Using Virtual Reality in Biomedical Engineering Education

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This study explored virtual reality (VR) as an educational tool to offer immersive and experiential learning environments to biomedical engineering (BME) students. VR and traditional two-dimensional (2D) videos were created and used to teach required communication skills to BME students' while working with clinical partners in healthcare settings. The videos of interdisciplinary teams (engineering and nursing students) tackling medical device-related problems, similar to those commonly observed in healthcare settings, were shown to BME students. Student surveys indicated that, through VR videos, they felt more immersed in real-world clinical scenarios while learning about the clinical problems, each team-member's areas of expertise, their roles and responsibilities, and how an interdisciplinary team operated collectively to solve a problem in the presented settings. Students with a prior in-person immersion experience, in the presented settings, reported VR videos to serve as a possible alternative to in-person immersion and a useful tool for their preparedness for real-world clinical immersion. We concluded that VR holds promise as an educational tool to offer simulated clinical scenarios that are effective in training BME students for interprofessional collaborations.

[DOI: 10.1115/1.4048005]

Keywords: virtual reality, interprofessional communication, biomedical engineering education, clinical immersion, simulation

Introduction

The collaborative nature of biomedical engineering (BME) profession where teams of engineers and healthcare providers work together to offer solutions for existing healthcare needs warrants interdisciplinary teaching environments within the BME curriculum. Clinical immersion has proven to be an effective tool in offering better preparedness of biomedical engineers in the real-world. While the efficacy of clinical immersion is proven in biomedical engineering education, it poses several limitations in accessibility and availability for large student cohorts. Recent work from our group reported simulation-based training (SBT) as an option to experience clinical immersion [1,2]. SBT included interdisciplinary teams of BME and nursing students working on a clinical problem through simulation manikins or standardized actors. However, limitations in forming interdisciplinary teams of engineers and healthcare providers, and access to simulation laboratories in educational settings still pose challenges. Efforts to seek alternative teaching tools and technologies that can create and enhance interdisciplinary experiential learning environments are still warranted.

For over two decades, virtual reality (VR) has served as an educational tool in healthcare training by creating virtual worlds for student immersion and experience [3–6]. VR tools typically incorporate existing computer technologies and scientific visualization to create a three-dimensional (3D) graphical environment where a participant would experience an environment that simulates the real world. VR technology has also been widely used to simulate surgical procedures [7–11], medical emergencies [12], and develop social and cognitive skills in children [13]. Additionally, VR tools have been used to teach anatomy and physiology in nursing and other clinical educational settings where the students have the ability to explore and interact with the anatomical models [14–16]. Medical education has further explored using VR in

teaching scenarios/cases that no other entity can replicate and helped overcome distance, time, and safety factors limitations [17]. Student learning and retention has been shown to be achieved through VR experience [18]. Altogether, the use of VR for medical and critical care training has been well established.

This study focused on using VR technology to create experiential learning environments of interdisciplinary settings for BME students. BME students watched VR and traditional two-dimensional (2D) videos of interdisciplinary teams working together in two simulated clinical settings and completed surveys to assess the efficacy of VR videos, over traditional 2D videos as well as in-person immersion, in achieving the learning objectives, namely, an understanding of the required communication skills in clinical settings, problem solving strategies, and roles and responsibilities of various professionals that are involved in the patient care.

Methods

Simulation Scenarios. Two engineering faculty, one nursing faculty and a simulation expert developed two simulation lab scenarios to teach and assess collaboration and communication skills in interdisciplinary teams of BME and nursing students. The scenarios were geared toward medical device-related problems that are often observed in real-world clinical settings. These scenarios challenged the teams to identify problems and develop solutions through effective communication and collaboration. Scenario A involved malfunctioning of an intravenous (IV) pump (Alaris Pump, West Bloomfield, MI) that was attached to a standardized patient. The students were provided a brief medical history chart of the patient before entering the room. They were also given verbal instructions to identify the problem and propose a solution. For scenario B, the teams entered the clinical room with a malfunctioning oxygen concentrator (Intensity, Ball Ground, GA) and had to identify the problem with the machine and propose a solution (Fig. 1(a)). The teams had a total of 10 min to complete the tasks for each scenario.

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Manuscript received May 1, 2020; final manuscript received July 23, 2020; published online September 11, 2020. Assoc. Editor: Alisa Morss Clyne.

Fig. 1 (a) Communication simulation lab details. Two scenarios were developed that involved medical device-related problems. 12/22 BME students participated in the in-person immersion with a nursing partner. (b) 16/22 BME students participated in video immersion of which eight BMEs had in-person immersion (cohort 1) and other eight BMEs had no in-person immersion experience (cohort 2). (c) During video immersion, each student watched four scenes (two per scenario), in both, VR and traditional 2D modes.

In-Person Immersion: Student Participants. The developed scenarios (developed over 2 months prior to offering the courses) were implemented as Communication Simulation labs in a 300-level biomedical device engineering course ($n=22$ BME) that was cross-listed with a 300-level evidence-based practices nursing course ($n=12$). In-person communication simulation labs were conducted with the BME ($n=12$) and nursing students ($n=12$) who volunteered to participate in the optional lab sessions of the courses that was being recorded for this study. On the day of the lab, 12 teams, each comprising one BME and one nursing student, attended one of the two simulation scenarios in the clinical classrooms of the Center for Simulation at the School of Nursing (Fig. 1(a)).

Video Development. During the in-person simulation labs for each team, an Insta360 EVO 3D-180 deg VR camera² mounted on a manikin using a custom-built head mount was used for video recording the activities, which was defined as a scene. This VR camera captured the scene using two adjacent lenses, each with a horizontal and vertical field of view of 180deg, giving a fully immersive view of the scene. Further, the separation of the two lenses enabled depth perception using the principles of stereophotogrammetry. Within two weeks, postprocessing of the videos was done in Adobe Premiere Pro.³ The videos were trimmed and then visual elements such as intro, outro screens, and electronic patient

record were added to the video project timeline. For all 12 videos, two versions of the final cut were created, namely, VR version and traditional 2D (rectangular 2D) version (Fig. 1(b)). In the VR version, the final edited video had a 360deg horizontal and 180deg vertical field of view at a 5760×5760 resolution for viewing on a VR headset. In the traditional 2D version, a window was chosen that captured the most activity on the scene. Then, a VR projection effect was applied to flatten the scene at a 1920×1080 resolution for viewing on a rectangular screen, which is referred to as traditional 2D videos (Fig. 2).

Video Immersion: Student Participations. Two weeks post-conducting the in-person simulation labs, all BME students that were enrolled in the 300-level biomedical device course and volunteered to participate in this study (16 out of 22) were grouped into two cohorts, namely, cohort 1: students with in-person communication simulation lab immersion ($n=8$), and cohort 2: students without in-person communication simulation lab immersion ($n=8$) (Fig. 1(b)). Each student, independently and individually, watched two scenes per scenarios (a total of four scenes each in VR and 2D modes) on a computer screen for traditional 2D videos, and using a VR glasses (Funspark, VR glasses, Google, WA), provided by the instructor to standardize their VR experience (Fig. 1(c)). VR videos immersion was limited to just watching videos in a 3D space and did not involve any decision-making. Students with in-person communication simulation lab immersion (cohort 1) did not watch their own videos. All 16 students were given a week to watch all eight videos and complete

²www.insta360.com/

³www.adobe.com/

Scenario A: IV Pump

VR

2D

Scenario B: Oxygen Concentrator

VR

2D

Fig. 2 Video (VR and 2D) images of teams with a BME student and a nursing student in scenario A (left): with a standardized patient attached to an IV pump, and in scenario B (right): with oxygen concentrator

the anonymous surveys related to course learning objectives and experiential learning environments of the videos.

Surveys. Surveys to evaluate video-based learning using the VR and traditional 2D videos, and comparisons with in-person immersion experience were developed by the two-course faculty and a simulation subject matter expert. Four additional teaching faculty members reviewed the survey questions to confirm construct validity. Details of the surveys are listed below (Table 1). All surveys were approved by the Institutional Review Board and were anonymously collected using online Qualtrics forms (Qualtrics, Inc., UT). Learning objectives were assessed through an in-class assignment for cohort 1 (for in-person communication lab immersion), and through online surveys for both cohorts (for all videos). The survey questions were either measured on a 1–5 Likert-type scale, Yes/No response or open-response items. Inductive thematic analysis was used to identify emerging themes from the open-responses.

Results

Video Immersion and Learning Objectives. After watching the videos, students answered questions that were directly related to the learning objectives of the communication simulation labs. These objectives included identifying: the clinical-based problem, steps taken to identify the problem, and active member of the team; understanding the role of nursing partner; and assessing the engineer's performance in each scene (Table 2 and Fig. 3). Their answers remained unchanged after watching the same video for the second time through VR glasses or on a traditional screen. The videos were randomly assigned such that the students could have watched a scene through VR glasses first and then on a traditional screen, or vice-versa.

Through watching the videos, 90% of students agreed to have an understanding of the roles of nursing and BME partners in problem solving in clinical scenarios. Over 75% of students also reported that watching examples of a scenario helped better understand the communication skills required in healthcare settings (Fig. 3). All students were also able to compare various scenes they watched and rate the four teams for their

communication skills in their respective scenarios and offer feedback on each team's performance.

Virtual Reality Versus Traditional Two-Dimensional Videos. Hundred percent of students reported VR videos to lead to a more immersive experience as compared to traditional 2D videos. VR was also preferred (66%) when assessing communication skills between nursing and BME partners. VR also served as a preferred tool for understanding collaborative nature of the biomedical engineering profession (63%), knowledge of the other profession (63%), and shared responsibility (66%). Furthermore, VR was the more preferred tool for developing skills leading to speaking up to other professions (63%) (Fig. 4). When assessing various teams, 30% students rewatched the videos and all used VR glasses over traditional 2D screen.

In-Person Immersion Versus Video Immersion. Students in cohort 1 had also attended in-person communication simulation labs. Each student attended only one lab and therefore was exposed to only one of the two scenarios. Also, none of the participants watched their own video. Student survey responses from this cohort indicated video immersion to be a promising alternative (100% gave a probably yes or better) to simulation in real-world scenarios. They also indicated the videos to offer a safer setting when having standardized patients (90%). Additionally, students reported VR videos to serve as a tool for better preparedness of students for operating room visits, which are a part of this course for clinical needs finding and has been detailed previously (Fig. 5(a)) [1]. When comparing in-person immersion to video immersion, the students reported VR to simulate their in-person experience more closely (100%), and reported VR to serve as an alternative to in-person simulation lab experience (60%). Furthermore, VR was a more preferred tool for understanding task complexity (90%) (Fig. 5(b)). Overall, students (100%) strongly recommended VR video immersion for future course offerings.

Discussion

This study implemented student immersion using videos of simulation-based clinical settings to promote BME student

Table 1 List of survey questions

Category details	Questions
Learning objective-based questions	
Scene-based learning (after every video)	<ol style="list-style-type: none"> 1. What was the problem? 2. What steps were taken to get to the problem (list at least 2 steps)? 3. Which member of the team was more involved? 4. Did the nursing partner help understand the clinical scenario? 5. How did the nursing partner help understand the clinical scenario (give two examples)? 6. Give two examples of good communication from engineer? 7. What could have the engineer done differently? 8. Give two suggestions for the engineer in the team?
Performance-driven question (after watching both scenes of a scenario)	<ol style="list-style-type: none"> 1. Which one of the two teams had better communication skills? 2. What were some good steps taken by the engineer (list at least two) in the team that performed better? 3. Did watching two examples per scenario help better understand the communication skills required in healthcare settings?
Overall learning objectives (After watching all four scenes)	<ol style="list-style-type: none"> 1. Do you understand the role of nursing and engineering partners in problem solving in clinical scenarios? 2. Which team, among the four teams, best understood the clinical problem? 3. How would you rate each team's interactions/communication skills (1: best and 4: least) among the four examples? 4. List a few learning points (atleast 2) from the best team you rated above. 5. Did you rewatch the video to answer any of the questions above? 6. Which video did you prefer? 7. Why? 8. For future teaching, which of the two video modes would you recommend?
Experiential learning-based questions	
VR versus traditional 2D videos (After watching each scene)	<ol style="list-style-type: none"> 1. Which of the two videos led to a more immersive experience? 2. Which of the two is more preferred tool for assessing communication skills between the nursing and engineering partners? 3. Which of the two is more preferred tool for understanding collaborative nature of your profession? 4. Which of the two is more preferred tool for understanding knowledge of other profession? 5. Which of the two is more preferred tool for developing skills leading to speaking up to other professions? 6. Which of the two is more preferred tool for understanding shared responsibility?
In-person immersion versus video immersion (cohort 1 only)	<ol style="list-style-type: none"> 1. Did the videos simulate real-world scenario? 2. Which of the two videos simulated the real-world scenarios more closely? 3. Which of the following can be a preferred as an alternative to in-person immersive simulation lab? 4. Watching other team interact helped better understand communication lab? 5. Did you feel safer working through the video than in person, especially in scenario 1 with standardized patient? 6. If yes, then which mode of video was more effective in feeling safe yet felt real? 7. Did the videos help understand task complexity? 8. Which of the two is more preferred tool for understanding task complexity? 9. Could the videos help in better preparedness of your operating room visits? 10. If yes, then which mode of video is more effective?

training in required communication skills while collaborating with healthcare professionals. Effective communication skills have been identified as an essential component of all healthcare curricula [19,20]. A typical healthcare team comprises of individuals from multiple disciplines, and standardized interdisciplinary communication is essential to enhance the efficacy of the team. Curriculum changes that increase opportunities to practice communication among interdisciplinary team members are needed to prepare an effective team of healthcare professionals. This is even more important for biomedical engineers, who are critical to finding solutions for existing problems in these settings.

Clinical immersion experience is a commonly employed approach to create interdisciplinary training environments for BME students [21–24]. However, the extent of these experiences typically ranges from one-time visits to a few weeks of clinical visits. While these experiences can be invaluable, they are limited with their broader translation to other clinical settings, thereby hindering adaptive learning goals of BME education. Also,

opportunities to observe and learn from other students, while they are immersed in a clinical setting, are unavailable due to ethical limitations of recording students while immersed in clinic. Simulation-based scenarios can help overcome these limitations by offering varied clinical immersion opportunities that are controlled, repeatable, and recorded for more effective learning through student reflections and teaching through instructor's feedback [25–32]. Efficacy of simulation-based training has been reported previously in teaching teamwork, communication, and collaborative learning [1,2,20]. While simulation-based training can offer effective immersion experiences, the cost associated with simulation manikins, access to simulation laboratory, and creating interdisciplinary environment with BME and other healthcare profession students are not always feasible.

Through a backward design approach, where the desired specific learning objectives are known, we explored video immersion to offer experiential learning environment to help meet the learning goals of our communication simulation labs [33]. The videos

Table 2 Exemplar student responses on learning objective for communication simulation lab after watching VR and traditional 2D videos

Learning-based questions for each example	Student responses for both scenarios
What was the problem?	<p>“IV was not working properly”—scenario A</p> <p>“The oxygen machine was not working properly”—scenario B.</p>
What steps were taken to get to the problem (List at least 2 steps)?	<p>“First, the nurse noticed that there was nothing to keep the IV in place and then noticed that the top part of the IV was not dripping and finally that there was no water collecting in the bag of the patient”—scenario A.</p> <p>“The nurse checked the tubing of the machine for problems. The engineer checked the machine for possible errors”—scenario B.</p>
Which member of the team was more involved?	<p>“Nurse”—scenario A</p> <p>“Both”—scenario B</p>
Did the nursing partner help understand the clinical scenario?	<p>100% Definitely yes—scenario A</p> <p>100% Definitely yes—scenario B</p>
How did the nursing partner help understand the clinical scenario (give two examples)?	<p>“She explained what a tegaderm was closer to the beginning. During the rest of the steps along the way she would explain her actions”—scenario A.</p> <p>“He explained to the engineer what the device was used for and what he knows about the device. He had very good communication with the engineer, so they were able to work together to solve the problem”—scenario B.</p>
Give two examples of good communication from engineer?	<p>“The engineer talked to the nurse about possible steps she might have missed when setting up the IV. The engineer observed that the IV was not dripping properly”—scenario A.</p> <p>“The engineer readily asked questions to understand the situation more and communicated to the nurse what he was doing to the machine”—scenario B.</p>
What could have the engineer done differently?	<p>“The engineer could have been more hands on”—scenario A</p> <p>“The engineer checked out the machine for any problems. While he was doing that, he should have communicated more with the nurse to let him know what he was doing”—scenario B.</p>
Give two suggestions for the engineer in the team?	<p>“The engineer should be more hands-on. He should also ask more questions to help understand the problem and learn more about the situation”—scenario A.</p> <p>“Keep asking good questions and maybe don’t press unfamiliar buttons”—scenario B.</p>

Fig. 3 Efficacy of video-based learning in achieving Communication Simulation lab’s learning objectives. All responses are reported as percentages.

were created in scenarios where students attained the learning objectives previously during their in-person lab visits. From a student perspective, watching various teams interact in the same scenario helped them better understand not only their own but also other profession’s expertise, roles, responsibilities, and challenges. By comparing performances of various teams and having the ability to rewatch the scenarios offered the students a template for their own decision-making process, while offering comparative and repeated learning opportunities that were previously missing in clinical immersion and simulation-based training approaches. From an instructor’s perspective, having standardized course content through these videos offered well-defined course

learning outcomes and a more standardized assessment of student learning. Additionally, the created videos will serve as teaching resources for future offerings of the course while overcoming the limitations of clinical immersion and simulation-based labs such as limited accessibility, availability, and scheduling conflicts.

Existing literature on using videos, such as virtual reality, as educational tools utilizes the SMART (specific, measurable, attainable, relevant, and timely) goals [34]. This study also utilized these goals in assessing the efficacy of videos in attaining learning objectives of the communication simulation labs. The specific (S) goals were to have students understand the required communication skills in clinical settings, problem solving

Fig. 4 Student assessment of VR versus traditional 2D videos for the four scenes recorded in the two scenarios. All responses are reported as percentages.

Fig. 5 Responses from cohort 1 that had an in-person immersion experience followed by video immersion using VR and traditional 2D videos. (a) Student feedback on VR videos and (b) VR versus traditional 2D videos. All responses are reported as percentages.

strategies, and roles and responsibilities of various professionals involved in patient care. These learning objectives were measured (*M*) using surveys created to assess student learning through both traditional 2D as well as VR videos. The goals for the videos were attainable (*A*) based on the previous offering of the labs with in-person immersion. The labs were very relevant (*R*) to the preparedness of biomedical engineering students in their profession. The labs could not have been more timely with the current impact of the COVID-19 pandemic requiring social distancing and remote learning.

An important assessment to support VR videos as a more effective teaching tool over traditional 2D videos was also made in this study. While student-learning outcomes were attained through both VR and traditional 2D videos, students reported VR videos to offer a more immersive experience. Learning objectives for assessing communication skills between BME and nursing partners, understanding collaborative nature of the biomedical engineering profession, knowledge of other professions, shared responsibility, and developing skills leading to speaking up to other professions were better attained through VR videos. Student feedback on why they preferred VR videos over traditional 2D videos unanimously indicated students perceiving themselves to be in the room while watching the videos through VR glasses, which enhanced their experiential learning.

In summary, preparing future biomedical engineers to have an ability to work in dynamic clinical environments warrants a more authentic approach to education than a traditional classroom and a

one-time or short-term clinical immersion experience. This study offers VR videos as a promising tool to enhance the immersion experiences for BME students in various simulated clinical scenarios. While limited availability of the desired VR videos, expertise required for developing the desired videos and the costs associated with VR cameras and glasses cannot be overlooked, this study confirms that the investment of time and money to create VR videos and acquire VR resources was worthwhile in creating an enhanced learning experience for BME students. We also recognize some limitations with the scale used in the survey questions of this study. Our future work will aim at overcoming the limitations of this study while exploring virtual immersion in global clinical settings thereby enhancing global awareness of medical device-related issues in future cohorts of BME students.

Acknowledgment

We thank the staff at our School of Nursing for offering simulation immersion and SBT lab experiences.

Funding Data

- National Institute of Biomedical Imaging and Bioengineering of the National Institutes of Health (Grant No. R25EB023857; Funder ID: 10.13039/1000000070).

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