Mixed Reality Learning Environments in Times of Pandemic: What Can We Learn?

Casey May, Mason Grabowski, Simrun Mutha, Raúl Frías Pérez, Sophia Borovikova, Yevgeniya V. Zastavker
Olin College of Engineering
{cmay,mgrabowski,smutha,rfriasperez, sborovikova,yevgeniya.zastavker}@olin.edu

Victoria Bennett, Tarek Abdoun
Rensselaer Polytechnic Institute
{bennev,abdout}@rpi.edu

Casper Harteveld
Northeastern University
{c.harteveld}@northeastern.edu

***Abstract*—This Work-in-Progress paper focuses on the qualitative aspects of a larger mixed-methods study about *GeoExplorer*, a game-based learning aspect of a mixed reality educational environment where students participate in a mock internship with the goal to complete a geotechnical mission involving Cone Penetration Testing, a civil engineering field technique students traditionally get very little exposure to due to its complexity and cost. This work seeks to understand how mixed reality learning environments, specifically game-based learning, support (i) creation of individualized hands-on learning opportunities, particularly during the pandemic-driven remote learning paradigm, and (ii) students' development along various non-cognitive axes - confidence and motivation. Methods of narrative analyses and grounded theory are used to identify emergent themes in interviews with 10 undergraduate civil engineering students who experienced *GeoExplorer* in their required geotechnical engineering courses. Our preliminary findings indicate that the *GeoExplorer* activity was perceived by students as a novel learning experience, particularly welcomed in a time of remote learning, that motivates them to engage more with content and creates individualized hands-on experiences. Students describe how the activity affects their perceived confidence, often gendered, regarding their ability to perform civil engineering fieldwork. Further analyses of these findings may shed light on the ways in which mixed reality learning environments support equitable learning opportunities for all students.**

***Index Terms*—Game Based Learning, Civil Engineering, Virtual Learning, Mixed Reality**

I. Introduction and Literature Review

The COVID era fundamentally shifted the teaching and learning paradigm and highlighted a lack of sufficient support and resources in the transition to remote learning, particularly in STEM education [1]. Given the lack of infrastructure for online personalized hands-on lab experiences [2], some virtual resources were developed to complement in-person labs, while others served to supplement a curriculum that otherwise lacked opportunities for students to engage in hands-on learning [3], [4]. The original goal of leveraging such virtual environments was to support development of students' positive motivational and other learning outcomes while diversifying learning experiences for all learners [5], [6].

Beyond COVID restrictions, students still face gaps in their learning imposed by extrinsic barriers [7], such as equipment cost, safety, and situations in which experiential learning is not possible (e.g., natural disasters) [6]. Our study focuses on a mixed reality learning experience, i.e., an alloy between a traditional lecture and a game-based learning (GBL) environment that aims to support students' learning. Specifically, this work investigates *GeoExplorer*, a GBL environment that allows students to explore aspects of geotechnical engineering that are too expensive to include in a traditional laboratory or require rare natural events to take place. In the current work, we focus on Cone Penetration Testing (CPT) field testing technique, a method used in geotechnical engineering to investigate soil stratification and its properties.

This study leverages motivational theories, more precisely Self-Determination Theory (SDT) [8], [9], to explore the effectiveness of mixed reality learning environments that engage *GeoExplorer*. Specifically, rich research and empirical evidence based on SDT indicate that instructors' support of students' basic psychological needs for competence, autonomy, and relatedness result in positive motivational, learning, and affective outcomes [8]-[10]. Current literature indicates that compared to traditional labs and lectures, students find GBL environments to be more engaging [12], [4], and promoting of learning by trial and error [13]. For example, in their study, Haruna et al. (2021) find that students experiencing serious gaming and gamification environments report a mostly positive perception of their learning; in contrast, students learning the same content through a traditional lecture-based pedagogy describe a mostly negative perception of the experience [14]. Pointedly, in a GBL environment, feedback can take shape in points/badges which have been demonstrated to engage students with the task at hand [13] and provide powerful contexts for constant information about students' quality of work, which are aspects of autonomous extrinsic motivation associated with positive learning and affective outcomes [15], [10], [11]. In addition, by creating personalized learning environments, GBL supports achievement of individualized learning goals, which can help students build confidence in their ability to complete each learning task and meet each learning goal, an aspect related to psychological need for competence that supports positive learning and affective out-

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comes [16], [10], [11]. In comparison, the psychological need for relatedness that is usually associated with teamwork in traditional labs is mostly absent in most GBL environments [7] by design, as they intentionally provide a more personalized learning experience. Although the research about the ways in which gamification affects student motivation is emergent and is becoming a focus of much scholarship, to date literature in this space is limited both in terms of our understanding of long term effects of gamification on all learners or identifying equitable opportunities for learning for all [17]. What is known and well-documented to date, however, is that the overall gamification of the learning experience does serve to provide a fun alternative to a typical, formal educational activity and, as such, deserves to be better understood empirically [12], [17].

This Work-in-Progress fills the gap in our understanding of students' motivational and other outcomes in a GBL environment through investigation of how students experience *GeoExplorer*. Even more salient to current times, this investigation is performed during the pandemic, which allows for an exploration of the ways in which a GBL environment may support positive motivational and other outcomes in a mostly online paradigm of learning. As this paper leverages the qualitative research paradigm, our goal is not generalizability; rather, we leverage qualitative methods to offer complex, rich, context-specific descriptions of lived experiences through inductive means [18]-[22]. In this way, our findings are grounded in qualitative data we collect, and rather than starting with a priori research questions, we allow research questions and themes to emerge [18], [23]-[27]. Accordingly, our three preliminary emergent themes describe the ways in which *GeoExplorer* serves to (1) promote students' motivation, (2) create an individualized, hands-on learning experience, and (3) affect students' confidence in civil engineering fieldwork.

II. Methods

This qualitative manuscript is a part of a larger mixed-methods study of the effectiveness of mixed reality learning environments in civil engineering. Research study sites represented here include three U.S. universities: two private R1 institutions and one private liberal arts college. At all three institutions, study participants engaged in a required introduction to a geotechnical engineering course, where *GeoExplorer* was introduced as a mixed reality laboratory or project (lecture followed by a GBL experience). *GeoExplorer* engages students to take part in a mock internship that requires completion of a Cone Penetration Testing (CPT) at various sites/missions including farmland, industrial, and coastal land. Students are required to complete at least two missions. At some institutions, the missions are chosen for the students by the instructor, while at others, students choose their missions. Assessment of students' performance is achieved differently at each institution – some leverage only the in-game scoring, while others also require a written report along with the students' in-game scoring.

The data sources for this paper include transcripts of interviews with ten undergraduate students (5 women and 5 men) studying civil engineering. We use a semi-structured, open-ended interview protocol about students' experiences in civil engineering, the shift into remote learning, and the mixed reality learning experience with *GeoExplorer*. Interviews for this study range in length between 1.5 and 2.5 hrs and are all done via the Zoom platform during the time of pandemic. As a way of acknowledging participants' effort and support of this work, each interviewee receives a $40 Amazon gift card upon successful completion of the interview. All interviews are digitally recorded, transcribed, and pseudonymized. Transcripts are then used by a team of eight scholars for further analyses.

In this study, we use narrative analysis and grounded theory methods [18], [4], [17], [23]-[27] to allow for emergence of preliminary research questions and themes. Multiple iterative readings of the interview transcripts result in a series of individual and group descriptive memos, followed by individual and group analytical memos. Analytical memo writing allows for identification of emergent constructs and themes that are then further investigated by additional iterative transcript readings and analytical memos to emerge analytically robust and coherent constructs and themes [18], [23]-[27]. Inter-rater reliability in identifying emergent themes was checked and combined memos were produced for further analysis. Our transcript analyses to date resulted in the identification of several emergent themes, three of which are chosen for this paper.

III. Results and Discussion

Our preliminary analyses indicate that most students enjoy the game-based learning environment afforded by *GeoExplorer*. Following is a discussion of some of our preliminary findings, including the relationship between students' engagement with *GeoExplorer* and motivation, individualized, hands-on learning, and student confidence to perform fieldwork.

A. *GeoExplorer and Promotion of Motivation*

The first theme emergent in our analyses focuses on the relationship between the *GeoExplorer* activity and promotion of students' motivation. When discussing *GeoExplorer*, students share multiple ways in which they engage with and are motivated by the activity. For example, students feel that the *GeoExplorer* activity's "unpredictability" or departure from "typical class structure" "spark[s] some of that motivation" and "lift[s] [their] spirit a little bit," particularly during the time of COVID.

Similarly, students express positive affect and feel more motivated by the non-educational aspects of the game. For example, as a part of their mission within *GeoExplorer*, students drive a CPT truck toward a specific location, a task they refer to as "exciting" and "a good amount of fun." In some cases, when speaking about their learning environments during the COVID era of remote learning, students refer to the game as a way of bringing back some of the "excitement" that they used to feel "in the labs portion … of the course." In their reflection on the gaming aspects of the learning experience, students also hypothesize that the game was intentionally designed for enjoyment. For example, Jack shares,

> *I got the sense that the creators valued us enjoying the game, and also us learning from it.*
>
> - Jack Whitehouse, Clearlake University

In addition to describing *GeoExplorer* as enjoyable, many students ponder about the ways in which this activity prepares them for their future careers by creating a learning experience that is both enjoyable and guilt-free. In fact, one study participant refers to his engagement with *GeoExplorer* as ”two hours of just good nutritional video games.”

Students also share that *GeoExplorer* allows them to learn through making mistakes, removing the fear of penalty that comes with mistakes in more traditional environments. Moreover, many students report the game design, which allows for multiple iterations to achieve a better grade, as helpful in "further[ing their] understanding." One student mentions that *GeoExplorer* is a "pressure-free" environment to "learn how a CPT test is done." All of these aspects of GBL design support the psychological need for competence in SDT [8]-[11].

While the students share their appreciation of the more relaxed learning pace afforded by *GeoExplorer*'s individualized nature, they also describe feeling isolated from their classmates during the pandemic and refer to the activity as an environment not explicitly designed to promote a sense of relatedness [8]-[11]. When prompted with a question about social interaction in gameplay, one student comments on studying with others as an "extra push" because they "can't study ... alone" while *GeoExplorer*'s goal seems to be focused on their personalized learning. Similarly, another student comments that "it's trick[ier] to stay motivated [at home] than it is on campus," citing not being able to "[sit] with a friend and [learn together] somewhere" and suggesting that *GeoExplorer* alone without the "mixed" component of a mixed reality learning environment fails to replace the social nature of in-person learning.

Students describe completing more missions than required by their instructors and report being curious about how they can either perform better or what else *GeoExplorer* can teach them. Students also express interest in sampling different sites, which supports the psychological need for autonomy [8]-[11]. For example, one student shares that she is motivated to engage with *GeoExplorer* beyond the required two missions because she sees applications of this game in her future career in that she expects that "every site is going to be different in the real world." Another student adds,

> *[GeoExplorer] showed me that there is still stuff I don't know, and stuff that I both need to know and stuff that I'm really curious about. But ... it definitely ... added to the fire underneath me, to burn even harder and give me more motivation.*
>
> - Alan Bouvet, Stoneleford College

These findings indicate that although *GeoExplorer* may be supporting the psychological needs of competence and autonomy, without the aspects of communal co-learning usually afforded by in-class environments, it may not be able to support the psychological need for relatedness[8]-[11].

B. GeoExplorer and Hands-On Learning Experience

The second emergent theme identified in our analyses highlights a connection between the *GeoExplorer* activity and individualized, hands-on learning. In our interviews, students reflect on the ways in which *GeoExplorer* creates hands-on learning experiences, particularly in a time of online learning. Interestingly, we find that students choose a variety of ways to describe "hands-on learning" as it relates to *GeoExplorer*. For example, *GeoExplorer* is characterized as "experiential learning," "almost real world experience that [students] didn't get the opportunity to do in [their] actual class," and an opportunity that "provid[es] that additional visual that a textbook or lecture didn't." One student portrays her experience with *GeoExplorer* as the one providing an opportunity to ”see [the CPT process] happening right in front of [her], ... observe it, and then ... recreate it for [herself]." Another student shares that engaging with *GeoExplorer* allows for "some freedom to kind of explore and see what works" in an experiential, hands-on way. In describing the hands-on nature of *GeoExplorer*, yet another student compares his engagement with the game with the rest of his online learning experiences during COVID,

> *[Online learning] was like watching the tutorial [on how to] kick a ball. ... This game was actually like, actually kicking the ball, trying to play soccer.*
>
> - Alan Bouvet, Stoneleford College

These results are aligned with the recent findings that higher professional skills development in experiential learning environments, including hands-on learning, "can be partially attributed to the realistic, complex, and contextualized learning experiences within" real-life learning experiences [28].

Students also reflect on the ways in which *GeoExplorer* allows for individualized learning where one can learn at their own pace to "get it fully down" after a few repetitions. Other students describe the process as individualized and hands-on in that it allows them to "try and learn from mistakes" and "help [them] with ... further understanding." In fact, the "try-and-learn" nature of this experience is touted by students as an important individualized, hands-on aspect of learning. One student notes that *GeoExplorer* supports his learning in that,

> *Oh, like it's you doing it yourself. It's like complete freedom ... there are directions, there are procedures, but it's still you driving the truck, going to that place, selecting which things to do first, even though they may be wrong. Like it's trial and error ... But in Zoom calls you can't really do trial and error. It's just facts. It's just knowledge that's just given to us.*
>
> - Jack Whitehouse, Clearlake University

In other words, Jack reports that *GeoExplorer* allows for individualized learning by providing him with "complete freedom" (i.e., psychological need for autonomy in SDT [8]-[11]) and giving him a chance to learn through "trial and error." Simultaneously, he shares that this is unlike other "Zoom calls," in which this kind of hands-on learning through "trial and error" is not possible.

However, students also share that the game could be more "in depth" or cover more of "the nitty gritty" for their hands-on skills development. They also acknowledge "starting to develop [these] skill[s]," but "need[ing] to get more ... of it done." We posit that both individualized and hands-on aspects of the game make *GeoExplorer* a valuable supplement but not a standalone resource – a result of the game's design goals. This is due to a relatively short duration of students' engagement with the game and *GeoExplorer*'s design, which does not capture the entire CPT process, vis-a-vis a fieldwork experience students may engage in, if relevant equipment is available.

C. GeoExplorer and Confidence in Fieldwork

The third emergent theme focuses on students' perceived sense of confidence, often gendered, to perform "real work" in the field upon completion of their engagement with *GeoExplorer*. For the most part, students share that the game provides a good "general" picture of the process, yet also describe the environment as a "little snippet" that does not completely address the "very specific" content of CPT. Some students mention that the game is "relatively quick" compared to what they imagine the real experience would be like. As such, *GeoExplorer* is referred to as helpful for their learning but not necessarily an environment that fully prepares them to perform "real work."

As reported above, multiple students respond positively to the leniency of *GeoExplorer*'s assessment – it helps them learn without the fear of penalty associated with mistake-making in more traditional learning environments. This, however, is also a reason students lack confidence; in the real world, they expect higher stakes and less guidance. For example, Ellie shares,

> *... in GeoExplorer, ... if you skip a step, they won't allow you to ... keep going. You just had to do that step before you can do another. Whereas in real life, if you skipped a step you just messed up, like, your results will come back wrong ... Whereas in GeoExplorer, it kind of guided you to the right step. In a real-life experience, you will mess up. You ... won't necessarily have someone to correct you.*
>
> -Ellie Norman, Stoneleford College

As such, students express that they would be "confident in helping someone do [CPT]" but not doing the test themselves.

While students generally do not feel prepared for fieldwork, responses suggest a gendered divide in their confidence. For example, participants who identify as men describe themselves as "more confident," while those who identify as women typically have responses like, "I wouldn't be comfortable, personally, with doing the actual test just yet."

IV. Conclusions, Limitations, and Future Work

GeoExplorer promotes an individualized experience and results in positive emotional and motivational outcomes, consistent with much literature [8]-[11], [29]. Our findings suggest that students are more motivated to complete tasks than they would be in lecture-based learning, but less than they would be in a more traditional hands-on learning environment (e.g., regular lab). Our analyses also indicate that students believe they have a better understanding of what fieldwork is like, but also lack confidence in their abilities to complete it. Importantly, *GeoExplorer* seems to be most effective when implemented in a mixed reality setting, where faculty scaffold an experience with social connections, focus on supporting autonomy (e.g., through one's own pace, making mistakes, and returning to or completing additional missions), and promote a sense of competence. In this way, when embedded into a mixed reality environment, *GeoExplorer* may more fully support development of students' positive motivational outcomes.

Our work to date also indicates that students emerge with their own definitions of hands-on learning and explore the ways in which virtual learning environments may serve to support their individualized learning. Finally, we find that although *GeoExplorer* may serve to promote students' confidence in their ability to engage with fieldwork, it may do so in somewhat gendered ways. More research is needed to understand the effect of *GeoExplorer* on the confidence of students with differing gender identities to determine how more equitable support may be provided for everyone.

This work has significant implications for mixed reality learning environments, particularly during the time of pandemic-related remote learning, as it has a potential to promote students' motivational attitudes, provide them with a sense of hands-on learning, and possibly support development of confidence to approach fieldwork. More research is needed to understand the nuanced ways in which these outcomes may be achieved, particularly with the goal of creating equitable learning environments.

Some of the limitations of this work are its early stages of analyses and ongoing data collection, which may result in further shining light on some of the emergent findings. At the time of writing of this paper, our team performed an additional ten interviews. Our next steps in this research involve analyzing the ways in which *GeoExplorer* may promote a sense of autonomy, if at all. In addition, we aim to explore the potential relationship between autonomy and trial-and-error as a method of learning observed in students' learning experiences. Our preliminary analytical findings will be checked with the findings from new interviews. We will also focus on the questions that relate to equity and access in the mixed reality learning environment afforded by *GeoExplorer*.

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