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Work-in-Progress: Developing an Interactive, Immersive, 360-Degree Virtual Media for Enhancing Student Learning in Additive Manufacturing

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Abstract

Workforce development is the most critical factor to maintain a sustainable manufacturing industry in the US. Despite the current efforts being made, job openings in the manufacturing sector exceed applicants, primarily due to a skills gap, resulting in part from the introduction of new advanced technologies and automation. Such technologies may not be immediately included in the manufacturing curriculums in higher education, especially in engineering programs with limited resources and access to capital manufacturing equipment. Virtual Reality (VR) technology offers immersive, interactive, and engaging experiences; and 360-degree media based on real-world recordings can offer a grounded and accurate representation of the world. Through collaborating with manufacturing centers in academia and/or industry, customized 360-degree media on advanced manufacturing technologies can be filmed and then displayed remotely in a virtual environment via VR headsets. This would bridge the skills gap in today's manufacturing education by facilitating open access to these advanced technologies, obviating the need for duplicate capital equipment, and enabling university curricula to keep pace with the industry. In this paper, ongoing work regarding a VR production workflow is presented by applying 360-degree filming to reproduce the scenes of real-world additive manufacturing equipment and adding interactive information to the virtual environment. In this pilot study, 360-degree videos and images of a consumer-grade 3D printer were filmed in the laboratory. Then these 360-degree media were edited in a web browser-based online platform, for creating interactive VR storytelling through multiple 360-degree scenes featuring embedded interactive hotspots. This further enabled a cohesive and interactive VR tutorial for enhancing students' learning in 3D printer operation and additive manufacturing technology. Plans for VR content production and student assessment were also reviewed and discussed.

1. Introduction

The manufacturing industry has been one of the major drivers of sustained economic growth in the US [1, 2, 3]. Despite the current efforts in workforce development, the number of openings of jobs in the manufacturing sector exceeds applicants looking for work due to the skills gap (i.e., skills mismatch) [4]. Based on Deloitte's report, the primary reason for the skills gap is the introduction of new advanced technologies and automation to the manufacturing sector [5]. Such technologies may not be immediately included in the manufacturing curriculums in higher education, especially for the engineering programs that have limited sources to access capital manufacturing equipment. A secondary reason for the skills gap is the negative perception of the manufacturing industry by students and their social networks. This is due to the lack of exposure to opportunities in manufacturing technologies and/or potential employers in the industry. A study performed by the Manufacturing Institute [6] reported that 63% of students select their career pathways based on their interests and experience rather than resources like their parents (32%), other family members (10%), teachers (8%), and friends (5%). Therefore, investigating new instructional technologies to facilitate early exposure and enhance the students' learning experience in manufacturing is a vital need.

Virtual Reality (VR) technology has been proven to be effective in promoting engaged learning compared to traditional media such as textbooks or videos [7, 8, 9] by offering users immersive, interactive, and engaging experiences [10]. For example, the integration of VR into a discussion of moon exploration with 4th-grade students resulted in enhanced vividness and interactivity during the student learning procedure [11]. This allowed students to associate virtual experiences as direct experiences, which facilitates motived exploration of a subject matter compared to passive learning modalities. Crosier *et al*. [12] noted that VR provided students with a safe environment such that students can adopt trial and error learning strategies without negative implications. These findings make VR an ideal candidate for enhancing the student learning experience in engineering education [13].

In this paper, our work in developing a VR production workflow is presented by (1) filming 360-degree media of additive manufacturing equipment; (2) reproducing that real-world environment in VR; and (3) adding interactive information to the virtual environment. In this pilot study, a consumer-grade 3D printer was selected as the testbed to film 360-degree videos and images about the equipment operation. Then these 360-degree media were edited in VIAR360 [14], a web browser-based platform for creating interactive VR storytelling through multiple scenes featuring embedded interactive hotspots. To this end, multiple hotspots were created for adding text boxes, 2D images galleries, and questionnaires to the virtual environment, enabling a cohesive and interactive VR tutorial for enhancing student learning in 3D printer operation and additive manufacturing technology. Lastly, plans for VR content production and student assessment were reviewed and discussed.

2. Literature Review

2.1 Augmented and Virtual Realities

Augmented Reality (AR) refers to integrating an actual scene occurring in the real world with computer-generated digital content [15]. Such content, also known as the AR layer, could be sound, video, graphics, or animation depending on the education needs. A simple example is to visit a museum and participate in a self-guided audio accompaniment tour. Visitors tour the actual physical environment while a pre-recorded commentary on the exhibits is played. AR can offer a creative and innovative way for audiences to interact within an augmented environment [16]. In the field of education, Liarokapis *et al*. [17] developed an AR-based course on mechanical gears in mechanical engineering. Chen *et al*. [18] applied AR in engineering graphics to better illustrate the relationship between 3D geometry and 2D projection. The authors concluded that such an AR-based approach can help students in solving complex spatial problems. Turkan *et al*. [19] and Radkowski *et al*. [20] investigated a mobile AR device in a context of an engineering mechanics course. Such a device can visualize the behavior of civil or mechanical structures under external loading conditions. Furthermore, the authors studied the different instruction modes when introducing the AR device to the class and found some students preferred the exploration mode with little guidance on the AR features. Since AR is the superposition of digital information on the physical environment, interactivity among real and virtual objects in real-time is required [21].

In contrast to AR, VR can let users immerse themselves in a purely artificial and simulated environment [22], which is a transitional interface between classroom learning and real-world learning [23]. Based on the level of interaction between the audience and the virtual environment, Vergara *et al*. [24] classified VR applications into three categories: passive, exploratory, and interactive levels. Briefly, the passive level refers to a predefined virtual environment from which users can only see and/or hear the scenes [25]. More user interactions can be achieved at the exploratory level, where users can navigate around the virtual environment to decide what to view. Some of the VR applications at this level can include virtual tours of historic buildings [26] and museums [27]. Lastly, the interactive level equips the users with more flexibility to explore, control, and modify the virtual environment [31]. When applied to manufacturing training protocols, VR-based trained participants committed fewer errors and took less time to complete tasks compared to traditionally-trained workers. VR provides the quintessential *learn by doing* platform [28]. VR technology has reached the level where it can be applied across the educational landscape to enhance the student learning experience and engage students who do not respond to traditional teaching methods.

2.2 Virtual Content Production

The quality of VR content is critical for simulating the immersive feeling that makes VR an effective active learning tool. In general, the virtual content can be categorized as an entirely imaginary universe or a reproduction of the real world [29, 30]. Virtual content made as part of an imaginary universe can be found in many VR applications such as the gaming industry, engineering education [31, 32, 33], safety training [34, 35], engineering inspection [36], and the upcoming Industry 4.0 or "digital twin" trends [37, 38]. However, imaginary virtual content usually requires extensive efforts in modeling, rendering, and testing; and if the virtual content is not well established, the negative consequences cannot be underestimated. For example, several studies [39, 40, 41] reported that when learners found the virtual environments to be inauthentic, their learning experiences were negatively affected. Schofield [42] further pointed out a few critical issues in creating an imaginary universe including viewpoint selection, camera movement, the realism of the virtual environment, media mode, audio rendering, lighting condition, and display resolution. Although many of these issues now can be addressed by applying advanced graphic engines such as Unity [43] and Blender [44], producing imaginary virtual content would be costly in equipping graphics capabilities and labor-intensive for achieving a realistic immersive experience [45].

On the other hand, using real-world authentic videos and/or images for creating the virtual environment can overcome many issues noted above. Authentic content ensures that the virtual environment looks and feels grounded in an accurate representation of the real world. The accuracy of the virtual environment's measurements (dimensions, colors, textures, etc.) in instances where real-world environments are replicated is crucial as it provides the foundation for authenticity [42]. From the technical perspective, authentic virtual content can be directly captured through filming using an omnidirectional camera (i.e., 360-degree camera). Based on the recorded 360-degree media, editing work can be further performed to cut or combine 360-degree images or video footage from different scenes, add guidance information to the virtual environment, and create interactions (e.g., hotspots) in the scene. The edited virtual content then can be displayed through a VR headset to create an immersive experience for users.

With the rapid development of 360-degree cameras in recent years, virtual content made by reproductions of the real world can be found in a variety of VR applications. For example, Arents *et al*. [46] applied 360-degree camera recording to create a VR video in an internship curriculum for training medical students. The authors concluded that such an approach offers a potential alternative to preparing students for their first operating room experiences. Ardisara *et al*. [47] filmed 360-degree VR videos for chemical lab sections and argued that such a method can capture detailed lab activities with a panoramic field of view. Ferdig and Kosko [48] deployed a similar VR prototype using a 360-degree camera for students in an elementary school. Results showed increased attention from participants in the mathematics learning experiences. Napolitano *et al*. [26] deployed a 360-degree camera to collect field images of historic campus buildings at Princeton University, based on which a virtual tour was created. Argyriou *et al*. [49] adopted a similar workflow to establish a VR-based cultural heritage tour at the historical center of the City of Rethymno in Crete, Greece.

2.3 Virtual Reality in Manufacturing Education

Many efforts have been performed in VR-based manufacturing education. Hashemipour *et al*. [50] developed a Virtual Learning System (VLS), an interactive teaching package that can be used by people with little computer knowledge. The system then was validated through instructions in mechanical and manufacturing engineering courses. Stratos *et al*. [51] proposed a novel VR-based learning framework for attracting students in secondary education to manufacturing. Through a virtual environment, students can assemble a series of critical components of a vehicle. Rogers *et al*. [52] reported findings in assessing students' learning in operating a computerized numerical control (CNC) milling machine in a virtual, game-like environment. The virtual environment was developed based on two new engines including the Integrated Virtual Environment for Synthesis and Simulation (IVRESS) and the Learning Environment Agent (LEA). Lopez and Tucker [53] investigated a novel VR-based approach to link course knowledge and student learning experience. The authors assessed the outcome of this new approach in industrial engineering education in a context of a power-drill robotic system. For a comprehensive overview of recent advances in VR-based manufacturing education, the reader is referred to [54, 55].

Despite the successes of previous investigations in VR-based manufacturing education, a commonality is that the virtual environment (platform) in these studies is based on an imaginary universe created by gaming engines. As discussed in Section 2.2 above, developing and maintaining such virtual platforms can be costly and labor-intensive. If not well-created, users' learning experience could be negatively affected due to the inauthenticity of the virtual environment. To the best knowledge of the authors, no literature developing interactive, virtual media for manufacturing education using 360-degree real-world authentic videos and/or images was found.

2.4 Embodied Cognition in VR-Based Engineering Education

There is strong evidence from the neuroscience and educational psychology literature to expect that an interactive VR experience with simulated manufacturing equipment can translate into a useful skill for operating the actual equipment in person. First, there is physical evidence from functional brain imaging [56, 57, 58, 59, 60] for the theory of *embodied cognition* [61], the view, among other tenets, that spatial cognition: (1) is situated, happening with continuous sensory input from task context and in an imaginary 3D mental environment of planning for and anticipating the results of action, (2) is *off-loaded* to the environment, in that we outsource elements of cognition to real objects we manipulate with our bodies (like when using an abacus) or to imagined objects recruiting the same sensory-motor brain regions (when imagining using an abacus), and (3) is *body-based*, even when reasoning "off-line", away from the original sensory-motor context of the task. In short, whether mentally planning a task, performing a simulated version of a task, or physically performing the actual task, these are all neurologically highly similar.

Recently, the field of *embodied learning* has shown great promise to emerge with virtual and mixed realities technologies [62]. In [63], researchers asserted that VR and similar technologies had strong potential for transforming education, provided the learning task design ensures: (1) sensory-motor activation of processes that underlie the target concept, (2) congruency between the gestures the user must perform and the content to be learned, (3) perception of immersion in the relevant context, (4) the augmentation of reality that is uniquely beneficial, (5) allowing students to experience or link unobservable phenomena, especially in the superficial information in the real context, enable multiple rapid experiments, or provide rapid, adaptive feedback, and (6) appropriate assessment of outcomes attainment, since positive effects of learners' understanding may not be detectable on traditional pencil-and-paper pre/post-test assessments, for the same reasons that pencil-and-paper instruction did not teach the concepts as well as embodied learning in the first place. The importance of these considerations was recently demonstrated by Makransky *et al*. [64], who found that an immersive VR science lab *decreased* learning gains, likely because the interface overloaded and distracted learners. However, in a study of a similar subject-matter area (electromagnetic fields and forces; and atomic orbitals) Johnson-Glenberg showed that careful consideration of the above design principles can positively affect education through an *increased sense of presence* and *embodied affordances*, unique opportunities to achieve learning outcomes, added by the *use of gesture* and *manipulation in the 3rd dimension* [65].

3. Methodology

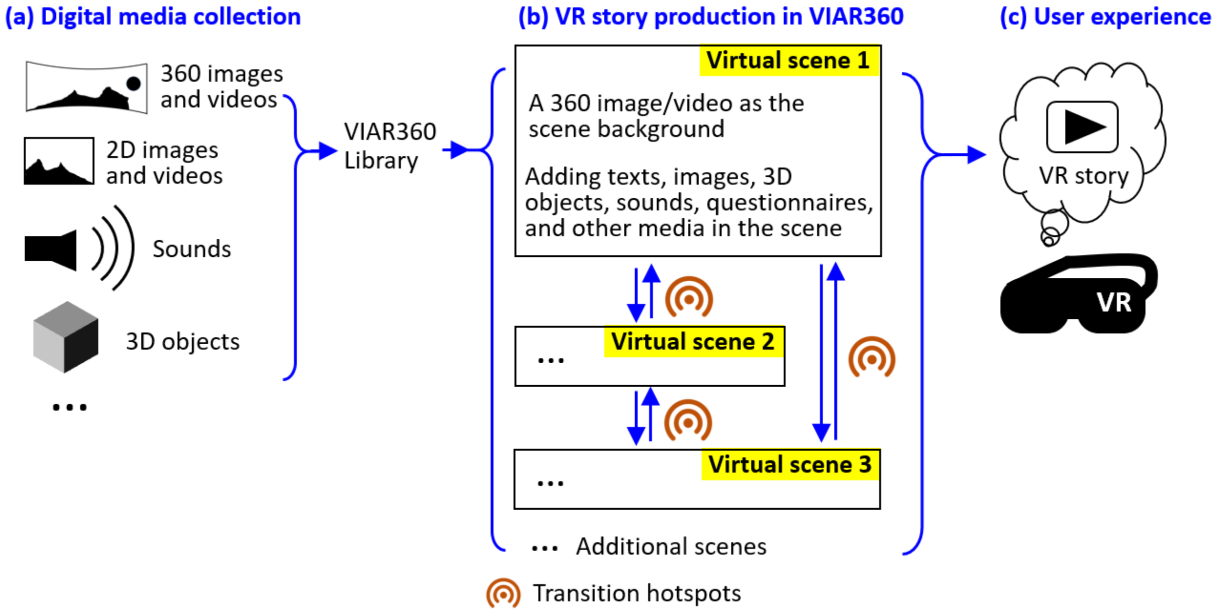
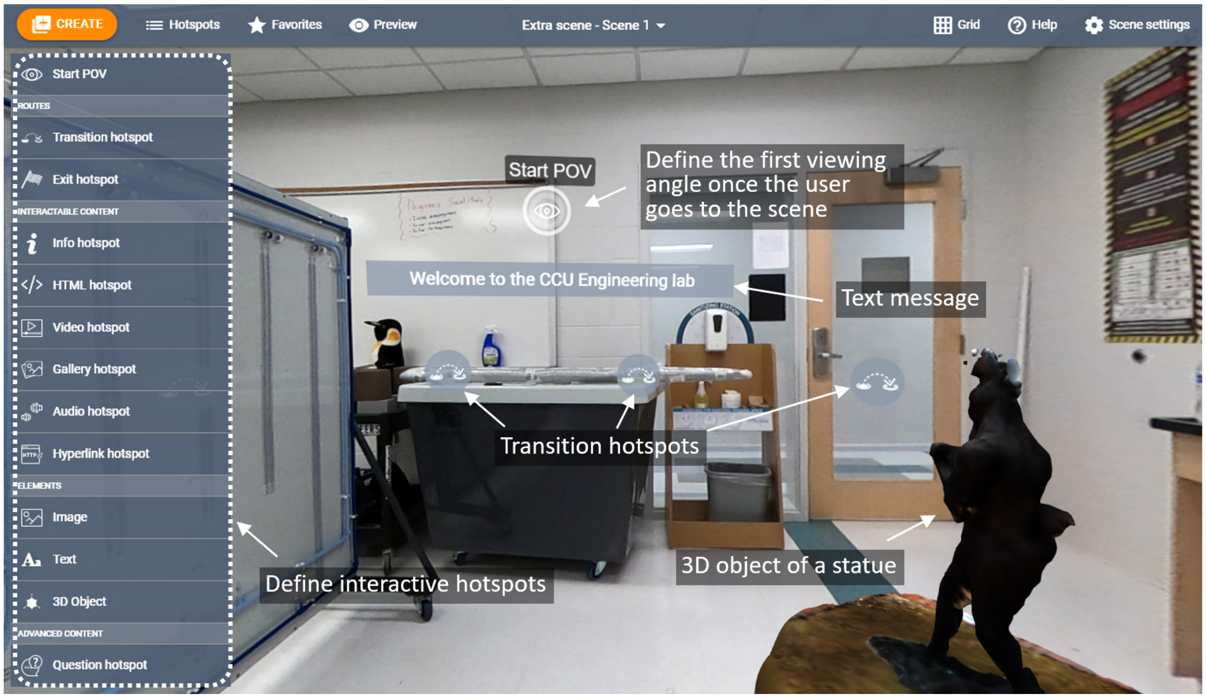


Figure 1. Flowchart for VR story production that includes (a) digital media collection; (b) VR story production in VIAR360; and (c) user experience.

The flowchart for the VR story production of this study is illustrated in Figure 1. Briefly, digital media is first collected *in situ* to serve as the raw materials for virtual content creation. Depending on the demand, the digital media could be 360-degree images and videos, traditional 2D images and videos, sounds, 3D objects, or others. Next, such media is uploaded to VIAR360, a web browser-based online VR editing platform, for virtual content production. To this end, several virtual 360-degree scenes are created using 360-degree images or videos. For each scene, hotspots are further added to enable interactive features in the virtual environment. For example, these hotspots reveal interactive texts in the scene once the user clicks the hotspot using the VR controller; spatial sounds that can be played in predefined directions; questionnaires that ask the user to complete; 2D images or video clips that can be displayed in a predefined location; or 3D artificial objects/models that are relevant to the content of the scene. Thereafter, transition hotspots are created in each virtual scene such that all individual scenes can be linked together as an organic virtual story to be played in a VR headset. This allows the user to fully control what and when the content he/she like to see in a self-explanatory and directly evident virtual world [66].

To demonstrate how the interactive content is created in VIAR360, a sample virtual scene that is edited by VIAR360 through its web browser-based editing platform is shown in Figure 2. The virtual environment of this scene is about an engineering lab and is filmed by a 360-degree camera. Some (interactive) features have been added to the virtual environment by creating different types of hotspots. First, a text message on the top of the scene offers instructions/guidance to the user. Then, three transition hotspots are created in the mid-height of the scene to direct the user to additional virtual scenes (not shown in this figure) depending on the user's choice via his/her VR controller. Next, a 3D object of a Chanticleer campus statue is placed close to the user's viewing point at the floor level. The 3D object is a virtual digital model that is created and rendered through a photogrammetry workflow. Adding this object shows the potential to blend real-world observation with artificial experience. Lastly, a start-point-of-view (POV) is added in the scene which defines the first viewing angle once the user approaches the scene.



Welcome to the CCU Engineering lab

Figure 2. A sample virtual scene loaded in VIAR360 with some (interactive) virtual content added to the scene and other available (interactive) content options listed in the manual on the left.

In addition to the virtual content discussed above, the manual on the left in Figure 2 lists all the available hotspots that can be added to the scene. For example, a gallery hotspot enables an image gallery in the virtual environment (will discuss more in Section 4.2); a question hotspot can be added to the scene, allowing users to answer a questionnaire to assess their learning experience; spatial audio (e.g., sounds of machine operation) can be placed at a predefined direction in the scene through the audio hotspot. The functionalities of available hotspots in VIAR360 are also listed in Table 1.

Table 1. Available hotspots in VIAR360

Name	Explanations
Start POV	Define the first viewing angle once the user goes to the scene
Transition hotspot	Direct the user to the next scene
Exit hotspot	Exit the current virtual scene
Info hotspot	Add text message to the scene
HTML hotspot	Embed an HTML code to the scene
Video hotspot	Add a 2D video clip to the scene
Gallery hotspot	Add a 2D image gallery to the scene
Audio hotspot	Add a spatial audio effect to the scene
Hyperlink hotspot	Add a hyperlink to the scene
Question hotspot	Post a questionnaire to the scene

4. Preliminary Results and Discussions

To demonstrate the potential of the proposed method in enhancing additive manufacturing education, a 3D printer (Ultimaker S5) in the machine shop of the engineering science program at Coastal Carolina University was selected as the testbed for this study. An interactive virtual story was created through the proposed methodology that includes two virtual scenes, defined as Scenes 1 and 2. Scene 1 was made based on a 360-degree image to show the 3D printer in the machine shop; while Scene 2 was a 360-degree video clip that illustrates the manufacturing process of an object under printing. The rest of this Section is organized as follows: Section 4.1 explains the strategy of media collection for virtual scene creation; Section 4.2 shows the results of edited virtual content; Section 4.3 further discusses the preliminary results.

4.1 Digital Media Collection

A 360-degree camera (GoPro MAX, www.gopro.com) was adopted for the filming of the 360-degree footage. The test configurations for collecting 360-degree media for both virtual scenes of this study are illustrated in Figure 3. To create Scene 1, the 360-degree camera was mounted on a tripod in front of the 3D printer in Scene 1 (Figure 3a). As the camera location mimics the user's point of view in the virtual environment, this camera position allows the user to have an ideal viewing angle to see the front side of the 3D printer while still observing the rest of the environment of the machine shop. A 360-degree image (5,760 pixels by 2,880 pixels) was collected. In Figure 3b, the camera was placed inside the printer container to obtain a better camera position for filming the nozzle, heat element, and object during the printing process. A 360-degree video clip (16 seconds; 4096 pixels by 2048 pixels) was collected for creating Scene 2. Notice that the printer's build platform raised and approached the camera position during the video collection, which was not shown in Figure 3b.

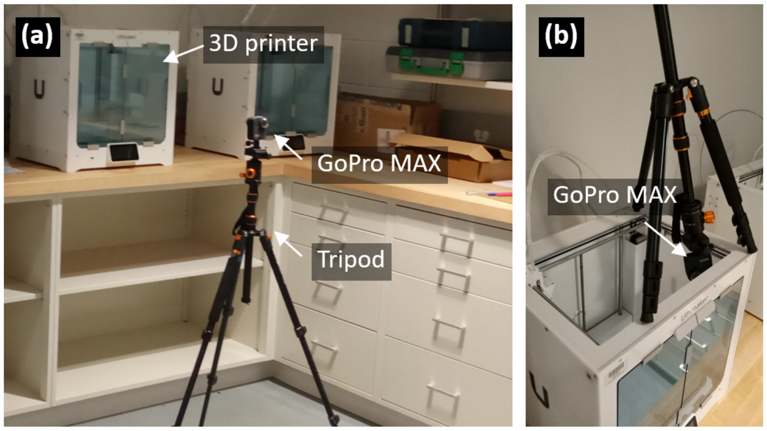
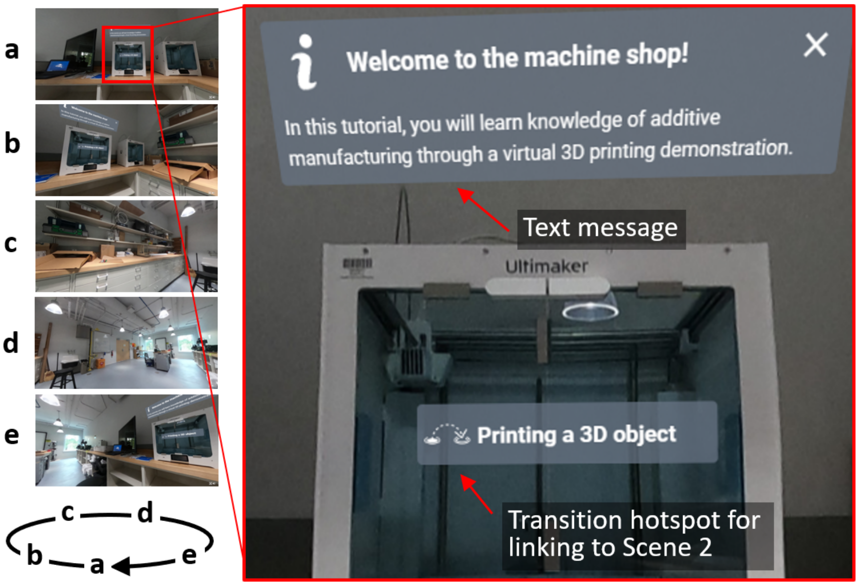


Figure 3. Configurations for collecting virtual media for (a) Scene 1 and (b) Scene 2.

4.2 Virtual Content Production

The edited virtual content of Scene 1 is shown in Figure 4, where Figure 4a through 4e are snapshots taken from different viewing angles of this virtual environment. Once the user enters the scene, the starting point of view is predefined as shown in Figure 4a. This allows the user to pay initial attention to the 3D printer. If the user further looks right and turns around a full 360-degree cycle, then the user can see other views of the machine shop as indicated in Figure 4b to 4e, accordingly. To offer instructions to the user, a text message is shown on the top of the printer. In front of the printer, a transition hotspot is created. Upon clicking the hotspot using a VR controller, a user can be directed to Scene 2 to obtain an immersive experience of 3D printing.


Welcome to the machine shop!

In this tutorial, you will learn knowledge of additive manufacturing through a virtual 3D printing demonstration.

Figure 4. Virtual content of Scene 1 where (a) to (e) are snapshots taken from the 360-degree virtual scene under different viewing angles.

The virtual content of Scene 2 under different viewing angles is shown in Figure 5. A user can start his/her view in Figure 5a and turn his/her head to the right to see the views shown in Figure 5b and c. Regardless of view selections, the bottom of the user's views is occupied by the printer's built platform. As discussed in Section 4.1, the camera was placed close to the printer's head during the 360-degree video collection. This further allows the user to closely observe the printing process by virtually positioning the user's view inside the printer. The user can also see the movement of the printer nozzle and hear the sound generated by the printer in this scene.

Some interactive content is added to Scene 2 as follows. In Figure 5a, a transition hotspot is created that can direct the user back to the machine shop (Scene 1). In Figure 5b, some notations are added in the virtual scene to label the object under printing as well as the build platform of the printer (see yellow texts). In Figure 5c, an image gallery is created in the virtual environment that contains four 3D views of the object under printing from different angles. The user can navigate different images in the gallery through his/her VR controller to learn more about the object.

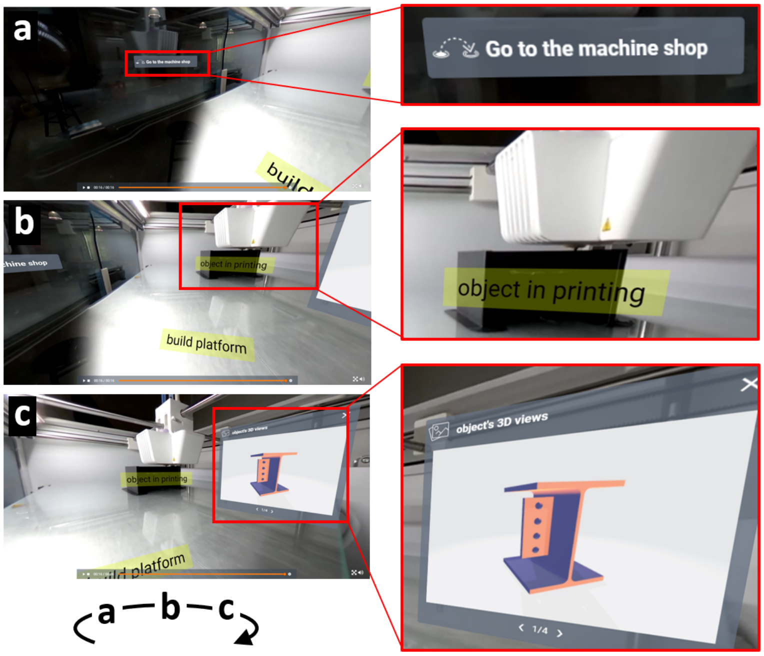


Figure 5. Virtual content of Scene 2 where (a) to (c) are snapshots taken from the 360-degree virtual scene under different viewing angles.

4.3 Discussions

Through the virtual content production in Section 4.2, a VR story can be produced and further be displayed in a virtual environment. In this study, the Oculus Quest 2 [67] was adopted as the VR headset for viewing virtual content. To this end, the developer mode was enabled in Oculus Quest 2 and then the VIAR360 app was installed. Next, a user can view the VR story after logging in to the VIAR360 app.

Because the scenes in the VR story of this study are created based on real-world authentic 360-degree videos and/or images, the user can obtain an authentic experience to explore knowledge in additive manufacturing. For instance, in Scene 2 the user can gain direct knowledge about the printing procedure by seeing the movement of the nozzle and hearing printing sound from the machine. These VR technologies that are based on the imaginary universe would need significant efforts in creating the scene of the machine shop and printer, simulating nozzle motion, rendering the sound of the machine, and other aspects to ensure the virtual environment is as realistic as our approach.

5. Future Work

5.1 Virtual Content Production

For virtual content production, future work will focus on two perspectives. First, to improve the VR story in this study, extra scenes will be added to the existing virtual content. Such scenes include a tutorial on the 3D printing software, a scene on the overview of additive manufacturing, and/or a scene to walk through key components of the printer. Once complete, these extra scenes will be linked to the existing VR story through transition hotspots. Also, an instructor will participate in the filming of some of these scenes to enhance the user learning experience.

Second, the proposed methodology will be scaled up to create a VR story of advanced manufacturing equipment. The attractiveness of this development and technology becomes apparent when applied to capital equipment that is not easily accessible by educational institutions. This includes dedicated or niche manufacturing equipment, such as automated or advanced (composite) manufacturing tools. Examples of suitable applications include operation, maintenance, and training concerning Automated Fiber Placement, Industrial robotics, and Automation Cells. Additional applications include applications where safety during training may be a concern, such as equipment or procedures involving high voltage, current, temperature, force, or other health-impacting conditions. The VR equipment can be used to prevent workplace injuries during training, perform mock-up procedures before shutting down the production equipment, or otherwise remove operational and safety risks from the training environment.

5.2 Assessment

While numerous researchers have evaluated individual aspects of using VR, e.g., the use of navigational aids [68], movement [69], and the positioning of multimedia [70], few, if any, have evaluated students' perspectives of learning engineering in VR from multiple evaluative domains, or the impact of learning engineering in VR on students' engineering motivation and career pathway selections. This gap in the research presents an opportunity for future investigation. With assessment data being collected in the future, continuous improvements to the proposed VR production workflow can be made.

Insights into students' perspectives about learning engineering in a virtual environment will be guided by quantitative and qualitative measures. Quantitative user testing data will be gathered from a combination of two comprehensive peer-reviewed instruments Lee and Cherner's [70] rubric for assessing instructional apps, and Fegely and Cherner's [71] addendum rubric for evaluating educational VR. User testing data will both guide the systematic improvement of the VR story, and provide data with which to evaluate students' VR experiences. Users will rate the VR story experience based on criterion-referenced indicator statements from 1 to 5, focused on six evaluative domains from the Lee and Cherner [72] and Fegely and Cherner [71] instruments: (1) Instruction, (2) Design, (3) Engagement, (4) Positioning of the EduVR, (5) Virtual Environment, and (6) Virtual Experience. The Fegely and Cherner [71] evaluative domain of Avatar Level will not be analyzed due to this VR story's development from the first-person perspective. Descriptive statistics will be produced, and inferential statistical tests will be utilized on the quantitative data. These data analyses will aid the researchers as they ascertain trends in consensus within the user testing ratings based on users' backgrounds. Qualitative data will be gathered on students' perspectives about learning engineering in a virtual environment through an open-ended survey about their experiences. These qualitative data will provide insights into the quantitative data.

Inductive analysis and open coding will be used to derive themes related to the students' VR experiences that will potentially help explain the changes in the quantitative data.

Furthermore, insights into how and to what extent the VR story experience impacts students' engineering motivation and career pathway selections will be gathered. Students' quantitative engineering motivation data will be gathered with a questionnaire adapted from the valid and reliable Science Motivation Questionnaire II (SMQ-II) developed by Glynn *et al*. [73] due to its excellent overall reliability ($\alpha = 0.91$) and criterion-related validity. Pre-post- Likert-type questionnaires will be used to collect data before and after students participate in the VR story experience. The pre- and post-questionnaire will assess students' intrinsic motivation, career motivation, self-determination, self-efficacy, and grade motivation related to engineering before and after completing their VR story experience. Descriptive statistics and inferential statistical tests will be used to gauge the impact of the VR story by analyzing the differences between the pre- and post- questionnaire ratings for each subscale in addition to the total measurements. In addition, semi-structured interviews will be used to gather qualitative data on students' engineering motivation. The quantitative findings from the engineering motivation questionnaire will be interpreted and then these results will be compared with the qualitative themes from the semi-structured interviews. In this way, the qualitative data will be used to emphasize and detail the quantitative findings, providing an additional explanation of what the quantitative results implied [74].

6. Conclusions

In this study, an ongoing effort in investigating a novel VR production workflow is presented to bridge the skills gap in today's manufacturing education. A methodology for creating interactive, immersive, 360-degree virtual media was proposed for enhancing student learning in additive manufacturing. To this end, 360-degree videos and images were filmed *in situ* to reproduce the scenes of real-world additive manufacturing equipment, and interactive information was then added to the virtual environment using a web browser-based online platform. To validate our proposed method, a consumer-grade 3D printer was selected as the testbed. Preliminary results showed the established VR story enabled an immersive and authentic experience that allowed the user to interact with the virtual content in the scenes, showing great potential to enhance student learning in manufacturing education. Future work will focus on adding additional virtual content to this VR story, scaling up the VR production workflow for large-scale advanced manufacturing equipment, creating demonstrations for assisting safety training, and performing assessments to evaluate user experience. The investigation of such a VR production methodology is highly impactful, as the technology also shows great promise in developing virtual content for other manufacturing-related training materials.

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References

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[1] Rocha, I. L. (2018). Manufacturing as driver of economic growth. *PSL Quarterly Review*, 71(285), 103-138.

[2] Haraguchi, N., Cheng, C. F. C., & Smeets, E. (2017). The importance of manufacturing in economic development: has this changed?. *World Development*, 93, 293-315.

[3] Schake, S., & Craft, J. (2019). Job applicants as the new customer: Strategies for successful recruiting in Midwest manufacturers. *International Journal of Managerial Studies and Research*, 7(4), 1-14.

[4] Weaver, A., & Osterman, P. (2017). Skill demands and mismatch in US manufacturing. *ILR Review,* 70(2), 275-307.

[5] Giffi, C., Wellener, P., Dollar, B., Manolian, H. A., Monck, L., & Moutray, C. (2018). Deloitte and The Manufacturing Institute skills gap and future of work study. Deloitte Insights.

[6] Attracting the Next Generation of Students The Role of Career and Technical Training, Manufacturing Institute, https://www.themanufacturinginstitute.org/wp-content/uploads/2020/03/MI-Attracting-the-Next-Generation-of-Students_Role-of-CTE.pdf

[7] Allcoat, D., & von Mühlenen, A. (2018). Learning in virtual reality: Effects on performance, emotion and engagement. *Research in Learning Technology*, 26.

[8] Fegely, A. G., Hagan, H. N., & Warriner III, G. H. (2020). A practitioner framework for blended learning classroom inquiry-based virtual reality lessons. *E-Learning and Digital Media*, 17(6), 521-540.

[9] Wang, Y., & Braman, J. (2009). Extending the classroom through Second Life. *Journal of Information Systems Education,* 20(2), 235.

[10] Pinho, M. S., Bowman, D. A., & Freitas, C. M. D. S. (2008). Cooperative object manipulation in collaborative virtual environments. *Journal of the Brazilian Computer Society*, 14(2), 53-67.

[11] Kwon, C. (2019). Verification of the possibility and effectiveness of experiential learning using HMD-based immersive VR technologies. *Virtual Reality*, 23(1), 101-118.

[12] Crosier, J. K., Cobb, S., & Wilson, J. R. (2002). Key lessons for the design and integration of virtual environments in secondary science. *Computers & Education*, 38(1-3), 77-94.

[13] McKenzie, S., Rough, J., Spence, A., & Patterson, N. (2019). Virtually there: the potential, process and problems of using 360 video in the classroom. *Issues in Informing Science and Information Technology*, 16, 211-219.

[14] VIAR360, www.viar360.com

[15] Farshid, M., Paschen, J., Eriksson, T., & Kietzmann, J. (2018). Go boldly!: Explore augmented reality (AR), virtual reality (VR), and mixed reality (MR) for business. *Business Horizons*, 61(5), 657-663.

[16] Reitmayr, G., & Drummond, T. W. (2006, October). Going out: robust model-based tracking for outdoor augmented reality. *In 2006 IEEE/ACM international symposium on mixed and augmented reality* (pp. 109-118). IEEE.

[17] Liarokapis, F., Mourkoussis, N., White, M., Darcy, J., Sifniotis, M., Petridis, P., ... & Lister, P. F. (2004). Web3D and augmented reality to support engineering education. *World transactions on engineering and technology education*, 3(1), 11-14.

[18] Chen, H., Feng, K., Mo, C., Cheng, S., Guo, Z., & Huang, Y. (2011, December). Application of augmented reality in engineering graphics education. *In 2011 IEEE International Symposium on IT in Medicine and Education* (Vol. 2, pp. 362-365). IEEE.

[19] Turkan, Y., Radkowski, R., Karabulut-Ilgu, A., Behzadan, A. H., & Chen, A. (2017). Mobile augmented reality for teaching structural analysis. *Advanced Engineering Informatics*, 34, 90-100.

[20] Radkowski, R., Karabulut-Ilgu, A., Turkan, Y., Behzadan, A., & Chen, A. (2018, July). Guiding or Exploring? Finding the Right Way to Teach Students Structural Analysis with Augmented Reality. In International Conference on Virtual, *Augmented and Mixed Reality* (pp. 452-461). Springer, Cham.

[21] Sahu, C. K., Young, C., & Rai, R. (2021). Artificial intelligence (AI) in augmented reality (AR)-assisted manufacturing applications: a review. *International Journal of Production Research*, 59(16), 4903-4959.

[22] Bonetti, F., Warnaby, G., & Quinn, L. (2018). Augmented reality and virtual reality in physical and online retailing: A review, synthesis and research agenda. *Augmented reality and virtual reality*, 119-132.

[23] Godat, M. (2007). Virtual golden foods corporation: Generic skills in a virtual crisis environment (a pilot study). *Journal of Educational Multimedia and Hypermedia*, 16(1), 67-84.

[24] Vergara, D., Rubio, M. P., & Lorenzo, M. (2017). On the design of virtual reality learning environments in engineering. *Multimodal technologies and interaction*, 1(2), 11.

[25] Borisov, N., Smolin, A., Stolyarov, D., Shcherbakov, P., & Trushin, V. (2016). The opportunities of applying the 360 video technology to the presentation of cultural events. In *Interactivity, game creation, design, learning, and innovation* (pp. 256-263). Springer, Cham.

[26] Napolitano, R. K., Scherer, G., & Glisic, B. (2018). Virtual tours and informational modeling for conservation of cultural heritage sites. *Journal of Cultural Heritage*, 29, 123-129.

[27] Kabassi, K. (2017). Evaluating websites of museums: State of the art. *Journal of Cultural Heritage*, 24, 184-196.

[28] Abidi, M. H., Al-Ahmari, A., Ahmad, A., Ameen, W., & Alkhalefah, H. (2019). Assessment of virtual reality-based manufacturing assembly training system. *The International Journal of Advanced Manufacturing Technology*, 105(9), 3743-3759.

[29] Elmqaddem, N. (2019). Augmented reality and virtual reality in education. Myth or reality?. *International journal of emerging technologies in learning*, 14(3).

[30] Chandrasekera, T., & Yoon, S. Y. (2018). Augmented Reality, Virtual Reality and Their Effect on Learning Style in the Creative Design Process. *Design and Technology Education*, 23(1), n1.

[31] Stauffer, S., Gardner, A., Ungu, D. A. K., López-Córdoba, A., & Heim, M. (2018). *Labster Virtual Lab Experiments: Basic Biology*. Springer.

[32] Häfner, P., Häfner, V., & Ovtcharova, J. (2013). Teaching methodology for virtual reality practical course in engineering education. *Procedia Computer Science*, 25, 251-260.

[33] Messner, J. I., Yerrapathruni, S. C., Baratta, A. J., & Whisker, V. E. (2003, June). Using virtual reality to improve construction engineering education. In *American Society for Engineering Education Annual Conference & Exposition*.

[34] Sacks, R., Perlman, A., & Barak, R. (2013). Construction safety training using immersive virtual reality. *Construction Management and Economics*, 31(9), 1005-1017.

[35] Leder, J., Horlitz, T., Puschmann, P., Wittstock, V., & Schütz, A. (2019). Comparing immersive virtual reality and PowerPoint as methods for delivering safety training: Impacts on risk perception, learning, and decision making. *Safety Science*, 111, 271-286.

[36] Veronez, M. R., Gonzaga, L., Bordin, F., Kupssinsku, L., Kannenberg, G. L., Duarte, T., ... & Marson, F. P. (2018, March). RIDERS: Road Inspection & Driver Simulation. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces* (VR) (pp. 715-716). IEEE.

[37] Kovar, J., Mouralova, K., Ksica, F., Kroupa, J., Andrs, O., & Hadas, Z. (2016, December). Virtual reality in context of Industry 4.0 proposed projects at Brno University of Technology. In *2016 17th International Conference on Mechatronics-Mechatronika* (ME) (pp. 1-7). IEEE.

[38] Liagkou, V., Salmas, D., & Stylios, C. (2019). Realizing virtual reality learning environment for industry 4.0. *Procedia CIRP*, 79, 712-717.

[39] Huang, H.-M., Rauch, U., & Liaw, S.-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*, 55(3), 1171–1182

[40] Le, Q. T., Pedro, A., & Park, C. S. (2015). A social virtual reality based construction safety education system for experiential learning. *Journal of Intelligent & Robotic Systems*, 79(3), 487-506.

[41] Schwaab, J., Kman, N., Nagel, R., Bahner, D., Martin, D. R., Khandelwal, S., ... & Nelson, R. (2011). Using second life virtual simulation environment for mock oral emergency medicine examination. *Academic Emergency Medicine*, 18(5), 559-562.

[42] Schofield, D. (2014). A Virtual Education: Guidelines for Using Games Technology. *Journal of Information Technology Education*, 13.

[43] Juliani, A., Berges, V. P., Teng, E., Cohen, A., Harper, J., Elion, C., ... & Lange, D. (2018). Unity: A general platform for intelligent agents. arXiv preprint arXiv:1809.02627.

[44] Blender, https://www.blender.org/

[45] Velev, D., & Zlateva, P. (2017). Virtual reality challenges in education and training. International *Journal of Learning and Teaching*, 3(1), 33-37.

[46] Arents, V., de Groot, P. C., Struben, V. M., & van Stralen, K. J. (2021). Use of 360° virtual reality video in medical obstetrical education: a quasi-experimental design. *BMC medical education*, 21(1), 1-9.

[47] Ardisara, A., & Fung, F. M. (2018). Integrating 360 videos in an undergraduate chemistry laboratory course.

[48] Ferdig, R. E., & Kosko, K. W. (2020). Implementing 360 video to increase immersion, perceptual capacity, and teacher noticing. TechTrends, 64, 849-859.

[49] Argyriou, L., Economou, D., & Bouki, V. (2020). Design methodology for 360 immersive video applications: the case study of a cultural heritage virtual tour. *Personal and Ubiquitous Computing*, 1-17.

[50] Hashemipour, M., Manesh, H. F., & Bal, M. (2011). A modular virtual reality system for engineering laboratory education. *Computer Applications in Engineering Education*, 19(2), 305-314.

[51] Stratos, A., Loukas, R., Dimitris, M., Konstantinos, G., Dimitris, M., & George, C. (2016). A virtual reality application to attract young talents to manufacturing. *Procedia CIRP*, 57, 134-139.

[52] El-Mounayri, H., Rogers, C., Fernandez, E., & Satterwhite, J. C. (2016). Assessment of STEM e-Learning in an immersive virtual reality (VR) environment. *American Society for Engineering Education*.

[53] Lopez, C. E., Ashour, O. M., & Tucker, C. (2019, June). An Introduction to the CLICK Approach: Leveraging Virtual Reality to Integrate the Industrial Engineering Curriculum. In *ASEE annual conference & exposition*.

[54] Carruth, D. W. (2017, October). Virtual reality for education and workforce training. In *2017 15th International Conference on Emerging eLearning Technologies and Applications (ICETA)* (pp. 1-6). IEEE.

[55] Salah, B., Abidi, M. H., Mian, S. H., Krid, M., Alkhalefah, H., & Abdo, A. (2019). Virtual reality-based engineering education to enhance manufacturing sustainability in industry 4.0. *Sustainability*, 11(5), 1477.

[56] Cohen, M. S., Kosslyn, S. M., Breiter, H. C., DiGirolamo, G. J., Thompson, W. L., Anderson, A. K., ... & Belliveau, J. W. (1996). Changes in cortical activity during mental rotation A mapping study using functional MRI. *Brain*, 119(1), 89-100.

[57] Kosslyn, S. M., DiGirolamo, G. J., Thompson, W. L., & Alpert, N. M. (1998). Mental rotation of objects versus hands: Neural mechanisms revealed by positron emission tomography. *Psychophysiology*, 35(2), 151-161.

[58] Wexler, M., Kosslyn, S. M., and Berthoz, A. (1998). Motor processes in mental rotation. *Cognition* 68 pp.77-94.

[59] Hauk, O., Johnsrude, I., & Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron*, 41(2), 301-307.

[60] Boulenger, V., Hauk, O., & Pulvermüller, F. (2009). Grasping ideas with the motor system: semantic somatotopy in idiom comprehension. *Cerebral cortex*, 19(8), 1905-1914.

[61] Wilson, M. (2002). Six views of embodied cognition. *Psychonomic bulletin & review*, 9(4), 625-636.

[62] Badets, A., Havard, V., Richard, K., & Baudry, D. (2020). Using collaborative VR technology for Lean Manufacturing Training: a case study. *In Proc. VRIC* (pp. 118-127).

[63] Lindgren, R., & Johnson-Glenberg, M. (2013). Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality. *Educational researcher*, 42(8), 445-452.

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[64] Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction*, 60, 225-236.

[65] Johnson-Glenberg, M. C. (2018). Immersive VR and education: Embodied design principles that include gesture and hand controls. *Frontiers in Robotics and AI*, 5, 81.

[66] Jerald, J. (2015). *The VR book: Human-centered design for virtual reality*. Morgan & Claypool.

[67] Oculus Quest 2, www.oculus.com

[68] Alghofaili, R., Sawahata, Y., Huang, H., Wang, H. C., Shiratori, T., & Yu, L. F. (2019, May). Lost in style: Gaze-driven adaptive aid for vr navigation. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (pp. 1-12).

[69] Baruah, R. (2019). *Virtual reality with VRTK4*. Apress.

[70] Parong, J., & Mayer, R. E. (2018). Learning science in immersive virtual reality. *Journal of Educational Psychology*, 110(6), 785.

[71] Fegely, A., & Cherner, T. (2021). A comprehensive rubric for evaluating eduVR. *Journal of Information Technology Education: Research*, 20(1), 137-171.

[72] Lee, C. Y., & Sloan, T. (2015). A comprehensive evaluation rubric for assessing instructional apps. *Journal of Information Technology Education*, 14.

[73] Glynn, S. M., Brickman, P., Armstrong, N., & Taasoobshirazi, G. (2011). Science motivation questionnaire II: Validation with science majors and nonscience majors. *Journal of research in science teaching*, 48(10), 1159-1176.

[74] Creswell, J. W. (2014). *Qualitative, quantitative and mixed methods approaches*. Sage.