is valuable for improving the efficacy and ethical delivery of future years' curriculum. The complementary role of the teaching assistant is to advocate for the students and to provide a safe and beneficial learning experience. It is critical that teaching assistants are fully trained on the technologies and ethical expectations, so that they can ensure best practices of accessibility, hygiene, and privacy, as well as properly monitor students' physical and psychological well-being during activities. The professor is obligated to enable equitable access to the technologies, foster an inclusive environment for those of all ability levels, establish an overarching ethical framework to work within, and ensure compliance with geoethical standards and intellectual property rights (both content inputs and outputs). Intellectual property is also of concern to the VR/AR developer, for whom it is important to continually navigate the evolving technological landscape, including keeping software and hardware up to date, and collaborating on troubleshooting and solutions. Together, all parties play integrated and integral roles in the development of students' technological literacy for VR/AR. Ultimately, through these various perspectives, we hope that the results and recommendations from our case study herein provides instructors with a useful roadmap for the creation and deployment of immersive educational material for pedagogy and skills training in the college classroom and beyond.

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