A Mixed-Reality Pedagogical Innovation in the Reality of a New Normal

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ABSTRACT

All of us will never forget the year 2020. Those of us in higher education will perhaps reflect on the Spring 2020 semester as a turning point in our approach to education. To prepare higher education for future crises and to create a more buoyant, elastic, and resilient educational paradigm, it is imperative that we learn, right now, from the COVID-19 crisis. This is of particular importance for *engineering education*, which relies on experiential pedagogical practices that are incongruent with online learning environments. Since 2014, a multi-institutional interdisciplinary team has been addressing improvements to engineering education through *mixed reality gaming*, an educational model that integrates traditional classroom experiences (e.g., lectures, laboratory work) with virtual activities (e.g., game-based learning). We posit that a mixed reality gaming educational model may help mitigate the impact COVID-19-like crises. Herein, we reflect on implementations of a mixed-reality gaming activity in an introductory geotechnical engineering course on five campuses during the pivot to remote

learning, which will be remembered as the hallmark of the Spring 2020 semester. Ultimately the data gathered from these implementations will be used to study the effectiveness of mixed reality gaming on student learning outcomes (specifically the ways in which student and instructor motivation shape and are shaped by this educational model) to understand (1) the role of mixed reality gaming; and (2) instructors' and students' motivational shifts during such crises.

INTRODUCTION

The COVID-19 crisis is uncharted territory, as a disruption of the educational system at this scale has not been witnessed thus far. However, due to continuing increases in world population and global interconnectedness on the one hand, and the impending impacts of climate change and antibiotic resistant superbugs on the other, COVID-19 may not be the last crisis of this scale. In fact, it can be expected that the intensity and severity of such (health) crises will only increase. Thus, it is imperative to learn, right now, from the current situation to better prepare higher education for future crises and to create an educational paradigm that is more buoyant, elastic, and resilient. For *engineering education* in particular this is important because, at its core, it is experiential (National Academy of Engineering 2005). A quality engineering education is marked by hands-on learning, "do-learn" environment, interdisciplinary and teamwork experiences, integrated learning opportunities, design, and many other components that are difficult to achieve through online education and which, to date, have not been achieved well in an online learning environment.

This project team has been testing how engineering education can be improved through *mixed reality gaming*, an educational model that allows for an authentic integration of traditional classroom experiences (lectures, laboratory work, field data, software models and simulations) with virtual activities, such as game-based learning (Abdoun et al. 2016; Bennett et al. 2017). The current work aims to understand the ways in which mixed reality gaming (through the *GeoExplorer* activity) can improve engineering education by creating opportunities for *practical experience* currently lacking in traditional engineering curricula (Feisel & Rosa 2005) and by fostering *engineering judgment* (Weedon 2016), a critical competency for practicing engineers. In addition, the work focuses on understanding students' and instructors' *motivational responses* to and *engagement* with STEM education (Dillon et al. 2016; Pintrich 1999). We believe that mixed reality gaming is an educational model that may help to mitigate the impact caused by crises, such as COVID-19, where the entire "in-person" education paradigm instantaneously shifts into an online one. The data collected during the Spring 2020 semester on such an abrupt shift will help the educational community understand and prepare for an educational paradigm that eventually may be more virtual/online. Because we already had implementations scheduled for the Spring 2020 semester and the opportunity arose to study the implications of the COVID-19 crisis on higher education, our surveys were modified mid-semester with the aim to understand whether and in what ways mixed reality gaming remains robust in the face of a crisis, particularly in this wave of "forced" online education. The preliminary findings included herein reflect student and instructor experiences from the *GeoExplorer* activity in the Spring 2020 semester. Ultimately and beyond the scope of this paper, our goal is to understand whether and how instructors' and students' motivational attitudes shift during crises, such as COVID-19, as well as whether and to which extent mixed reality gaming may serve to help support positive shifts in instructors' and students' motivations during these times. The following research question is guiding this work:

How is mixed reality gaming experienced by instructors and students during COVID-19 in teaching introduction courses in geotechnical engineering?

RATIONALE

The COVID-19 crisis provides an opportunity to study a severe disruption in higher education and the role of game-based learning in such a crisis. We already had access to a great number of undergraduates through our planned implementations. In the Spring 2020 semester, we included additional questions about COVID-19 on our surveys and invited students for an interview to talk about game-based learning and COVID-19. We believe this work is critical right now to gain insight into this crisis and its impact on student learning. In this section, we explain why we are exploring game-based learning in engineering education, what our current effort entails, and what we seek to study in the context of COVID-19.

Game-Based Learning in Engineering Education. In the past decades, gaming has gained widespread attention as a powerful educational tool (Harteveld 2011), including engineering education (Mayo 2007). The most recent engineering education literature review found 191 manuscripts published since 2000 where an educational game was used in an undergraduate engineering course (Bodnar et al. 2016). Of these, only 62 discuss relevant learning outcomes, of which 87% report positive findings. This suggests a dearth in empirical evidence about effectiveness of game-based learning, which was cited by other authors as well (Deshpande & Huang 2011). We believe that a mixed reality approach may foster adoption of game-based learning in engineering education. By "mixed reality" we mean the combination of traditional curriculum elements (e.g., analyzing data, physical lab) with virtual ones (e.g., field-testing in a virtual environment). The current crisis provides a unique opportunity to learn from the use of mixed reality gaming.

GeoExplorer. *GeoExplorer* is part of a larger effort to transform engineering education with game-based learning, specifically targeting civil engineering content. The game's vision is to provide students experiential opportunities with various field-testing techniques used in civil engineering context. Our first step in developing *GeoExplorer* was to focus on Cone Penetration Testing (CPT). Students traditionally get little to no hands-on exposure with this field-testing technique due to its complexity and cost. In the game, students join a fictitious engineering company called Terra Inc. as interns by applying on the company's website, and then complete scenarios in a realistic 3D environment (see Figure 1 and 2). As a part of the game, students retrieve CPT data and graphs that they analyze using traditional software and then write a report.

Figure 1. Driving the CPT truck (left) and inside the CPT truck (right).

Figure 2. Interpreting the CPT computer (left) and communicating with the boss (right).

APPROACH

In Spring 2020, we implemented the CPT module of *GeoExplorer* at five universities: New York University (NYU), Manhattan College (MC), California State University Fullerton (CSUF), Rensselaer Polytechnic Institute (RPI), and Jackson State University (JSU). To study the impact of COVID-19, we made the following additions to our data collection with *GeoExplorer*. First, our survey instrument included items pertaining to the COVID-19 crisis. Second, we conducted a set of interviews with faculty and students with the focus on COVID-19. To date, 9 student interviews have been completed with representation from NYU, MC, and RPI; additionally, 1 instructor from each study site provided written reflections on the Spring 2020 implementation. In this section, we provide further details on our approach.

Curriculum. The Spring 2020 implementations were conducted in the second half of the semester in introductory geotechnical engineering courses with a laboratory component. The curricula vary slightly between campuses depending on whether this course is a stand-alone required offering or is part of a sequence, though the core topics are similar: origin of soils, phase relationships, classification of soils, permeability, effective stress, seepage, consolidation, shear strength, slope stability, and bearing capacity. As an example, at RPI, the targeted course was Introduction to Geotechnical Engineering, a 4-credit required course for civil engineering majors that includes 4 hours of lecture per week and 2 hours of laboratory experiments per week for approximately 9 weeks of the 15 week semester. This course is normally taken in the spring of the sophomore year along with three other introductory courses to the other civil engineering concentration areas (structural, transportation, and environmental). Seventy-three students were registered in this course in the Spring 2020 semester. A version of the *GeoExplorer* activity had been implemented in five prior offerings of the Introduction to Geotechnical Engineering course at RPI. A typical implementation was described in Bennett et al. (2020). The spring 2020 implementation was far from typical. The core components of the activity, the lecture and the game play, were of course conducted remotely. The lecture was delivered in a synchronous session during the scheduled class lecture time on April 23 and virtual office hours in a synchronous session during the scheduled class lecture time on April 27 served as the troubleshooting time for gameplay in the virtual environment. After sharing the instructor's selfie through the activity handout, students were asked to send a selfie of themselves playing during the April 27 class time (Figure 3). Both synchronous sessions (along with all other synchronous content) were recorded and shared with all students through an Unlisted YouTube channel. The primary communication method was announcements through the learning management system (Blackboard), which had been in place since the beginning of the semester. The option to immediately email all students with any Blackboard announcements was always used. The *GeoExplorer* activity was vaguely included on the syllabus as one of nine laboratory experiments – "Cone Penetration Test (Virtual Experiment)" – but was first referenced in the course through a Blackboard announcement on April 21. Between April 21 and April 29, eight Blackboard announcements were used to communicate new information or reminders regarding the *GeoExplorer* activity.

Survey. We included five 7-point Likert scale items on students' learning experience in the course in general ("Please rate how much you agree or disagree with the following statements about the ways in which you are experiencing your learning in this course at the moment during the COVID-19 crisis"), and six 7-point Likert scale items on students' learning experience with the CPT Virtual Environment (VE) specifically ("Please rate how much you agree or disagree with the following statements about the ways in which you experienced the CPT Virtual Environment (VE) as part of the *GeoExplorer* activity during the COVID-19 crisis"). Table 1 provides an overview of all ten items. After each set of five items we asked students to elaborate in an open response on their answers. At the end of the post-survey, we asked students if they were interested in participating in an interview for a compensation of $35.

Figure 3. Selfies taken during the *GeoExplorer* activity at home.

Interviews. We conducted interviews with students who expressed an interest in being interviewed and set up a semi-structured interview, intending to last approximately one hour but frequently exceeding two hours. The interview has four different sections, each with a set of questions: general life situation, online learning, *GeoExplorer*, closing section. Through these student interviews we aimed to get a more in-depth understanding of the student perspectives. We also contacted the instructors of each site by email and asked them to reflect on the implementation, and then followed up with each one of them.

Participants. A total of 214 students participated across the pre/post-surveys. Of these, 169 students participated with the post-survey that included the COVID-19 related questions, and as follows from the five institutions: CSUF (n = 43), JSU (n = 11), MC (n = 38), NYU (n = 23), and RPI (n = 54). The average age was 21.12 years old (SD = 2.54). Participants self-identified as a man (64%), woman (32%), or preferred not to answer (4%). While playing *GeoExplorer* was required as part of the curriculum, participation in this research was voluntary and we obtained informed consent in advance from each student.

STUDENT AND INSTRUCTOR REFLECTIONS

In this section, we provide the preliminary findings from the COVID-19 related survey items and the interviews with students and instructors in order to get an initial understanding on how both students and instructors experienced mixed reality gaming during COVID-19.

Student Closed Survey Responses. Table 1 shows the descriptive statistics on the 7-point Likert scale items. Regarding students' learning experience in general, we can draw a few conclusions. First, students find it clearly more difficult to concentrate (Mdn = 6, IQR = 5-7). Second, overall there is no clear impact on motivation, learning online, or spending time effectively (Mdn = 4 for all); however, especially for motivation and time we see that the tendency is to disagree and thus that a fair amount of students do feel less motivated and are not able to spend their time effectively. Third, students tend to agree that the quality of the learning has decreased because of the online format (*Mdn* = 5, *IQR* = 4-6).

From the questions related to the VE, we learn the following. Importantly, students seem to not have difficulty concentrating while playing the VE (*Mdn* = 4, *IQR* = 2-4) and disagreed that they did not learn from playing (*Mdn* = 3, *IQR* = 2-4). Furthermore, while students do not agree strongly with how the VE made them feel more motivated or escape from the current crisis (*Mdn* = 4), students do tend to agree it is an escape from the current online learning environment and wish that more of their current school work would make use of this technology (both *Mdn* = 5, *IQR* = 4-6).

Table 1. COVID-19 related survey items and their results.

Item	Description	*Mdn*	*IQR*
Learning experience in general in the course			
1	I find it more difficult to concentrate on this course.	6	5-7
2	I feel more motivated to perform in this course.	4	2-4
3	I recognize that I can easily do this course online.	4	3-5
4	I can spend my time more effectively in this course.	4	2-4.5
5	I feel the quality of my learning in this course has decreased because of the online format.	5	4-6
Learning experience with the CPT Virtual Environment (VE)			
6	I found it difficult to concentrate while playing the VE.	4	2-4
7	Playing in the VE made me feel more motivated to perform in this course.	4	4-5
8	I felt I was not learning from playing the VE.	3	2-4
9	Playing in the VE felt like an escape from the current online learning environment.	5	4-6
10	Playing in the VE felt like an escape from the current crisis.	4	4-5
11	I wish more of my current school work would include the use of a VE.	5	4-6

Student Open Survey Responses. Using thematic analysis, we find four major themes in the student responses to elaborate on their general experience. First, they speak about their "personal life" and how this has been impacted, for example in terms of the activities they can do and how they cope with school and the stress that the pandemic is providing. Second, students refer to the "setting" of where their learning takes place in. Predominantly, students call out the lack of hands-on learning or access to labs:

"it impacted it a lot since I'm not able to witness the lab work in real life and interact physically in the lab activities. the geoexplorer does help us to understand but it still different than doing the lab with our own hands."

Third, students talk about the impact it has on their "academic performance". The majority indicates the impact has been negative, suggesting they have more difficulty managing their time, are less productive, have to do more work, and find it above-all more challenging to learn. There are, however, a few students who indicate that it does not change much for them and even some point out the positives, expressing they have more time because they do not have to commute for example. Fourth, students indicate how it has impacted their "academic engagement". Specifically, they mention they are not able to concentrate as well on their school work, and feel less motivated:

"Due to quarantine I have difficulty with online courses because distractions are very accessible making it difficult to focus."

In elaborating on their responses about the VE, we find three major themes. The first concerns their "judgment". The majority are positive, particularly stressing how engaging the experience was and that they learned from it, which may in part stem from the contrast of all their other learning activities at that time:

"I really enjoyed [it] because it has been the only form of learning outside ZOOM."

The second theme revolves around the "value" that students perceive from playing the VE. We find here that students in part speak to how *GeoExplorer* at least feels like a form of hands-on or a lab that they are used to getting in their engineering education but more so they express its value as providing much-needed practical field experience. They note how the visualization helps bring the content alive and, as such, gives them a better understanding of the content and how CPT works in reality. The last theme is specific to COVID-19. In addition to expressing how it is different from what seems to be learning through Zoom, students also note of how the experience itself felt as a bit of an escape:

"Playing was an escape from family and current crisis"

Student Interview Reflections. Through the small set of interviews conducted after the Spring 2020 implementations, the project team was bolstered by the observation that students almost universally preferred hands-on experience, but in the majority of cases, where hands-on experience was impossible due to the COVID-19 crisis, students much preferred the virtual environment of *GeoExplorer* to performing labs remotely, e.g., analyzing pre-collected data after watching a recording of a laboratory experiment. One of the interviewees referred to *GeoExplorer* as application in a "semi-hands-on way." Some of the other telling quotes include:

"This type of educational game, it was valuable, it was intrinsically motivating"

"You could say it [*GeoExplorer*] is supplementary, I would actually argue it's more complementary to the class… I feel like it's a lot better explained if you have that experience, if you're actually doing the test itself, and if you're able to analyze from the equipment, like the data, and you're able to go through that process…"

Instructor Reflections. Instructors who participated in the Spring 2020 implementations of the *GeoExplorer* activity were asked to reflect on how the current crisis situation changed their perspective and views of the *GeoExplorer* activity. The best way to share their reflections is in their own words:

"Due to the lack of any other available resources, and with a tremendous amount of camaraderie and support from a wide array of geotechnical educators across different universities, laboratory experiments were video-recorded without the presence of students in the labs. Students watched the recorded experiments and were then provided with a set of data files for analysis. A review of the submitted laboratory reports and analyzed data, however, indicated a general lack of enthusiasm and curiosity among the students. The lack of in-depth analysis of laboratory data was indicative of difficulties we faced to effectively replicate the hands-on experiments with a hands-off distance experience. The general lack of enthusiasm that was evident during the video-recorded laboratory lectures was not observed when the class was introduced to *GeoExplorer*. Students were eager to get their hands on the virtual reality game. Many of them downloaded the software and the program instruction and began to run the program with minimal engagement from myself or my teaching assistant."

"Transitioning from in-person instruction to purely online mode eliminated important pedagogical tools, such as in-class demonstrations, hands-on lab experiments, and internships. It is clear to me that under such circumstances, tools like *GeoExplorer* are extremely valuable. *GeoExplorer* allowed me to demonstrate the application of lessons taught in the classroom in a real-world scenario. Students in turn were able to experience, virtually, these applications, perhaps more efficiently than what would otherwise only become available to them as part of a summer internship. One of the advantages of *GeoExplorer* is that it incorporates real world experience into lessons taught in the classroom, *during the semester, i.e., near real-time*. This one-to-one correspondence of theory with observations can greatly enhance learning. Students no longer have to wait six months or a year to gain real-world experience on the topics learned in the classroom."

CONCLUSION

Our lives will be forever changed by the events that unfolded in the Spring 2020 semester. For those of us in higher education, this may also be a permanent change to our professional lives. Even just considering the short-term impacts of the COVID-19 crisis, it is important that educators learn, right now, from the lessons of the Spring 2020 pivot to online instruction. We believe that a mixed reality gaming educational model may help mitigate the impact of COVIS-19-like crises. Student and instructor reflections captured quantitatively and qualitatively through mixed modes revealed confirmation of this belief. *GeoExplorer* is a tool that is under development to include more practical experience and opportunities for students to develop engineering judgement. The CPT module of *GeoExplorer* utilized by five universities in introductory geotechnical engineering laboratory courses during the Spring 2020 semester proved to be engaging and something different than the new normal of Zoom/WebEx lectures.

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