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The development and evaluation of an educational board game on basic geotechnical soil characterization

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Article

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Abstract

This paper discusses the potential of gamification as a tool for teaching and learning in geotechnical engineering. Gamification involves incorporating elements of gameplay such as challenges, rewards, competition, and cooperation into teaching and learning environments to make the process more interactive and engaging. Although gamification is widely used in many fields, it is still relatively new in geotechnical engineering. This paper presents the 'Soil Character' board game developed by the GeoFUN group as an example of successful gamification in geotechnical engineering education. The game focuses on basic soil characterization, including soil classification systems, index properties, and geotechnical characterization tests such as sieving, sedimentation, and Atterberg limits. The paper provides background information on the development of the game, and a description of the game components. The online Portuguese version of the game was tested with eight civil engineering undergraduate students who had successfully undertaken the introductory soil mechanics module. Student's satisfaction in terms of game design, rules, and gameplay was measured via a questionnaire. Results of the questionnaires showed that the game was well evaluated in all aspects. Student volunteers reported that they felt very motivated, and that they wished they had been able to play the game when they were learning the topic. Thus, results presented in this paper suggest that gamification has the potential to make geotechnical engineering education more interactive and engaging. Exploring the effectiveness of the game in various contexts and with diverse student populations constitutes a key direction for our future research.

1. Introduction

Introductory soil mechanics courses underpin key concepts of Geotechnical Engineering and commonly involve several topics that can be complex to students. As a result, students often struggle, particularly with theoretical content, which can be presented in a repetitive and tedious manner through traditional teaching methods. Meanwhile, lecturers also face difficulties, even when adapting their teaching methods, in motivating students to engage with and learn the content.

As in any other engineering discipline, laboratory experiments are an important part of geotechnical engineering education (Bhathal, 2011; Feisel & Rosa, 2005; Magin & Kanapathipillai, 2000), as they provide students with hands-on experience and reinforce theoretical concepts. However, there are several challenges in implementing effective soil mechanics lab practices in undergraduate curriculum.

One of the challenges is the cost and availability of equipment and materials. Many universities may not have access to the latest equipment or may not have sufficient funding to purchase expensive equipment (Nyemba et al., 2017). This can limit the types of experiments that can be conducted in the lab, which can in turn limit the students' exposure to different types of soils and testing methods.

Then, a related challenge is dealing with the mismatch between the number of equipment available and the number of students. The shortage of equipment and resources can lead to reduced opportunities for hands-on learning experiences (Magin & Kanapathipillai, 2000), where demonstrations are chosen over "one student-one equipment" approach. This can result in a suboptimal student experience and a reduced ability to develop the practical skills necessary for success in geotechnical engineering. In addition, the limited access to equipment can make it difficult for students to develop an understanding of the limitations and challenges of the testing methods, which is critical for the accurate interpretation of geotechnical data.

Furthermore, soil mechanics lab experiments can be time-consuming and require a significant amount of preparation

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and setup. This can be challenging for lecturers who are already balancing teaching responsibilities with other research and administrative duties (Jaksa et al., 2016; Tight, 2016; Lai et al., 2014). Then, there is the challenge of engaging and motivating students during lab experiments. Some students may find the experiments boring or repetitive and may not fully understand the relevance of the experiments to their future careers in geotechnical engineering (Edward, 2002).

In this context, Nordstrom & Korpelainen (2011) demonstrated that unconventional teaching tools are effective in promoting deep learning of scientific knowledge and various skills associated with scientific disciplines to engineering students. One of the unconventional approaches is the use of gamification as a tool for teaching and learning, which according to Subhash & Cudney (2018), is considered an excellent option for didactic complement in the classroom as they encourage competition and teamwork, facilitate socialization, and arouse students' interest, promoting playful learning. Gamification offers the opportunity to lecturers to cater to different learning styles (Buckley & Doyle 2017) by incorporating visual, auditory, and kinesthetic elements into the learning process.

Despite the very limited use, successful implementations of games in the geotechnical context such as the GeoExplorer (Bennett et al., 2017; Bennett et al., 2020), Rockbowl (rock mechanics quiz held during the Brazilian Conference on Soil Mechanics and Geotechnical Engineering – COBRAMSEG, since 2014) and Geobowl (similar to Rockbowl but in general Geotechnical Engineering context, held during the Geotechnical Engineering Seminar of Rio Grande do Sul – GEORS in Brazil, since 2017), demonstrated the potential of gamification to the geotechnical community.

Thus, gamification has the potential to address some of the challenges associated with soil mechanics. The interactive and engaging learning experience can be particularly beneficial for lab-related content, as students may be more motivated to participate and learn if they are presented with a challenge or a goal to achieve.

In addition, gamification can provide a low-cost and accessible complement to traditional soil mechanics lab experiments. While not a replacement for hands-on lab experience, gamification can be used as a supplementary tool to reinforce theoretical concepts and provide a more engaging learning experience.

Games, whether physical or virtual, on mobile phones or computers, are part of the daily lives of most young people in university age. According to Moran (2015), the younger generation, who are accustomed to playing games, find the language of challenges, rewards, competition, and cooperation attractive and easily comprehensible, highlighting the usability of such methodologies in the teaching process.

Thus, this paper presents the development and evaluation of an educational board game on geotechnical soil characterization testing called 'Soil Character'. The game was developed by the GeoFUN group and focuses on soil characterization. The game was designed to be used as a supplementary tool for undergraduate students taking modules on soil mechanics, and to provide a more interactive and engaging learning experience. The learning objectives of the Soil Character board game are to:

- Introduce students to the different soil classification systems, including the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) Soil Classification System;
- Teach students the basic principles of soil index properties;
- Introduce students to the different geotechnical characterization tests, including sieving, sedimentation, and Atterberg limits;
- Provide students with a fun and engaging way to learn soil characterization.

In this paper, the background and motivation for the development of the Soil Character board game are discussed. The game and the game components are described and then the results of a survey conducted with undergraduate students who tested the online Portuguese version of the game (known in Portuguese as "Show Solo") as well as the moderation team are presented. Finally, enlightened by the findings of the surveys, the potential of gamification as a tool for teaching and learning in geotechnical engineering is discussed.

2. Materials and methods

This work was divided into three main stages: the design and development of the game itself; the application of the game; and evaluation of the play tests.

2.1 Design and development of Soil Character

This game is part of a series developed by the GeoFUN Group, aiming to promote interactivity within geotechnical classrooms. The GeoFUN group is a dynamic team of lecturers and researchers from Brazilian and UK higher education institutions, dedicated to exploring the exciting intersection of geotechnical engineering and game development. This game was developed in Portuguese by two undergraduate students from Universidade Federal de Roraima (UFRR) in Brazil closely supervised by two GeoFUN lecturers.

The first stage of this project was defining the game's theme. For that, the team involved considered several key questions, such as whether it would aid in learning Soil Mechanics and whether students typically struggle with the subject matter when taught traditionally. They also assessed whether the chosen theme was broad enough to be effectively explored within a didactic board game. Once these questions were answered, the decision on the theme became more objective.

This game was the first developed by the group, and naturally it focused on bringing the fundamentals of soil mechanics into perspective, mainly focusing on laboratory tests, since equipment is not always available for individual

practices. A challenge was to incorporate both information that adhere to both Brazilian and international standards.

Once the content was established, various styles of games were considered. Since the development of the game started during the COVID pandemic it was important to the team to focus on board games that could be adapted to digital formats, while remaining relevant to the chosen theme. Extensive research was carried out on existing games in the market, both didactic and non-didactic, to identify the most suitable format and dynamics.

Following the idea's conception, the team proceeded to create the game, including the design of the board, development of rules, and formulation of questions for the cards used. These questions were a blend of theoretical and practical knowledge, intended to incite student's curiosity. Once the physical game was finalized, the team promptly created an online version using Google Slides for diagramming.

2.2 Application of Soil Character – playtest

Since the game was developed during the pandemic period, the playtest took place remotely. Eight undergraduate civil engineering students from Universidade Federal de Roraima (UFRR) in Brazil tested the Portuguese version of the game (known in Portuguese as "Show Solo"). All students had already successfully undertaken the introductory soil mechanics module. The GeoFUN group moderate the play test and split the students into two groups of four, who played the game simultaneously in separate virtual rooms.

At the beginning of the test, the volunteers took some time to read the rules, followed by a Q&A session with the GeoFUN team to clarify the game's process. Then the game was played. At the end of the test, all players and moderators completed a game evaluation questionnaire.

2.3 Game evaluation questionnaire

To evaluate the effectiveness of the game, two questionnaires were developed. One questionnaire (Q1) was given to the student volunteers who participated in the play test, while the other (Q2) was given to GeoFUN moderators who facilitated the test. The Q1 questionnaire aimed to assess the design, rules, dynamics, questions, and content of the game as well as the student's overall satisfaction with the experience. On the other hand, the Q2 questionnaire aimed to assess the moderators' perceptions of the experience.

Table 1 outlines the questions of Q1 covering each aspect of the game. The answers were measured using a

Table 1. Aspects and questions analyzed in Q1 questionnaire.

Aspects analyzed in the game	Statements
(a) About the design	1. I like the board design.
	2. I like the design of the cards.
	3. The appearance of the game is attractive and harmonious.
	4. Game design connects with subject matter.
(b) About the rules and dynamics of the game	5. Written explanation of game rules is clear and easy to understand.
	6. The time allotted for the game was appropriate.
	7. I found the game tiring.
	8. I found the game boring.
	9. The proposed challenges made the game more fun and challenging.
(c) About the questions and content covered	10. The way the questions were divided made the game too complicated.
	11. The questions on the topic addressed were very easy.
	12. The game had so much information that it left me confused, making it difficult to identify and remember important points.
	13. The game content will be useful to me.
	14. I was able to relate game content to things I saw, did or thought.
	15. The content addressed complements subjects seen in the classroom.
(d) Satisfaction	16. The game made me want to learn more about the subject.
	17. After playing, I can better understand the theme presented in the game.
	18. After playing, I can remember more information related to the theme presented in the game.
	19. Getting the right answers and completing the challenges gave me a sense of accomplishment.
	20. The game kept me motivated to keep playing.
	21. Overall, I found the game boring.
	22. This game was not challenging for me.
	23. I will recommend the game to others.
	24. I would play this game again.
(e) Additional comments	25. Additional comments.

five-point scale ranging from "I completely agree" to "I completely disagree".

Regarding Q2 questionnaire, its purpose was to monitor and document the impressions of the test from the perspective of the game developers. This questionnaire was similar to Q1 questionnaire but focusing on the observations of those who moderated the testing process. Table 2 presents the aspects and questions examined. Once all data was compiled, the game was evaluated, and the developers deliberated on any necessary modifications. Since the feedback was overall positive, no major alterations were deemed necessary. At this stage, an English version was also produced.

3. Results and discussions

3.1 Soil Character game

3.1.1 Game components and number of players

The game can be played by 2 to 4 players. It is composed of the Board (Figure 1), 4 pawns, 48 "Your choice", 32 "Is it true?" and 27 "Mystery" Cards. Figure 2 shows the design of the "Your choice" and "Is it true?" cards. As these cards

Table 2. Aspects and questions analyzed in Q2 questionnaire.

Aspects analyzed in the game	Statements
(a) About the design	1. Volunteers appeared to approve of game design.
(b) About the rules and dynamics of the game	2. Volunteers easily understood the rules of the game.
	3. Volunteers had no difficulty using the platform chosen for the online version of the game.
	4. Volunteers looked bored.
	5. The time allotted for the game was appropriate.
(c) About the questions and content covered	6. Volunteers in general did not have great difficulties with the questions.
	7. The degree of difficulty of the questions seemed about right – not too hard and not too easy.
	8. Volunteers understood most of the questions.
	9. Volunteers seemed motivated throughout the game.

Figure 1. Board with pawns in black square (top left corner of image).

contain technical questions, Tables 3 and 4 bring examples of their contents, respectively. Meanwhile, the "Mystery" cards introduce a fun component to the game with random rewards and punishments. Figure 3 presents three examples of this card deck.

The "Your choice" cards (Table 3) feature multiple choice questions with four options. This set of cards can be associated with the lower levels of Bloom's Taxonomy - remembering and understanding (Bloom, 1956). These cards require the players to recall facts, concepts, and information related to the theme of the game. The players must choose the correct option from four alternatives, which tests their comprehension of the material.

The "Is it true?" cards (Table 4) are true or false questions. These cards are more challenging than the previous set, even though they have a 50% chance of success. This deck can be associated with the higher levels of Bloom's Taxonomy - analyzing and evaluating (Bloom, 1956). These cards require the player to evaluate the truthfulness of statements related to the theme of the game, which involves higher-order cognitive skills such as analysis and evaluation. The foundational content of these questions, for both decks of cards, is derived from established sources in the field, notably Knappett & Craig (2019), a widely recognized textbook in soil mechanics. Finally, the "Mystery" cards (Figure 3), bring an element of unpredictability and fun to the game, as they may offer rewards or punishments without any associated action.

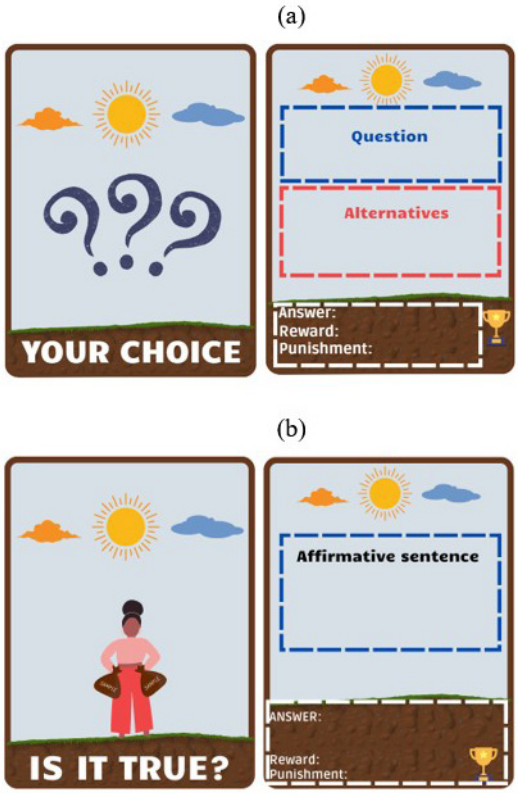

Figure 2. Cards design: (a) "Your choice" and (b) "Is it true?".

3.1.2 Playing order

Players must decide among themselves which pawn color they will use and the order in which they will play.

3.1.3 How to win

The player who first reaches the final square, "The end", of the board wins the game.

3.1.4 How to play

The squares on the board are stamped with the symbol of each card deck. During the game, players must turn over cards from the decks corresponding to the squares they landed on. Each card contains a reward if the player gets the answer right or a punishment if the player misses the answer.

In the first-round players must always draw a card from the "Your choice" deck. If the player correctly answers the question asked, his/her avatar must fulfill the reward indicated on the card; otherwise, the player must remain at the start, passing the turn to the next participant.

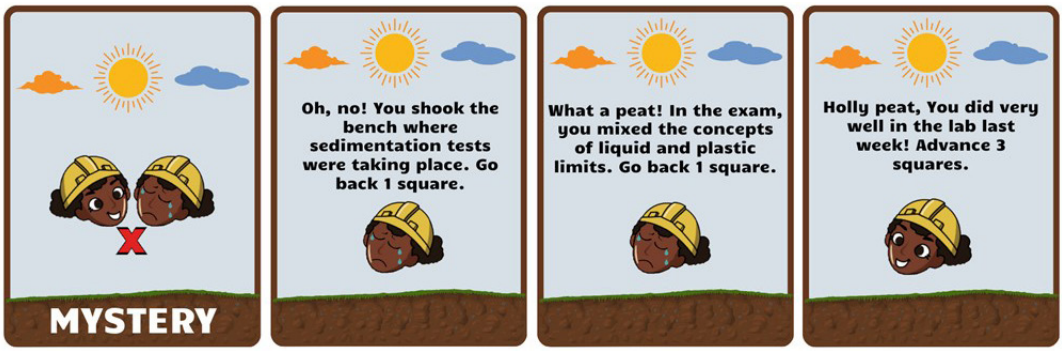

Figure 3. Examples of "Mystery" cards.

Table 3. Sample of questions of "Your choice" cards.

Question	Alternatives	Answer	Reward/ Punishment
How is it called the water content at which fine-grained soils change from a semi-solid to a solid state?	a) Liquid limit b) Plastic limit c) Shrinkage limit d) Atterberg limit	C	Advance 4 squares/ Stay where you are
You're in charge of finding the dry unit weight of a soil sample, for that you'll need the weight of solids and:	a) Volume of voids b) Total volume c) Volume of solids d) Volume of water	B	Advance 3 squares/ Skip next round
According to the Unified Soil Classification System (USCS), how it is classified a material in which more than 50% of the particles are retained on sieve 200 (0.075 mm) and less than 50% of the coarse fraction are retained in sieve 4 (4.75 mm)?	a) Gravel b) Sand c) Organic Silt d) Peat	B	Advance 2 squares/ Stay where you are
Which of the following is not presented as a percentage?	a) Water content b) Porosity c) Degree of saturation d) Void ratio	D	Advance 3 squares/ Go back 1 square
What is the particle size test used for materials passing the 200 sieve (0.075 mm)?	a) Sieving b) Flocculation c) Sedimentation d) Gradation	C	Advance 3 squares/ Go back 1 square
The relationship between porosity (n) and the void ratio (e) is given by:	a) $1 + n = 1/(1 + e)$ b) $1 - n = 1/(1 + e)$ c) $n = 1/e$ d) $n = e/(1 + e)$	D	Advance 5 squares/ Stay where you are
In the Highway Classification System (HRB), what percentage passing the #200 sieve is used to classify silt and clay-type materials?	a) 50 b) 35 c) 45 d) 60	B	Advance 3 squares/ Skip next round
The percentage of soil retained in each sieve, in the sieving test, is obtained by measuring:	a) Total mass b) Total weight c) Soil density d) Total volume	A	Advance 2 squares/ Go back 2 square
If the porosity of a soil sample is 20%, what is its void ratio?	a) 0.30 b) 0.27 c) 0.28 d) 0.25	D	Advance 6 squares/ Stay where you are
What is the name of the device commonly used to obtain the liquid limit of a soil material?	a) Darcy's device b) Casagrande's device c) Bernoulli's device d) None the above	B	Advance 3 squares/ Go back 1 square

Table 4. Samples questions of "Is it true?" cards.

Affirmative sentence	Answer	Reward/ Punishment
The Atterberg Limits are: Plasticity Limit, Liquid Limit and Shrinkage Limit.	True	Advance 2 squares/Go back 1 square
The following parameters can be obtained through laboratory tests: moisture content, specific gravity and dry unit weight.	True	Advance 4 squares/Go back 2 square
According to the Unified Soil Classification System (USCS), a soil in which more than 50% of the particles are retained in the 200 sieve (0.075 mm) is classified as coarse.	True	Advance 3 squares/Skip next round
Sieving is carried out by placing the various sieves one above the other in descending order of their openings from top to bottom.	True	Advance 3 squares/Stay where you are
The weight of voids in a soil is equal to the weight of water.	True	Advance 4 squares/Go back 1 square
The soil void ratio is given as a percentage.	False. Void ratio is dimensionless and given as fraction.	Advance 3 squares/Skip next round
According to the Unified Soil Classification System (USCS), when coarse soil (G, S) has low compressibility (L), it is classified as GL.	False. L cannot complement G or S.	Advance 4 squares/Stay where you are
When the soil is fully saturated, there are no voids present in it.	False. Voids are filled with water.	Advance 2 squares/Go back 3 square
Experimentally, the Liquid Limit corresponds to the moisture at which the soil closes a certain groove under the impact of 15 blows.	False. 25 blows.	Advance 5 squares/Skip next round

3.1.5 Online version

As previously mentioned, after finalizing the entire concept of the physical game, an online version was developed. The online version of Google Slides was used, so players could simultaneously access a page, through a link.

Six slides were produced: one for the cover of the game; one for the rules; one for the board; and 3 slides for the cards: "Your choice", "Is it true?" and "Mystery" cards, respectively (Figure 4).

One of the challenges in adapting the physical game to an online version was how to prevent the answers of the card questions from being exposed to all players. To address this, a tag was placed over the answer section of the card, and a background grid guide was added to help organize the pile of cards (Figure 5). Another challenge faced by the team was how to recreate the natural player interactions, such as teasing, banter, and discussions, that occur during board game play. To solve this, a video call via Google Meet was utilized. The use of these two tools demonstrated that the online play could be both interactive and easily accessible without requiring the download of any additional applications. In fact, the entire process could be accessed using just two links.

3.2 Questionnaire analysis

The data representing the feedback collected from students who play-tested the Soil Character educational board game is presented in Figure 6. The responses of the students are a useful indicator of the effectiveness of the game in terms of both its design and educational value.

The responses of questions regarding the game design (questions 1 to 4 - Figure 6a) show that the board design, card design, and overall appearance of the game were well-liked by most of the students. This is an excellent indicator of the game's success in terms of its visual appeal, which can have a significant impact on a player's engagement with the game.

Regarding rules and game dynamics, responses 5 and 6 (Figure 6b) indicate that the written explanation of the game rules was generally clear and easy to understand, and that the time allotted for the game was appropriate. These are positive indicators of the game's usability and playability. Responses 7 and 8 (Figure 6b) indicate that the game was not found to be tiring or boring by the majority of students, which is a positive sign that the game was engaging and enjoyable. Response 9 (Figure 6b) shows that the proposed challenges made the game more fun and challenging, which is a positive indicator of the game's ability to maintain a player's interest.

In terms of questions and content, response 10 (Figure 6c) indicates that the way questions were divided did not make the game too complicated, which is a positive sign that the game's structure was effective in facilitating gameplay. Response 11 (Figure 6c) indicates that students did not find the questions on the topic addressed to be too easy, which suggests that the level of difficulty was appropriate. Response 12 (Figure 6c) shows that the game content did not leave students confused, which is a positive indicator that the game's educational content was well-organized and presented effectively. Responses 13 to 15 (Figure 6c) show that students found the game content to be useful and complementary to subjects seen in the classroom, which is a positive indicator of the game's educational value.

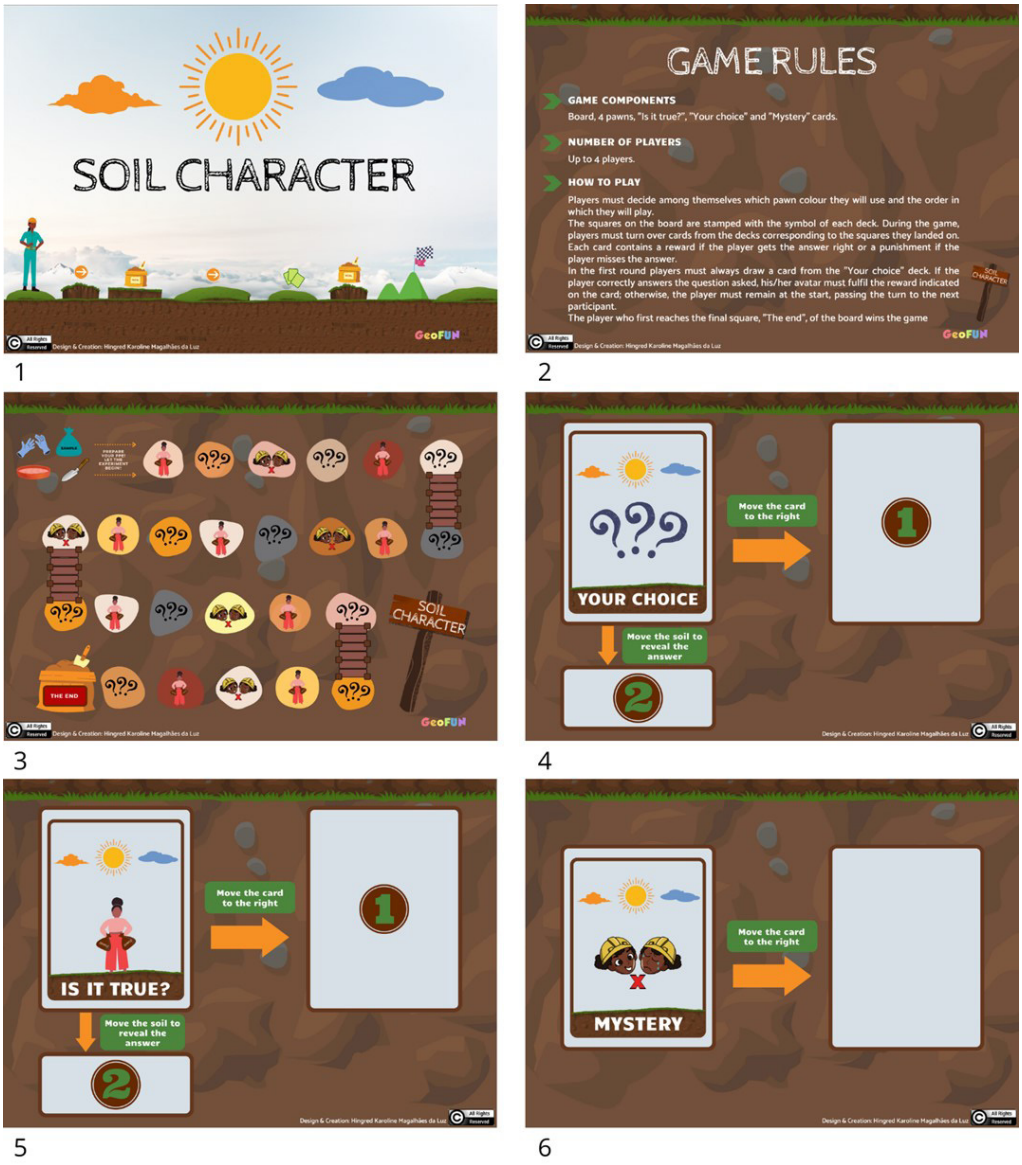

Figure 4. Slides used on the online version of the game.

Figure 5. Online version solution: (a) question revealed with tag over answer, reward and punishment section; (b) answer, reward and punishment of the card in question revealed.

Lastly regarding students' satisfaction, responses 16 to 18 (Figure 6d) indicate that students generally found the game to be effective in facilitating learning and retention of information related to the game's theme. Response 19 (Figure 6d) shows that completing challenges gave students a sense of accomplishment, which is a positive sign that the game's structure was effective in rewarding players for their progress. Responses 20 to 24 (Figure 6d) show that the game was motivating, enjoyable, and challenging for most students, and that they would recommend the game to others and play it again themselves.

Student's additional comments are presented in Table 5. It is evident that the game was well-received by the students, and it provided a unique and entertaining learning

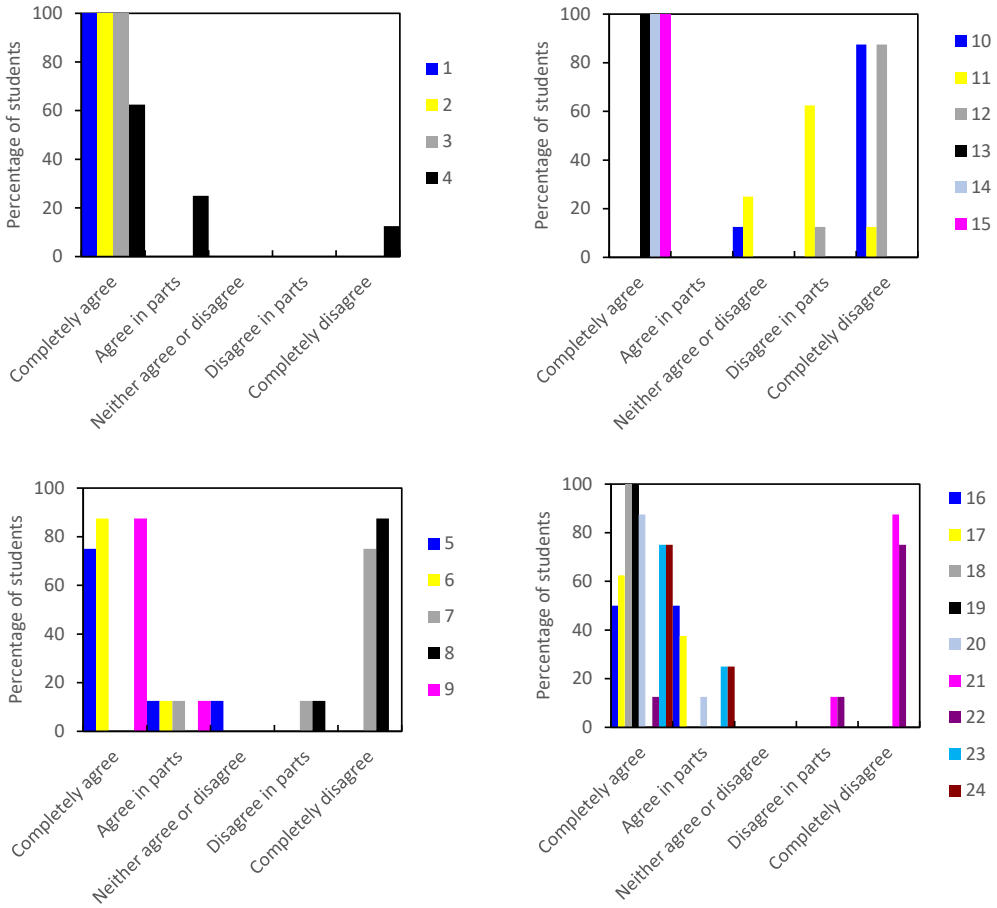

Figure 6. Q1 questionnaire results: (a) about design (1-4), (b) rules and game dynamics (5-9), (c) questions and content (10-15), and (d) satisfaction (16-24).

Table 5. Q1 questionnaire results: Additional comments.

Student	Additional comments
Student 1 (Group 1)	No comments
Student 2 (Group 1)	*"Very entertaining and also adds knowledge without giving the feeling that we are taking a test."*
Student 3 (Group 1)	*"I loved the opportunity to be able to play and I enjoyed the game a lot, both in terms of design and content. It was a great learning experience."*
Student 4 (Group 1)	*"There could be a variation between easy and difficult questions, which would give more chances for those who are behind to advance and for those who are in front to either go back or stay put. Congratulations to everyone involved, the game is very entertaining, and the design is beautiful!"*
Student 5 (Group 2)	No comments
Student 6 (Group 2)	No comments
Student 7 (Group 2)	*"Very well-made game. Congratulations on the idea:)"*
Student 8 (Group 2)	*"One of the questions was confusing regarding washing the passing material in the 4.5mm sieve, in the grain size distribution test. The game is very dynamic, and the design is fun, a unique and motivating experience that is also very entertaining."*

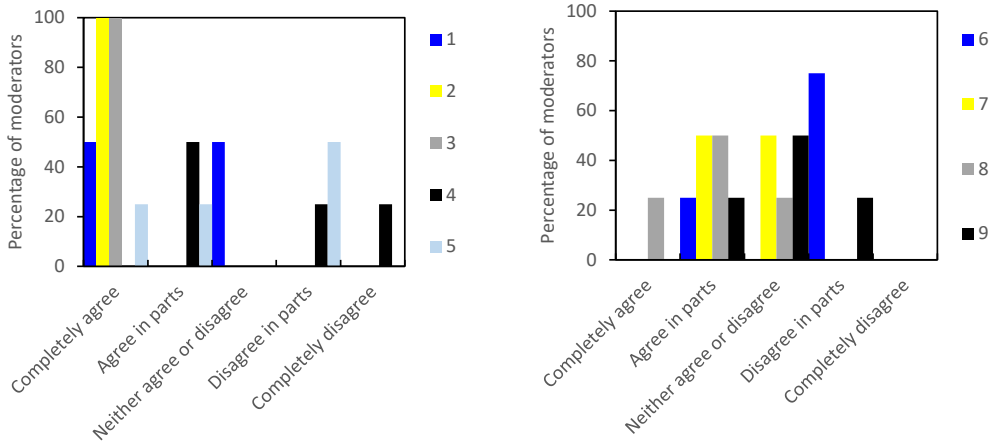

Figure 7. Q2 questionnaire results: (a) about design, rules, and game dynamics (1-5), and (b) questions, content, and satisfaction (6-9).

experience. Only two suggestions were made. The first one (Student 4 – Group 1) regarding mixing the level of difficulty of the cards can be easily addressed by shuffling the card. The second suggestion (Student 8 – Group 2) was dealt with by the team – the question was properly revised and modified accordingly. Overall, the data suggests that the game was successful in terms of its visual design, usability, engagement, and educational value.

Figure 7 shows the results of Q2 questionnaire. Data collected during the playtest shows some interesting findings regarding the moderators' perception of students' experience with the game. Based on the data provided, the moderators had mixed perceptions of the students' play testing, particularly in relation to the design and content of the game.

In terms of the game design (Figure 7a – question 1), half of the moderators completely agreed that the volunteers approved of it, while the other half had neutral opinions. On the other hand, moderators had more positive perceptions regarding the rules and dynamics of the game. All of the moderators completely agreed that volunteers easily understood the rules of the game (Figure 7a – question 2), and that there were no difficulties in using the online platform chosen for the game (Figure 7a – question 3). These are positive findings as they indicate that the game's instructions were clear and concise, and the online platform was user-friendly and easy to navigate and had not interfered with the experience.

In terms of volunteers' engagement with the game, half of the moderators somewhat agreed that the volunteers looked bored during the game (Figure 7a – question 4). This could indicate that the game did not fully capture the interest or attention of all participants, which could be a concern for the overall effectiveness of the game in promoting learning. However, this perception was not substantiated by the students' feedback (Q1: question 8 - Figure 6b and question 21 - Figure 6d).

In terms of the questions and content covered, the moderators' perceptions were mixed. While 75% of moderators disagreed in parts that volunteers did not have great difficulties with the questions, half of them agreed that the level of difficulty of the questions seemed about right (Figure 7b – question 6). Moderators also had mixed perceptions of volunteers' understanding of the questions, with 50% agreeing in parts, 25% agreeing completely, and 25% disagreeing in parts (Figure 7b – question 7). Lastly, moderators were divided on the volunteers' motivation throughout the game (Figure 7b – questions 8 and 9).

The mixed perceptions among the moderators could be associated with their different backgrounds and expectations. The fact that half of the moderators were undergraduate students while the other half were lecturers suggests that they may have had distinct expectations of what the game should be like and how the volunteers should have responded to it. For example, the undergraduate students may have been more attuned to the volunteers' perspective and may have had different expectations of what makes a game engaging and fun. Meanwhile, the lecturers may have had higher standards for the quality and educational value of the game. This difference in expectations could have contributed to the mixed perceptions among the moderators, particularly in relation to the design and content of the game. It would be interesting to explore these differences in expectations further and consider how they might influence the design and implementation of future educational games.

After the playtest and the analysis of the questionnaires followed by a slight refinement of the game, the physical and online versions of the Soil Character game were also translated to English.

4. Conclusion

This paper investigated the potential use of gamification as a tool for teaching and learning in geotechnical engineering. The Soil Character board game developed by the GeoFUN group provides an effective example of gamification, incorporating

game mechanics and social learning to enhance student engagement and motivation in learning soil characterization.

The evaluation of the game with eight civil engineering undergraduate students showed high levels of satisfaction with the game design, rules, and gameplay. The feedback collected from the students indicates that the game was well-liked, engaging, and effective in promoting learning. Most students found the game to be motivating, enjoyable, and challenging, and they would recommend it to others and play it again themselves. These findings suggest that the game was successful in achieving its intended goals and was well-received by the target audience of students. On the other hand, the moderators' perceptions were more mixed, particularly in relation to the design and content of the game. The mixed perceptions among the moderators could be explained by their different backgrounds and expectations since half of them were undergraduate students while the other half were lecturers.

These findings suggest that gamification can be a valuable tool in making geotechnical engineering education more interactive and engaging. The Soil Character board game can be used as a supplementary teaching tool in soil mechanics courses, as well as being adapted to other fields of engineering and science that involve complex concepts and terminology. Further research is needed to explore the effectiveness of the game in different contexts and with different student populations.

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Declaration of interest

The authors have no conflicts of interest to declare. All co-authors have observed and affirmed the contents of the paper and there is no financial interest to report.

Authors' contributions

Mariana Ramos Chrusciak: conceptualization, visualization, validation, investigation, methodology, formal analysis, supervision, writing – original draft, writing – review & editing. Hingred Karoline Magalhães da Luz: conceptualization, data curation, visualization investigation, methodology. Rebeca Dias de Souza: conceptualization, visualization. Bruna de Carvalho Faria Lima Lopes: conceptualization, visualization, validation, investigation, methodology, formal analysis, supervision, project administration, writing – original draft, writing – review & editing

Data availability

The datasets generated analyzed in the course of the current study are available from the corresponding author upon request.

List of symbols and abbreviations

e	void ratio
n	porosity
AASHTO	American Association of State Highway and Transportation Officials
COBRAMSEG	Brazilian Conference on Soil Mechanics and Geotechnical Engineering
G	gravel
GEORS	Geotechnical Engineering Seminar of Rio Grande do Sul
HRB	Highway Classification System
L	Low compressibility
S	Sand
UFRR	Universidade Federal de Roraima
UK	United Kingdom
USCS	Unified Soil Classification System

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