How Can Game-Based Learning Affect Engineering Students' Confidence?

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***Abstract*—This Work-in-Progress Research paper focuses on digital game-based learning (DGBL), which refers to the use of a virtual environment to support students' learning. In this exploratory study, we examine how students engage with *GeoExplorer*, a digital game-based learning environment that simulates Cone-Penetration Testing (CPT), an on-site test used in geotechnical engineering to investigate soil properties that students typically don't have access to. In *GeoExplorer*'s CPT activity, students participate in a virtual internship in which they examine several sites with varied types of soil. This paper investigates DGBL environments by leveraging Self-Determination Theory (SDT) to ask the following research questions: (1) How do "freedom" and autonomy within *GeoExplorer* encourage students' new emergent learning strategies? and (2) How do emergent learning strategies in *GeoExplorer* support students' confidence as they self-guide their learning? Ten open-ended semi-structured interviews were performed with civil engineering students from three U.S.-based institutions. The data are analyzed using narrative analysis and a grounded theory approach. Our preliminary findings indicate that, while *GeoExplorer* is intended as a complement to in-person learning, it serves both as a complement and supplement to the online learning that helps to engage students during the pandemic. Students share that a felt sense of "freedom" within *GeoExplorer* encourages them to engage in different emergent learning strategies, such as repetition and trial and error. Students also describe that these emergent learning strategies promote knowledge retention and understanding, and further support their confidence in performing CPT. Our preliminary findings provide opportunities for students to practice autonomy and develop competency – two out of three basic psychological needs in SDT – in their educational processes.**

***Index Terms*—Game-Based Learning, Civil Engineering, Virtual Learning, Mixed Reality, Motivation, Confidence, Autonomy, Competency**

I. Introduction and Literature Review

During the global COVID-19 pandemic, educators at all levels had to adapt to a widespread paradigm shift towards virtual learning [1]. Even prior to this shift, some educators incorporated digital game-based learning into their pedagogical practices noting a positive impact on student learning outcomes [2] and supporting student learning processes [2][3]. The pandemic-driven virtual learning environment allowed for the use of game-based learning to be utilized more widely. This work focuses on digital game-based learning (DGBL) defined in literature as an environment in which students use virtual "games to enhance [their] knowledge and skill acquisition"[4]. To date, much scholarship in STEM education has described a positive correlation between DGBL and improved learning outcomes, such as better performance in content knowledge assessments and reported higher self-efficacy [4][5]. For example, aspects of game design, such as game mechanics and visual characteristics, can greatly impact students' learning outcomes in areas like motivation, learning retention, and problem-solving [6]. Studies show that interactive e-learning, such as practice simulations, improves students' learning experience and leads to a measurable increase in self-confidence and knowledge retention, which have been shown to be an essential part of students' readiness for real-world applications [7]. In particular, virtual environments have proven to increase students' confidence heading into on-site applications by enabling a safe learning environment that encourages repetition to build familiarity with a task [8].

Self-Determination Theory (SDT) [9][10] when applied to educational practices allows for theorizing and changing praxis around supporting development of and "promoting in students an interest in learning, a valuing of education, and a confidence in their own capacities and attributes," which are connected to students' intrinsic motivation development as well as supporting and improving self-confidence [9], and self-regulation for academic performance [11]. SDT postulates that satisfaction of three basic human needs – autonomy, competency, and relatedness – results in shifts of motivation from the extrinsic to intrinsic end of the motivational spectrum with associated positive learning outcomes. However, there is a gap in literature connecting SDT to DGBL environments, and scholars only recently began to explore this connection [12][13].

To this end, the current study explores the impacts of DGBL environments on students' learning experiences and outcomes, such as learning strategies and confidence, through the lens of SDT. Specifically, we examine how *GeoExplorer*, a DGBL 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," [14][15] affects students' sense of autonomy and competency when engaging in a Cone Penetration Testing (CPT) experiment. CPT is used in geotechnical engineering to

investigate soil properties. In the *GeoExplorer*'s CPT activity, students participate in a virtual internship in which they explore several sites with varied types of soil. Basic instructions received from a virtual internship manager come through an in-game cellphone to help guide students through the open-ended setup of the missions they are to explore [15][16].

GeoExplorer's DGBL environment offers an opportunity to investigate students' learning through the SDT lens. Using this lens, we explore the following research questions: (1) How do "freedom" and autonomy within *GeoExplorer* encourage repetition or trial and error emergent learning strategies? and (2) How do emergent learning strategies in *GeoExplorer* support students' confidence as they self-guide their learning?

II. Methods

This paper draws from transcripts of 10 interviews that used a semi-structured open-ended protocol, with students (self-identified as 5 men and 5 women) across three U.S. based institutions. At all three institutions, students participating in an introductory geotechnical engineering course engaged with *GeoExplorer*, which is introduced to students as a virtual lab that allows for applying knowledge gained in an in-class lecture. Students are required to do 2 or 4 missions within *GeoExplorer* that allow students to understand various soil compositions in different landscapes and settings. Some instructors assign specific mission sites, while others provide students the option to choose their own investigation sites. Assessment types vary from one classroom to another, in that some instructors leverage the in-game scoring by requiring students to submit screenshots of their mission results, while others request a written report in addition to the screenshots of students' completed CPT missions.

All interviews were conducted virtually through Zoom during the COVID-19 pandemic. The interviews, each lasting between 1.5 and 2.5 hours, focused on students' learning experiences before and during virtual learning, i.e., before and during the pandemic, as well as their experience with *GeoExplorer*. Interviewees were compensated for their time with a $40 Amazon gift card. Transcribed interviews were pseudonymized to preserve the interviewee's anonymity.

This paper uses narrative analysis and a grounded theory approach [17][18][19][20]. Multiple iterative narrative and analytical memos were written by 3 individual scholars to identify preliminary themes of interest. The individual memos were then leveraged in creating comparative memos between the scholars, a process that allowed for identification of common themes for further investigation. Open coding and a constant comparative approach were then used to further identify emergent categories and themes, which serve as a source for the analyses described below.

III. Results and Discussion

The nature of the COVID-19 pandemic forced educational systems to shift to a virtual learning paradigm [1]. This presented a particular concern for STEM educational environments, where students report that hands-on and laboratory learning were now performed through a combination of (1) watching videos of– rather than performing – laboratory experiments, (2) analyzing existing experimental data instead of collecting one's own data, (3) performing analyses of data often collected using different experimental procedures and equipment than what students are presented with in their lectures, and (4) formulating lab reports based on existing data instead of engaging with the data and context for data collection, analyses, and syntheses of new findings. Students in our study report that this shift to a different way of engaging with laboratory assignments resulted in a movement away from an enjoyable or even fun experience to something that was in the least "not the same" and in the worst "boring" and something that one could not "remember a week after the lab." For instance, Norah shares,

> *I really enjoyed geotechnical [lab] when it was in person. I enjoyed the labs a lot because we had to play with dirt and that was fun. And then it became virtual and I had to watch videos of people do[ing] it and it just wasn't the same. Our lab became re-writing our lab manuals.*
>
> - Norah Browning, Stoneleford College

Similarly Jack shares,

> *the YouTube videos that we watched during quarantine or ... the ones that the instructor [sent] us of him doing it... I don't remember that a week after the lab.*
>
> - Jack Whitehouse, Stoneleford College

Our initial findings indicate that, while *GeoExplorer* was intended as a complement to in-person learning, in the words of Francis (Clearlake University), it served "both as a complement and supplement to the online learning" that helped to engage students during the pandemic. Moreover, students reveal that they found *GeoExplorer*'s activities enjoyable and "a different way of doing labs during pandemic," which literature finds to be correlated with improved motivational outcomes shifting students' motivations toward the intrinsic end of the motivational spectrum based on the SDT framework [21]. In the following sections we explore explicit ways in which students describe engaging with and experience *GeoExplorer*. Specifically, we investigate: (1) how "freedom" and autonomy within *GeoExplorer* encourage new emergent learning strategies of repetition or trial and error, and (2) how these new emergent learning strategies in *GeoExplorer* support students' confidence as they self-guide their learning.

A. Freedom in GeoExplorer and Emergent Learning Strategies

All students interviewed for this study were introduced to *GeoExplorer* during pandemic, after several weeks of online learning. Although initially designed with the intent to complement in-person education, as a cheaper alternative to generally less-accessible and specialized equipment, students report that *GeoExplorer*'s CPT activity fills the lack of interactive labs

during the pandemic. Students also note that while *GeoExplorer*'s learning environment does not allow one to "play with dirt" with their own hands, it does create opportunities for them to "play" and to engage in an experiential experimental process. There are, however, significant differences that students report in this virtual experimental format in comparison to the strategies taken up in traditional labs. For example, while students share that in traditional laboratories, they have "to get things right," DGBL allows them to learn through "doing it right." In other words, traditional labs are performed with the final deliverable in mind that is assessed using summative assessment practices, while *GeoExplorer*'s DGBL environment allows for a process-oriented engagement with learning that allows for making mistakes and an assessment practice that has a formative feeling to it. Specifically, *GeoExplorer* by its very design enables students to focus on their comprehension and learning of experimental processes instead of aiming for immediate "correct" results or worrying about damaging expensive equipment while learning about it. Most students interviewed describe *GeoExplorer* as a "pressure-free environment" for them to learn from their mistakes. For example, Brooke shares that,

> *with doing GeoExplorer I felt like it was this pressure-free environment for me to actually learn how a CPT test is done. I didn't have someone staring over my shoulder going, "Oh, you're doing that wrong," or, "Oh, you didn't do that right." It's just shown at the end and I'm like, "Okay, we'll do another one and we'll do better."*
>
> - Brooke Herbert, Stoneleford College

In their interviews students reveal that *GeoExplorer* provides them with the "freedom to kind of explore and see what works" and encourages them to feel more comfortable with making mistakes. Furthermore, students describe the ways in which *GeoExplorer* invites them to engage with different learning strategies, such as repetition, trial and error, and seeking their own solutions and/or processes. Several students specify that they repeated missions in *GeoExplorer* to "troubleshoot what [they] did wrong" and "learn from those mistakes." For example, Kevin shares that,

> *it was good because I was allowed to make mistakes... in certain cases, the game told me I was making a mistake. But in other cases it didn't tell me, which I enjoyed because when [I] got the grade at the end and I realized something was wrong, I went back and sort of troubleshooted what I did wrong, what I could have changed or how I could have done it better, how I could have done it more efficiently and stuff like that. I like that, because if the game just told me outright, "Oh, you didn't calibrate this machine properly" or something, then it wouldn't help, because when I went to the next site I would make the same mistake. But if I had to figure that out for myself, it was nice.*
>
> - Kevin Shah, Richmond College

Kevin feels that his learning benefited from being able to make mistakes for himself and being able to diagnose origins of error and areas of improvement as a part of his learning process. This iterative approach allowed him to learn the "how" of CPT and prevent him from making "the same mistake," which serves as evidence of potential improved learning and knowledge retention. Several other students share similar sentiments, in that they directly connect making mistakes, repetition, and trial and error to an improved learning, explaining that they "learn based on trying and learning from mistakes," and that they "did all of [the missions] and then... did a couple over again... just to familiarize [themselves] with it."

When describing their ability to work in a "pressure-free" environment and to adapt their process to best learning outcomes within *GeoExplorer*, students often choose such words as freedom or autonomy. In Jack's case, when asked to clarify what autonomy means to him, he explains,

> *It's like complete freedom in a way... selecting which things to do first, even though they may be wrong... it's trial and error... I learned a lot from trial and error.*
>
> - Jack Whitehouse, Stoneleford College

Jack expresses a felt sense of freedom when interacting with *GeoExplorer*. By using the language of "in a way" with regard to *GeoExplorer*'s freedom, he shares that it may be a different type of freedom than one might conjure in their minds in a general sense or even within educational spaces. However, here, within the DGBL environment, he has an autonomy to choose what "to do first" regardless of whether his choice may lead to a wrong process or incorrect results. This freedom to choose then allows him to learn from his mistakes because he would not "get it right" on the first try, which serves as an acknowledgment and acceptance of a new emergent learning process for him.

B. Supporting Students' Confidence Through GeoExplorer

Our analyses indicate that trial and error, the process which inherently involves repetition and learning through iteration, is a common emergent learning strategy, which most students find to be successful when engaging with *GeoExplorer*. Alia further shares,

> *of course I needed some trial and error to understand how to drill in the ground,*
>
> - Alia Bouvet, Stoneleford College

tying in the learning process of trial and error to his understanding of "how to" complete tasks. Similarly, Jack adds to his aforementioned statement about trial and error process, stating that

> *there was a lot of trial and error and doing it a couple of times makes me remember it.*

- Jack Whitehouse, Stoneleford College

These sample quotes from Alia and Jack demonstrate students' acknowledgment that trial and error as a learning strategy supports their mastery of knowledge and promotes knowledge retention by allowing them to build familiarity with and "remember" processes better.

Furthermore, students report that the self-guided nature of their learning with *GeoExplorer* leads them to feeling more confident in their ability to apply their knowledge in the future while performing CPT in person. Most students share that it is their ability to "explore and see what works" and "learn from [their] mistakes" within the *GeoExplorer* environment that provides them with this promoted sense of confidence. For example, Alia engages with GeoExplore with the mindset that he is "probably not going to understand some of the specifics on the first try." Rather, he believes that due to the complexities of CPT, he might not be able to understand everything after just one attempt. Therefore, he engages in the iterative process of trial and error in order to "understand" and learn "how to" complete a CPT test, which he describes as a "rough skill that needs to be polished."

With the continuous use of trial and error, Alia builds familiarity with, practices and "polish[es]' this new skill. When asked about his confidence in completing the CPT task in-person and on-site, he responds,

> *I'm more confident now because I'm starting to get a feeling for how it is, and I'm starting to develop this skill.*
>
> - Alia Bouvet, Stoneleford College

GeoExplorer's support of Alia's iterative learning process serves to build competency in CPT. Alia speaks of this competency as a developing "feeling for how it is" and connects it to an increased sense of confidence to perform CPT on site.

Similarly, Clara reports an increased confidence in her ability to engage with the CPT in-person and on-site as a result of her learning with *GeoExplorer*. When recounting her initial experiences with this DGBL environment, Clara describes using "repetition ... to get it fully down" and to better "understand the material." She indicates that she "would feel decently confident going out to do [CPT] testing" in the field after having recently completed *GeoExplorer*'s activity.

Students report that this confidence in performing the CPT task upon completion of the *GeoExplorer* activity stems from the iterative nature of DGBL environments. Students share that repetition and practicing of "go[ing] through all the motions of getting prepared, and then completing the task, and [realizing that] things could go wrong within it," allows them to develop a deeper comprehension of the content and procedures in comparison to what is presented to them in traditional class lectures. Through simulations of real-life application of CPT, engagement with new emergent learning strategies, and a felt sense of freedom to learn provided by *GeoExplorer*, students report a sense of competency and improved confidence or, in their words, "understand[ing] the material a little bit better after completing all the activities."

IV. Conclusions

Digital game-based learning has seen a rise due to its observed positive impacts on student learning outcomes and the pedagogical challenges created by safety concerns during the COVID-19 pandemic. As learning begins to shift away from remote environments back to an in-person paradigm, educators have a unique opportunity to leverage research findings on best practices related to DGBL to bring the gifts of game-based learning environments into in-person learning spaces.

The preliminary findings in this paper illuminate the ways in which DGBL – in this case *GeoExplorer* – provide opportunities for students to practice autonomy and develop competency in their educational processes. According to the Self-Determination Theory of motivation, autonomy and competency are the two basic human needs that when satisfied lead to better learning and affective outcomes. Our preliminary analyses indicate that a felt sense of freedom or autonomy provided by *GeoExplorer* allows for development of new learning strategies and is correlated with improved competency and confidence in students' ability to perform CPT in real life.

Our work barely scratches the surface of the connections between DGBL and SDT as we attempt to fill the gap in literature to connect the two. While we begin to explore autonomy and competency aspects of SDT, much work remains to be done to understand more fully the mechanisms by which these two basic needs are satisfied within the *GeoExplorer*'s learning environment. As well, our work to date does not explore the ways in which the basic psychological need of relatedness is supported by *GeoExplorer*. Furthermore, this paper presents findings based on the initial set of ten interviews. As an ongoing study with additional interviews being currently investigated, we expect that new findings will come to light.

As we continue to investigate the connection between DGBL and SDT, we invite the FIE audience to surface conversations about the best ways we can support engineering students' learning and development of positive motivational attitudes in an environment that most probably will continue shifting back and forth between in-person and virtual paradigms and the overall movement to more hybrid learning spaces.

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