

Virtual Technology to Support Student Engagement and Collaboration in Online Engineering Courses

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Abstract—This study evaluated the use of Terf® virtual world technology to support student communication, collaboration, and engagement in an online undergraduate, sophomore-level computer engineering course in digital design and a computer science course. Virtual world technology provides a persistent 3D immersive environment in which students and faculty log into the platform with personalized avatars and enter customized virtual workspaces that support avatar navigation, text chat, voice communication, shared resources, and a webcam. Most importantly, the Terf® product allows student teams to work collaboratively on shared documents and images, facilitating team projects and improving student interaction and communication. The virtual collaboration tool also supported interaction with 3D models, virtual office hours, virtual lectures, and a team final project virtual poster session. Overall, the feedback from the students was positive and the students judged the tool as beneficial to improving student interaction, engagement and collaboration in the online courses.

Index Terms—engineering education, online education, student engagement, virtual worlds

I. INTRODUCTION

The benefits of online learning include asynchronous access to learning resources, flexible scheduling, meeting demands of non-traditional and adult students, multi-campus and international participation, and accommodating learning preferences for many students. Some of the challenges of online learning include student isolation, difficulty communicating and collaborating with other students on team projects, and challenges in engagement and in the effective presentation and sharing of team projects. Research has shown that active learning experiences, student-to-student and student-to-instructor communication, student collaboration, group work, community, and

assessment are important components to successful online courses [1], [2], [3], [4], [5].

This study evaluated the use of Immersive Terf® (3D ICC)¹ virtual world technology to support student collaboration and engagement in an online, undergraduate, sophomore-level computer engineering course in digital design, and in an introductory computer science course (C++ and MATLAB), both offered through the Penn State Abington campus. Virtual world technology provides a persistent 3D immersive environment in which students log into the platform with personalized avatars and enter customized virtual workspaces that support avatar navigation, text chat, voice communication, and a webcam. Course materials and lectures can be made available to the students through the virtual world, as well as 3D models, such as circuit boards, microcontrollers, and FPGAs. Many examples of research involving the integration of virtual worlds into engineering education and related fields conclude that, while offering many advantages, virtual world technology faces challenges such as non-standard development tools and a lack of integration with existing course management systems [6], [7], [8], [9]. Maher [10] examines 3D virtual worlds in the context of evaluating virtual environments to support collaboration in the design process and Parsons [11] presents the immersive advantages of a 3D virtual world to support problem-based learning (PBL). Nunes [12] explored the integration of a course management system with a virtual world experience and noted improvements in student performance. Kinney found that, in general, engineering faculty and students have little exposure to virtual world technology [3].

The immersive 3D features and communication capabilities of virtual worlds go beyond the feature set of traditional course management systems. The virtual world acted as a supplement to the course management system in this study. Most importantly, the Terf® product allowed student teams to work collaboratively

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¹ Immersive Terf® is the 3D platform created by 3D ICC. Terf® is an immersive 3D avatar-based online environment that requires a subscription. For more information, see 3dicc.com.

and interact, communicate, share documents, display documents and images on virtual display panels to facilitate team projects. The virtual world technology also has several distinct advantages over conventional collaboration tools, such as Google Hangouts, Skype, Facebook, and Adobe Connect. Some of the benefits of virtual worlds include:

- Immersive nature of avatar-based interactions;
- Ability to customize 3D virtual environments (such as lecture halls, laboratory spaces, virtual instrumentation, etc.) based on the course topics;
- Ability to create and import relevant 3D models into the virtual space; and
- Programmatic control of 3D objects to develop interactive simulations (with or without a physics engine).

The virtual world technology in this study supported many activities, including special topics lectures and demonstrations on robotics, virtual discussion sessions involving 3D models of microcontrollers, virtual office hours and mentoring, and a virtual poster session. The virtual poster session allowed teams of students to present work that was shared in a 3D environment with other students in the class as well as students from other courses, and potentially to be shared with individuals around the globe.

The research goal of this pilot study was to assess the communication, collaboration, and engagement opportunities afforded by the use of the Terf® virtual world platform to enhance online engineering lecture courses. This paper reviews the virtual world collaborative activities and presents the results of the integration of the Terf® virtual world technology into the two online courses offered at the Penn State Abington campus. A discussion of the student assessment data will be presented and reviewed, followed by recommendations for future research and directions.

II. VIRTUAL WORLD TECHNOLOGY INTEGRATION STUDY

All students enrolled in a fall 2016 section (38 students) and a fall 2017 section (51 students) of an online computer engineering course in digital systems, as well as 14 students in a computer science course in spring 2017, were required to purchase a semester-long (four-month) license (\$30) for the Terf® collaboration software available from 3D ICC. This software solution was selected to support communication and engagement

in a 3D setting and was used as a supplement to the university's learning management system. The digital systems course was a 15-week lecture online course that covered Boolean algebra, logic gates, combinational logic, minimization, number systems, MSI devices, sequential circuits, finite state machines, memory and programmable logic devices, and FPGA technology. The course is a requirement for sophomore-level computer science, electrical engineering, and computer engineering students. There is a separate, traditional, in-person laboratory course associated with the lecture course, but not all of the students in the online lecture course are required to enroll in the laboratory course.

This study focused on the online lecture course only. The computer science course was an introductory, 15-week course covering C++ and MATLAB programming. Both online courses were similar in terms of delivery mode. Lecture videos (created by the current author) and corresponding PowerPoint slides were delivered asynchronously on the course management system for both courses. Quizzes and exams were administered online. Students in the digital design course were required to complete weekly circuit design homework assignments on an individual basis, using the Multisim™ circuit simulation tool and upload circuit solutions to the course management system.

Both the 2016 and 2017 offerings of the digital systems course were identical in all ways relevant to this study. In the case of the computer science course, C++ and MATLAB programs and projects were required. There was a discussion forum available for posting questions, and the students were required to post (and reply to) five summaries of articles or videos of their choice dealing with state of the art computer technology. The primary mode of communication and homework support is individual email communication (and secondarily, the discussion forum) between students and the instructor. Prior to this pilot study, there were no collaborative or team assignments or team projects in either online course.

The research methodology was to design, create, and implement select collaborative course activities that used the virtual platform, and then evaluate the effectiveness of this tool in terms of supporting enhancements in communication, collaboration, and student engagement. The goal was to select activities, which were collaborative in nature and commonly part of face-to-face offerings but were not easily supported in an online course with a traditional course management system. In particular, interactive special topics lectures and a team poster session were not included in previous online sections (until this study) but

existed in prior in-person offerings of these courses. The exercises and activities developed were conducted in both online courses involved in the study.

At the start, the students participated in two virtual world orientation exercises. In one exercise, students practiced customizing their avatars, selecting a nametag and experimenting with avatar navigation. At the completion of the exercise, students took a screenshot “selfie” of their avatar with nametag in a virtual “mirror.” Extra credit was awarded if the image contained multiple avatars. In the second orientation exercise, each student was instructed to place a “sticky note” text message with his or her name and intended major and post it on a wall in the virtual environment (see Fig. 1 below). This ability was later used to generate and display notes in-world to allow students to leave comments on team project displays at the conclusion of the course.

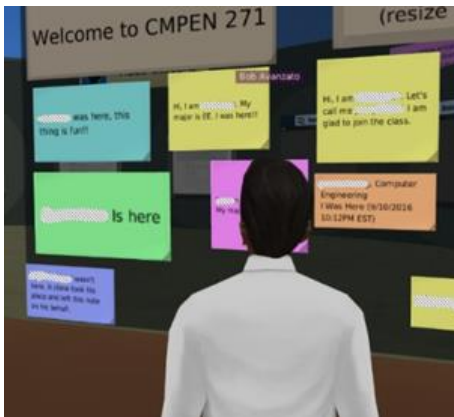


Fig. 1. Sticky note introductions (student names redacted).

Virtual office hours were scheduled each week in the evening for meetings between students and the instructor (the current author) as needed, and students were also encouraged to meet with the instructor in Terf® at other arranged times. One of the strengths of the Terf® tool is the ability to easily share screens from your workstation or laptop onto display panels, which can be distributed throughout the virtual venue. The display panels can be created on demand, positioned in spatially meaningful ways, relocated, and removed when not required. Word, Excel, and PowerPoint files can also be “dropped” into display panels for shared review and co-editing.

In Fig. 2, a student and the instructor are debugging a homework solution involving a circuit simulation shared in the Terf® platform. The use of virtual “laser pointers” to highlight areas of the screen display is also useful and is shown in the figure. The yellow arrow icon

at the top of the screen can be clicked to bring the display into full screen mode regardless of any avatars blocking the view. While there are many available tools that support screen sharing, the screen sharing in Terf® was found to be more flexible, due largely to the advantages of working in an immersive, persistent virtual 3D space. For example, the ability to setup and use multiple display panels supporting multiple shared windows and image displays was particularly effective. It was also possible to move from one station to another and interact with multiple groups of students. Terf® also supports “sound proof” areas, so that multiple voice conversations can be supported without interference. Other students (avatars) were welcome to log in, join the discussion, observe, and participate in any of the mentoring sessions. These mentoring sessions were generally held using texting or voice or a combination thereof. Most of the questions from students were still facilitated by email, but the Terf® environment was used effectively for cases where a combination of screen sharing, and voice communication was more appropriate.

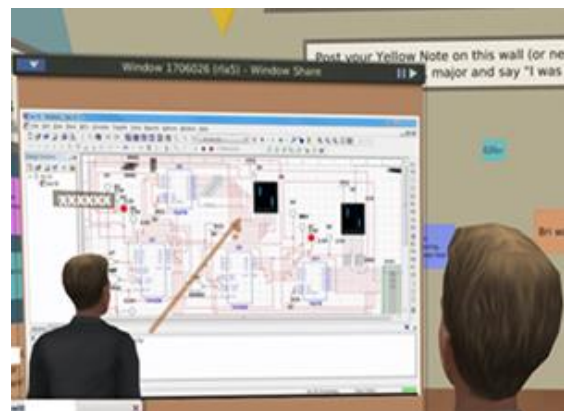


Fig. 2. Debugging circuit simulation during office hours.

A 3D model of an Arduino microcontroller was imported into the Terf® environment, and a student exercise was created requiring each student to identify the analog inputs of the microcontroller with the “laser pointer” (see Fig. 3). Students were also encouraged to meet in groups to accomplish the task. An image of the student using the “laser pointer” to identify the analog ports was captured and submitted to complete the assignment requirement. The 3D model of the microcontroller remained on display in the virtual platform throughout the semester and served as a stimulus for several group discussions about microcontroller applications throughout the course. This exercise also demonstrated the ease with which existing

3D models could be imported from asset libraries (such as 3D Warehouse, etc.). Terf® supports models generated and exported from tools in a variety of formats such as Sketchup (kmz), VRML (wrl), Collada (obj) and 3ds Max (ase). Not only the instructor, but also the students or teams of students can import existing models or create custom 3D models to be imported to Terf®.

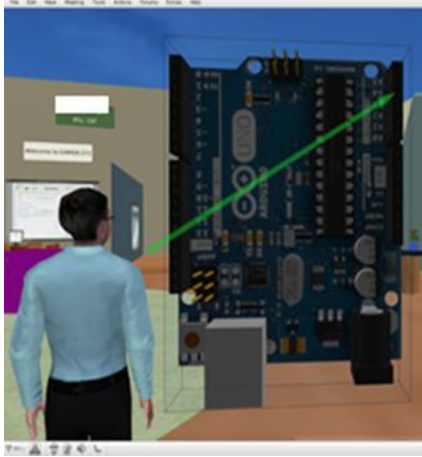


Fig. 3. Identifying analog ports on Arduino microcontroller.

In another set of student experiences created for this pilot study, three optional special topic lectures (with video presentations and software demonstrations) in the area of robotics were offered to the students in the evenings in Terf®, for extra credit. The goal was to encourage groups of students to engage in presentations and demonstrations of state of the art technology and to engage the students in conversations during and following the presentation. It also forged a stronger professional relationship between the students and the instructor, which is important in online courses. In several cases, the lectures were repeated to allow for more participation.

The first lecture discussed the design of a teleoperated storm water pipe video inspection robot that was requested by a local township public works department. The user console and robot platform used Arduino technology and Ethernet communication over a 300-foot cable. The instructor and participating students were able to reference the 3D models of the Arduino microcontrollers during the presentation. The robot project was completed by students in a senior level robotics design class, and the discussion was well received by the sophomore students. The technical support to deliver a PowerPoint presentation with accompanying video clips was well supported by Terf®. The presentations were delivered in voice by the instructor, along with webcam video. The students

communicated in both voice and text. Approximately 25 (out of 34 respondents) attended one or more of the virtual lectures in the digital design course. Approximately five students (out of seven respondents) attended one or more virtual lectures in the computer science course.

The second lecture topic was telepresence robotics; a group discussion of innovative applications and future technology followed the presentation (see Fig. 4).



Fig. 4. Virtual robotics lecture.

The third presentation was on the topic of ROS (Robot Operating System) and the Turtlebot mobile robot. Examples of MATLAB code using the Robotics System Toolbox interface to ROS were explored during the presentation. Significantly, the instructor was able to interactively demonstrate the robot operation using the Gazebo 3D robot simulation tool on a display panel in Terf®. It was possible to change the MATLAB software during the presentation and demonstrate the resultant robot motion in the Gazebo simulated world. Some basic informal quiz questions were posed to the students in attendance, and the students were able to highlight answers to multiple choice questions on the screen by use of their “laser pointers.” Again, the goal was to allow students in an online course to interact virtually with faculty and fellow students in an informal group setting in the context of promoting interest in advanced topics in engineering. Clearly, it is important to differentiate between the tool of delivery and the content. However, the Terf® tool successfully facilitated the delivery of these presentations and demonstrations in a manner that would not have been as immersive and engaging if not delivered in a 3D virtual environment.

In the next virtual collaborative activity, the operation of a telepresence robot was shared in the Terf® environment. Students in the class were invited to participate in a virtual tour of a physical robotics lab at one of our campuses. Although the instructor operated

the telepresence robot from the remote location, the instructor was also logged into the virtual world and could communicate directly with the students in the virtual world as the robot toured the physical lab. Live video from the robot was displayed to the students in the virtual world while the robot navigated in the real space. This activity also allowed students from a senior robotics course to interact directly with sophomore students in the virtual world. Overall, the online students in the virtual world succeeded in remotely visiting a robotics class and experienced a tour of a fabrication facility via the telepresence robot. The operation of the telepresence robot and interaction with the robotics class was very successful, opening up many future opportunities. The key to this demonstration is that students, potentially from all over the globe, enrolled in an online course could be interacting as a group along with an instructor in the virtual world, and participate in communication and interaction with individuals and facilities at a remote venue using a telepresence robot or other remote technology.

Finally, the key collaborative experience was a team final project poster exhibit supported by the Terf® virtual world. The ability to facilitate collaborative team projects and offer a poster session exhibition in an online class was one of the prime motivations for this study. Eight to ten student teams (four to five students each) presented and displayed digital circuit design solutions in the virtual world in both offerings of the computer engineering course. Four student teams (two to four students each) presented virtual posters in the computer science course. Each team presented a voice-enabled presentation in the Terf® virtual world to the instructor and other classmates in a group setting. Each team exhibit consisted of several display panels with images and PowerPoint slides as well as any 3D objects that the students chose to import (Fig. 5).

In one case, students were designing a finite state machine to simulate the turn signals on a car, and they were able to incorporate a 3D model of a car as well as 3D models of integrated circuits (ICs), to enhance the exhibit. The project themes were primarily in the areas of shift register applications, sequential circuits, and finite state machine applications. An open house virtual poster session was held on two successive evenings, in which the students made presentations and fellow students critiqued the other exhibits by posting “sticky notes” with comments to the exhibit areas.



Fig. 5. Final team project poster session (Digital Design Course).

From a logistic and academic perspective, the virtual poster session was very successful, and all the teams were able to set up poster exhibits in the short time frame available. Students from the senior robotics course were also invited to attend the event in the Terf® virtual world and interact with the sophomore students. This is yet another opportunity for exploration and development; this virtual world event supported the interaction of students from various course and academic levels (both online and resident) that would have been very challenging to accomplish in the real world. For the computer science course, teams of students presented results of a final project involving a MATLAB simulation of a mobile robot and each team successfully presented the results in Terf® to the instructor and fellow students (Fig. 6).

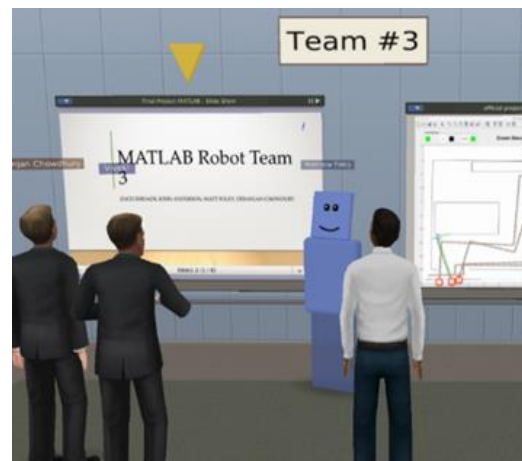


Fig. 6. Final team project poster session (Computer Science Course).

III. ASSESSMENT

This section will review and assess key results of data collected by way of an online anonymous survey distributed at the conclusion of the course. Fourteen enrolled students (37%) out of a total of 38 volunteered to participate in the survey from the 2016 CMPEN 271 digital design course and 20 students (39%) out of 51 participated in the survey in the 2017 CMPEN 271 course. Seven out of a total of 14 students (50%) participated in the survey from the CMPSC 201 computer science course. As shown in Table I, a total of 23 (56%) of the 41 students overall indicated that they were taking an online course for the first time. The 2016 and 2017 results for CMPEN 271 digital design course are combined throughout.

Question		Yes	No
Is this course the first "online" course you have ever taken?	CMPEN 271 (n=34)	20 (59%)	14 (41%)
	CMPSC 201 (n=7)	3 (43%)	4 (57%)

In Table II, the students were asked to assess the effectiveness of the Terf® 3D platform in supporting: 1) lectures and demonstrations; 2) interacting with 3D models; and 3) the final team project poster session. The possible response values in the survey were: Excellent (5); Good (4); Fair (3); Poor (2); and Very Poor (1). The average results for each of the three questions ranged from 3.8 (3D models) to 4.5 (final team projects). Question 4 in Table II asked the students to rate Terf® overall as a tool to support student communication and collaboration in an online course; the average response was 4.3 (out of 5) for the Digital Design and 4.2 (out of 5) for the computer science course.

In Table III, the students recommended whether to use the Terf® tool in future online sections of CMPEN 271 Digital Design; the majority of students, 27 (79.4%), indicated "yes." When asked if Terf® should be included in other online courses (other than CMPEN 271), 25 students (73.5%) indicated "yes." The results were similar for the computer science with 71.43%

recommending Terf® be used again for this course as well as for use in other online courses.

Table IV tabulates representative student responses when asked to comment on what aspects of Terf® they liked "best" and what aspects they liked "least." There were 28 responses for each of the two questions for the digital design courses and four responses (best) and five responses (least) for the computer science course. The comments for "best" features varied over a wide range, including statements about enhanced communication, engagement, group activities, faculty interaction, office hours, and the poster session. One student, who had evidently completed an online course prior to this course, commented, "You felt more a part of the course than your 'normal' online class, better interaction between students and the teacher..." The responses to the aspects of Terf® "least liked" included statements regarding difficulties with performance lag (noted in seventeen responses), communication (three responses), price (three responses), and general difficulties in usage (two responses). These technical issues will be investigated and addressed in future studies with this tool. For this pilot study, a hosted solution from 3D ICC was used, which permitted a maximum of 20 concurrent avatars in-world.

Although the sample size for the survey was relatively small and the majority of the students were taking an online course for the first time, the results of this exploratory study were sufficiently positive to warrant further use and investigation of the Terf® 3D virtual world tool to support student engagement and collaboration. Future studies with larger sample sizes and a sample group containing a higher percentage of students with prior experience taking online courses will be useful in determining the full potential of 3D virtual environments such as Terf®.

It should be noted that Terf® offers many additional features, beyond the feature set used for this study, which can be used by educators to support education objectives. These additional features include customization of 3D environments, detailed analytics of student activity (including when students log in and for how long, resource usage, etc.), administrative management tools, and a Python API for scripting interaction with objects in the virtual world, as well as other features. The discussion of these features is beyond the scope of the current paper; it is the intent of the author to explore these features in future studies, as needed.

Questions		Excellent (5)	Good (4)	Fair (3)	Poor (2)	Very Poor (1)	Average
1. How would you rate the overall effectiveness of using Terf® to attend a lecture or demonstration?	CMPEN 271 (n=29)	14	12	3	0	0	4.4
	CMSPC 201 (n=5)	2	3	0	0	0	4.4
2. How would you rate the overall educational value of viewing and interacting with 3D models (such as the Arduino microcontroller board) in Terf®?	CMPEN 271 (n=33)	13	15	3	2	0	4.2
	CMSPC 201 (n=7)	3	1	2	1	0	3.8
3. How would you rate the overall educational value of the final team project poster exhibit held in Terf®?	CMPEN 271 (n=33)	21	8	3	1	0	4.5
	CMSPC 201 (n=6)	3	1	1	1	0	4.0
4. How would you rate Terf® overall as a tool to support student communication and collaboration in an online course?	CMPEN 271 (n=34)	16	14	3	1	0	4.3
	CMSPC 201 (n=6)	4	1	0	0	1	4.2

Questions		Yes	No	Not Sure
Would you recommend that Terf® be used in the future for online sections?	CMPEN 271 (n=34)	27 (79.4%)	3 (8.8%)	4 (11.8%)
	CMSPC 201 (n=7)	5 (71.43%)	2 (28.57%)	0
Do you think Terf® should be considered for student use in other online courses?	CMPEN 271 (n=34)	25 (73.53%)	3 (8.82%)	6 (17.65%)
	CMSPC 201 (n=7)	5 (71.43%)	2 (28.57%)	0

TABLE IV
SURVEY QUESTIONS ON BEST AND WORST ABOUT TERF®

Questions	Student Responses (representative)
What did you like "best" about Terf®?	<ol style="list-style-type: none"> 1. It was easy to communicate with the professor¹ 2. You felt more a part of the course than your "normal" online class, better interaction between students and the teacher, help see and realize out of textbook information that we were learning (real world uses)¹ 3. The ability to use voice, an online avatar in an interactive world, and the instructor being able to use a webcam all remotely from anywhere in the world, with little to no crashing, made Terf an extremely worthwhile tool. Everything about it was my favorite.¹ 4. I like how TERF enabled an online class to be engaging. When there was a presentation, you could see the other students walking around the room or sitting in the presentation area.¹ 5. Online project exhibition.¹ 6. I liked the ability to walk around a virtual classroom and be able to physically see and hear my fellow classmates, just as in reality.¹ 7. I think it give an online course the ability to stay connected. I like how students can review their work with the professor and have live conversation about it. It really facilitates a positive learning experience!² 8. Everything was great when everything worked. The best part was being able to share our screen in office hours so the professor could look at our code.² 9. The fact that you can share your screen!² 10. It is very easy to communicate.²
What did you like "least" about Terf®?	<ol style="list-style-type: none"> 1. There was some lag.¹ 2. At times it was difficult to use.¹ 3. Had some issues with my mic, but I don't think it was the TERF software. I think it was my hardware or settings on my PC. 4. The price.¹ 5. The poor graphics.¹ 6. It took so much processing power that it made my computer run slow.² 7. A lot of lag issues and weird things (bird noises), I think it took too long to logon overall.² 8. Lagging.²
	Notes: ¹ Denotes responses from Digital Design Course (2016 and 2017) ² Denotes responses from Computer Science Course

IV. CONCLUSIONS AND FUTURE DIRECTIONS

The feedback from the students was positive overall, and the virtual world technology allowed the instructor to assign collaborative activities to strengthen student-to-student and student-to-faculty interaction in two online courses that would not have been possible without the virtual world tool. Although the academic performance overall in both cases was comparable to online offerings of the same course without the use of virtual world support, the virtual world technology improved engagement and facilitated student team collaboration in the engineering online course, basically expanding the "scope" of the courses. In particular, the virtual technology supported: 1) the addition of special topics lectures and demonstrations in robotics in a group setting, which facilitated discussion; 2) virtual office hours with screen sharing for mentoring; and 3) a poster session exhibit with 3D models for team projects. While other collaborative tools may support student interaction and collaboration, the collaborative design and presentation of team poster exhibits with the use of 3D models in a persistent, immersive online environment is not supported by traditional collaborative software such as Google Hangouts and other similar tools. The virtual

activities conducted in both courses were the same and the results from the survey indicated consistency across the two courses. The current author plans to use this tool in additional online offerings and evaluate with a larger sample size. It is also of interest to apply this virtual technology to enhance collaboration and engagement in additional courses in the engineering department and also to potentially partner with other faculty across disciplines outside of engineering. It is also intended to explore the benefits of customized environments, analytics, and the Python scripting tool for more interactive experiences in the 3D environment, including virtual laboratory experiences. Based on the student feedback, the author also intends to provide additional orientation and training for the students, as well as to investigate some of the performance and voice-related issues reported.

As online engineering courses become more prevalent, virtual world technology, such as demonstrated by the Terf® platform, will play an integral role in offering a more engaging and academically rich environment, especially with regard to student collaboration, engagement, communication, and interaction with 3D models. As virtual world technology advances, it is anticipated that 3D virtual

world technology will be integrated into course and learning management systems and textbook resources.

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