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Problem-based Learning in A Theoretical Course in Civil Engineering: Students' Perspectives

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ABSTRACT

More than a half century has passed since the first integration of problem-based learning (PBL) in higher education teaching. Despite the extensive investigation focused on this pedagogy, rigorous research on the impact of PBL in civil engineering is limited. Thus, this study aims to provide a thorough evaluation of students' perceptions of PBL in a civil engineering course. The course was designed based on best practices from the literature while addressing, with the intent to minimize, the inhibitors of PBL success indicated in past research. The semester-long project was focused on creating an artifact to demonstrate geological phenomena chosen by the students, to then be displayed in an exhibition. The course included formative and summative assessments of students' performance throughout the semester. Data was collected and analyzed methodically from over 150 students from two cohorts, one with a one-year post-course perspective, using a survey. The results indicate high satisfaction with several aspects of the course, including the perception of soft skill development. The analysis also showed that students from an ethnic minority group had significantly higher satisfaction and perceived benefit from the course. These findings demonstrate the possibility of turning a theoretical civil engineering course into a valuable PBL course, suggesting that PBL may promote greater equality for ethnic minority groups.

Key words: Problem-based learning, Civil engineering, Students perception

INTRODUCTION

For decades, accumulated evidence indicates the inadequacy of engineering graduate skills to meet industry needs (Mills and Treagust 2003; Beagon, Niall, and Ní Fhloinn 2019). Notwithstanding having been proven ineffective in achieving required skills such as teamwork, problem-solving, decision-making, and communication (Mills and Treagust 2003), lecture-based teaching still dominates engineering education. Several processes were initiated to identify the competencies, skills, and qualities required by the engineering graduate (Beagon, Niall, and Ní Fhloinn 2019). These processes supported efforts to offer pedagogies to facilitate their development (e.g., Akop, Rosli, Mansor, & Alkahari, 2009; Kamaruddin, Kofli, Ismail, Mohammad, & Takriff, 2012). One such approach is problem-based learning (PBL).

Problem-based learning is an established pedagogy that involves learning through activity. Faculty members in the medical school at McMaster University in Ontario developed PBL in the 1960s (Quinn and Albano 2008). Problem-based learning commences with presenting an ill-defined problem, which forms the core of the learning process and provides the context and motivation for students' learning. Thus, PBL is process-oriented and grounded in the constructivist theory (Chin and Chia 2004b). The PBL concept is based on the assumption that students should not be passive recipients of knowledge because passivity hinders deep understanding of the presented material and its application to real-world situations (Gijselaers 1996). Moreover, PBL has been shown to promote interest and facilitate the development of transferable skills such as teamwork, communication, negotiation, and innovation (e.g., Beagon, Niall, & Ní Fhloinn, 2019).

Problem-based learning has been implemented into engineering, and in some unique cases, at the curriculum level. The most prominent higher education institute applying PBL throughout its engineering undergraduate program is Aalborg University, which, in each semester, devotes half the curriculum to projects (Kolmos, Holgaard, and Dahl 2013).

Many studies focused on and found contributions of the pedagogy to the development of soft skills (McKenna, Gibney, and Richardson 2018), sometimes also referred to as professional skills (e.g., Siller et al. 2009). This exploration relied on the assumption that PBL provides the students with the opportunity to learn in a more business-like environment (compared to lecture-based teaching), thereby enabling them to practice desirable employment skills (Vogler et al. 2018). The definition of soft skills varies in different studies but generally considers intrapersonal and interpersonal skills (Tadjer et al. 2020). Different studies explored various soft skills, but many focused on communication, teamwork, and time and management skills. These skills are also addressed in the ABET engineering accreditation criteria (Accreditation Board for Engineering and Technology 2021). For example, Warnock and Mohammadi-Aragh (2016) identify teamwork, communication, problem solving and self-directed learning as most important by relevant stakeholders (graduates, educators and employers). They found PBL to promote the development of these skills.

However, more than a half-century has passed since the introduction of PBL in the McMaster University medical school, and despite the extensive research focused on this pedagogy, PBL in engineering, specifically in civil engineering, has received limited attention. Chen, Kolmos, and Du (2021) reviewed the past 20 years of research about PBL in engineering and found that only 11 papers focused on civil engineering. Furthermore, when they examined the methodology deployed to explore the benefits of PBL in some of these studies, they found several issues. Some researchers had relied on the impression of the course instructors, while others used anecdotal comments from students. Furthermore, some studies report the use of surveys with very small samples, or unknown response rate to surveys, or surveys with no indication of the validity of the instrument. Moreover, McKenna, Gibney, and Richardson (2018), reviewed papers on PBL in civil engineering published between 2003 and 2018 and found that 5 of 27 did not include any PBL evaluation. Another seven studies used only descriptive statistics in their analysis, and some of the others relied on impressions of the researcher or anecdotal student comments. Thus, McKenna, Gibney, and Richardson (2018) suggest that a more rigorous and quantitative evaluation of PBL in civil engineering is required. Furthermore, Ulger (2018) indicates that previous research suggests the importance of the need to explore the benefits of PBL in different disciplines and student populations.

Research about PBL also revealed that, like many other innovative pedagogies, the introduction of PBL may raise difficulties and resistance from students. Some of the students in those studies felt that they could put the time to better use in a traditional lecture-based approach (Ahern 2010; Iborra et al. 2014), or that the project was time-consuming (Fernandes 2014; Souza, Moreira, and Figueiredo 2019). Some of the students felt they did not have comprehensive coverage of the material due to their work on their specific task (Warnock and Mohammadi-Aragh 2016), while others wanted to maintain their traditional and passive learning role (Fernandes 2014).

The sparseness of rigorous research of PBL in civil engineering, with the diversity of method of implementation and some adverse reactions of students in some cases, suggests a methodological exploration of effective ways to integrate PBL in civil engineering courses may contribute to the body of knowledge and motivates this study. Thus, this research aims to provide a rigorous evaluation of various aspects of students' perceptions of the contribution of PBL in civil engineering course. The course design was based on best practices from the literature while addressing inhibitors of PBL success indicated in past research, as detailed next.

The course selected for this research is named Introduction to Engineering Geology, and is taught in the civil engineering department at Shamoon College of Engineering in Israel which operates a bachelor's degree program in structural engineering. The four-year program of the department aims to prepare its graduates to engage in the constructive design of structures and enable them to register as licensed construction engineers in the regulatory institution in the country. Around 500 students are enrolled to the program (about 125 students in each year). Thirty to forty percent of the students enrolled to the course (and the program) belong to an ethnic minority in Israel, which is 3.1 times more likely to be below the poverty threshold than the ethnic majority group in Israel (Dopez and Neeman 2021). This portion is higher than the group's percentage of the country's population (approximately 20%) and much higher than its percentage of all students in higher education (10.7%) (Shafir and Yagur-Carol 2018). It approximates enrollment representation in parallel programs in other higher education institutes in the country.

As part of the curriculum, students learn a series of courses in the field of geotechnics. The courses focus on the design of the foundation systems of structures and other elements that interact with rocks and soils, such as retaining walls and underground structures. The series of the geotechnical courses begin in the first semester of the second year of study with the "Introduction to Engineering Geology" course.

The main goal of the course is to help students attain familiarity with the basic principles of geological sciences so that later in the curriculum, they can learn and understand the mechanical behavior of geological materials. The course is taught in the scope of the 3.75 European Credit Transfer and Accumulation System (ECTS) and is theoretical. Upon completion of the course, students are expected to be able to: (a) detail the composition of the earth, (b) explain the phenomena associated with plate tectonics, (c) explain what a mineral is and describe the mineral groups that make up the earth's crust, (d) list the groups of rocks that make up the earth's crust and describe the primary soils in the country, (e) explain basic principles in the fields of stratigraphy and hydrogeology, (f) detail what geological structures are and explain their formation, and (g) detail methods for site investigation.

Although the course had been taught in a traditional lecture manner, it became increasingly noticeable that the lecture format was unsatisfactory. Student attendance was dropping. Students indicated that they were having difficulty summarizing the material learned in class or learning from the literature by themselves. Therefore, the course staff decided to change the course structure and aim for a more active learning process to facilitate more meaningful learning (Gijselaers 1996). The course has been taught in PBL format since the fall semester of the 2018–2019 academic year. Additional learning outcomes for the course have been defined. Specifically, it is expected that upon successful completion of the course, students will be able to: (a) locate literature sources, (b) work in a team, and (c) present in front of an audience.

In light of the changes made to the course and the previously limited rigorous research on PBL in civil engineering, this study aims to comprehensively and methodically examine students' perceptions of PBL teaching methods, as detailed next.

MATERIALS AND METHODS

The overall course design and the methodology employed to evaluate it are discussed below.

Course Design

The course was carefully designed while considering three aspects: the characteristics of the course (as described in the previous section), PBL principles, and obstacles identified in the literature to inhibit the successful implementation of PBL. The principles directing the course design involved presenting the students with an ill-structured problem. The students work in teams to identify what they need to learn to develop a suitable solution, with instructors acting as facilitators rather than primary sources of information (Prince and Felder 2006). Additionally, as indicated, in the design of the course some of the main inhibitors of PBL success identified in the literature were considered. Specifically, the time consuming nature of PBL (Fernandes 2014; Souza, Moreira, and Figueiredo 2019), the necessity of scaffolding of students learning (Beagon, Niall, and Ní Fhloinn 2019) and the need for comprehensive knowledge acquisition of the subject matter (Perrenet, Bouhuijs, and Smits 2000).

The course begins with a weekly two-hour-long face-to-face lecture in each of the first two weeks of the semester (see Figure 1). These lectures provide a general overview of the geology world and some geoengineering consequences, and function as the first step in supporting students' comprehensive subject knowledge. One of the reasons for holding these sessions is to address one of the observed obstacles when applying PBL in engineering studies - the gap between the hierarchical nature of engineering knowledge and the unstructured nature of PBL (Perrenet, Bouhuijs, and Smits 2000).

Next, the course objectives are introduced. With course staff guidance, the students participate in creating a topic list of geological phenomena (see an example of a list compiled during the 2020–2021 academic year in Appendix A). Students team up into work-groups of three to four students and choose from the list a topic they are interested in learning. Additionally, students seeking to expand their knowledge on topics that interest them and are related to the course material are encouraged and supported by the teaching staff. Compiling the list with the students and asking

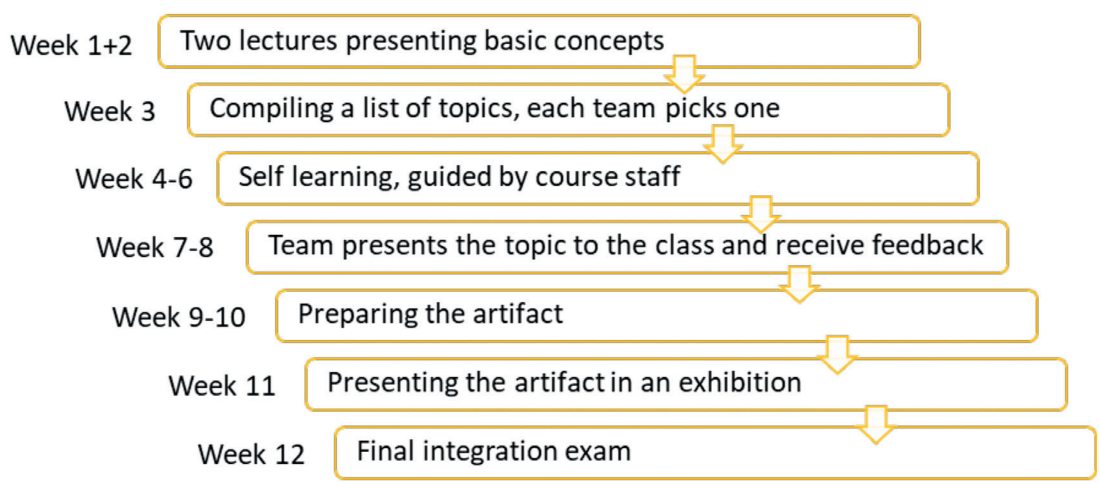

Figure 1. Course design.

them to pick a topic of their choice to work on, is aimed at supporting student's interest and sense of ownership (Chin and Chia 2004a). This, in turn, is expected to facilitate inquiry-based and student-centered learning (de la Puente Pacheco, de Oro Aguado, and Lugo Arias 2020), and may promote autonomous motivation (Wijnia et al. 2015).

The students' final goal (their project) in the course is to design a model that illustrates their chosen topic, and to present it in an open-to-the-public exhibition. In order to create such a model, the students need to learn about the topic they chose and decide upon the best way to demonstrate it using an artifact. Two examples for such artifacts are shown in Figure 2. One artifact (Figure 2A) demonstrates the tectonic plates that make up the earth's crust. The demonstration consists of a model made of metal showing the current state of the tectonic plates. Using magnets, the metal plates can be detach from and connect to various points on the model, thus displaying the location and motion of the tectonic plates throughout geological history, including an explanation of the mechanism that causes their movement. The second artifact, (Figure 2B) demonstrates the impact of an earthquake. The demonstration explains a geological rapture along which the earthquake occurs, an explanation of the evolution of seismic waves and their effect on a structure located on

A B

Figure 2. A) Tectonic plates, B) The impact of earthquakes on structures.

the ground surface. These examples demonstrate students' need to study in depth the various topics, and the numerous options for an original and creative presentation of them.

As can be seen, the assignment is not a typical PBL authentic and complex problem to solve, due to the early stage of the course in the program (an introductory course in the subject of engineering geology). However, students are required to choose what and how they learn about the phenomenon and how to demonstrate it using an artifact, thus presenting the students with an ill-structured problem to direct their learning, as PBL pedagogy suggests (Prince and Felder 2006).

In order to provide scaffolding, another key element of PBL (Beagon, Niall, and Ní Fhloinn 2019), students teams meet with the teaching staff for a guidance session. The topics to be studied are highlighted in these meetings, and the students are directed to the relevant literature. The students are allocated three weeks to focus their efforts on learning the subject. If necessary, they contact the teaching staff for further assistance and guidance.

During the next step, each group presents its topic to other members of the class (see Figure 1, above), explaining how the model in the exhibition is going to be designed and what goals they want to achieve at the model presentations, which will take place later, at the exhibition. Students receive feedback about their presentations from their classmates and the lecturer. After receiving and discussing the feedback, the students submit an abstract summarizing the theoretical background of the topic they have studied. The abstract is reviewed by the course teaching staff and returned to the students for amendments, after which the revised abstract is published on the course website.

On at least two occasions (when presenting it to the class and on their submitted abstract), each group receives feedback and the opportunity to revise their work. This process facilitates formative assessment, a fundamental PBL design principle (Chin and Chia 2006).

Students devote their time to their project throughout the rest of the semester, and no face-to-face lectures are held. This choice is based on the understanding that working on the project is very time-consuming. Students identified this issue as one of the main obstacles in PBL implementation (Fernandes 2014; Souza, Moreira, and Figueiredo 2019).

In the final week of the course, the exhibition is held; the exhibition is open to invited members of the public. A referee panel examines the artifacts and observes the students' presentations during the exhibition. The referees evaluate students' knowledge and creativity in designing of the artifact and its visibility and determine how well the students convey their ideas and understandings. The referees are asked to give a score between 1 and 7 for the following questions:

1. How visually appealing and attractive is the display?
2. How creative is the way the message is conveyed?
3. Is the message understandable and focused?

4. How well do the students know the subject?
5. Provide your general impression of the students' work.

Based on the referees' assessment, the score of each exhibition artifact is determined. The members of the referee panel include the teaching staff, experts in geology, and city science park representatives.

Project-based learning as itself was found to promote students' motivation by making studying more relevant and interesting (Terrón-López et al. 2017, citing others). As researchers have suggested (Gomez-de-Gabriel et al. 2010; Frank, Lavy, and Elata 2003), but not thoroughly examined, competition may generate additional incentives. Thus, in the course, the exhibition also includes a competition. The three best models are showcased in the city's science park. Hence, the winners are publically recognized in the college, but also by visitors at the city's science park. This reward choice for the winning projects may be associated with esteem- the fourth tier in Maslow's hierarchy of motivational needs (Maslow 1943; McLeod 2018).

The presentations and the abstracts that each team has prepared serve as sources of learning for the entire class as they prepare for the course's final integration exam, held after the exhibition. Because students' choices do not cover all course topics, some topics are taught face-to-face by the teaching assistant, during the semester. The final exam, the peer instruction by the classmates, and the teaching assistant's teaching sessions all complement the two introductory sessions at the beginning of the semester, and ensure comprehensive coverage of the essential material of the subject. As mentioned in the literature regarding PBL, this combination of methods is aimed to meet a student-expressed concern focused on the limited knowledge acquired through PBL (Warnock and Mohammadi-Aragh 2016).

Students' final grades in the course are comprised of the presentation in class (20%), the submitted abstract (20%, where 10% is for the preliminary abstract and another 10% for the revised abstract), the referee panel's assessment at the exhibition (40%) and the final exam (20%).

Pedagogy Evaluation

Because the evaluation method of students learning in the course changed profoundly as the course transition to PBL format, comparing students' performances before and after the change is irrelevant. Therefore, the evaluation of the course and the pedagogy focuses on students' perceptions. In order to examine this perceptions as rigorously as possible, multiple aspects of the learning experience were explored with two groups of respondents, using a questionnaire. The first group of respondents included students who completed the PBL-formatted course in the current academic year (2020–2021 academic year), after the final exam in the course. The second group of respondents were students who completed the same course in the previous year (2019–2020 academic year).

Both groups responded to the same anonymous online questionnaire that was available for 10 days on the course website (for the 2019 students the questionnaire was posted on the web site of the consecutive course, i.e., the next course in the series of the geotechnical courses students learn in the program). Students provided their informed consent to participate in the study before filling out the questionnaire. Students who completed the questionnaire received three bonus points on their final grade in the course. The final questionnaire instrument was adapted from previously developed tools (Abrantes, Seabra, and Lages 2007; Acero, Payan-Duran, and Espinosa-Diaz 2017; Gray and DiLoreto 2016; Molinillo et al. 2018; Vasan, DeFouw, and Compton 2009). The questionnaire explored both cognitive and emotional aspects of students' perceptions of the course. Specifically, the questionnaire focused on (a) the contribution of the course to students' understanding and learning of course material and the domain (geology), (b) their attitude towards the domain, (c) the contribution of the instruction methods to their learning and the development of soft skills, specifically, written and oral communication, reaching agreement with peers, solving problems creatively, time management, working autonomously, planning and coordinating with others and taking initiative, and (d) their general satisfaction with the course and the pedagogy deployed, including interest and challenge, effectiveness and usefulness and enjoyment. The questionnaire concluded with a few demographic questions (age, gender, and ethnicity). A pre-test was conducted to examine the instrument's clarity and relevance. The questionnaire was introduced and a semi-structured interview of a limited number of students who took the course was undertaken. Each of these students provided feedback for each question and the entirety of the questionnaire. Based on this feedback, the wording of some of the items was changed; the finalized instrument contained 32 statements. Respondents were asked to indicate the extent to which they agreed (or disagreed) with each item. This was done using a 5-point Likert scale where 1 indicated strong disagreement and 5 indicated strong agreement. A single additional open-ended question asked students to describe other skills they acquired in the course. The data gathered through participant responses are detailed in the next section.

RESULTS

A total of 166 students completed the survey. The response rate was 74.8% (95 out of 127 students enrolled in the course) for the 2020–2021 academic year students and 79.8% (71 out of 89 students enrolled in a consecutive course) for the 2019–2020 academic year students. As shown in Figure 3 and detailed in Appendix B, most of the students who filled out the questionnaire were males (78.9%) between the ages of 21 and 26, reflecting the characteristics of the students' population in the course. The majority of respondents (59%) belong to the ethnic majority in Israel.

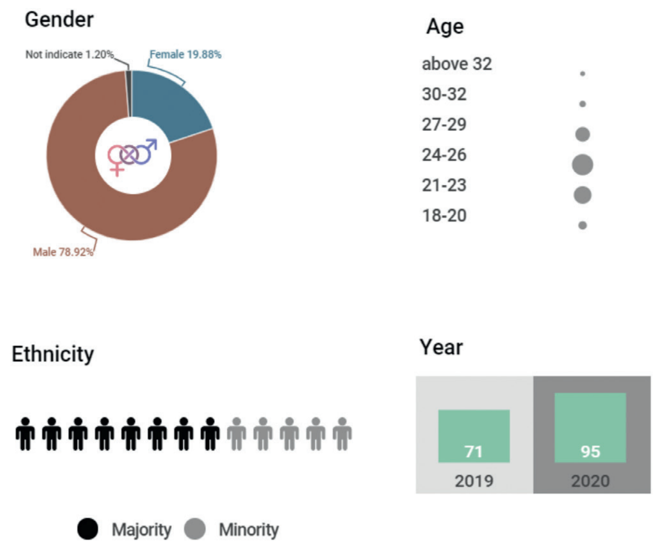

Figure 3. Respondents' demographics.

As mentioned, students' academic performances were not examined in this study, primarily because the learning evaluation methods changed dramatically. However, the instructors in the course and other instructors who teach these students in more advanced courses that rely on the knowledge acquired in the course generally indicated that student understanding of the material remained similar to the past.

As noted, for data collection we used a survey format that was generally based on a five-point Likert scale, where 1 indicated that the respondent strongly disagreed with the statement under consideration, while 5 indicated strong agreement with the statement. Our findings showed that the overall perception of the course and the pedagogy that was used to present the course material was favorable, with averages responses ranging between 3.41 and 4.25. Table 1 shows the results in more detail. The statement that produced the highest agreement (4.25 out of 5), was item 6, which focused on the project's contribution to learning. The statements with next two highest response averages were concerned with the emotional aspect of the course – "The activities in the course were enjoyable" (item 23) and "I am satisfied with my overall experience in this course" (item 17). Statements that received the lowest, albeit a relatively high average agreement focused on cognitive aspects of course –"I learned skills that will help me in the future" (item 4) and "The course was intellectually challenging" (item 22). These results suggest that the emotional aspect of course activities was more substantial than the cognitive aspect. Statements concerning soft skill development, one of the most often-stated benefits of PBL (Mills & Treagust 2003), were between 3.48 and 3.87, with higher agreement on oral communication and initiative statements. Nonetheless,

Table 1. Means and standard deviation of responses.

	Statement	Mean*	St. Dev.
1	The course enabled me to better understand the subject of geology.	3.95	0.88
2	I learned more in the course than I anticipated.	3.65	1.03
3	I learned skills in the area of geology.	3.63	0.99
4	I learned skills that will help me in the future	3.42	1.06
5	The learning activities (learning by yourself, presentation in front of the class, writing an abstract, and making a display) promoted learning.	3.95	1.02
6	I learned a lot from the project.	4.25	0.92
7	I learned a lot in this course.	3.66	0.99
8	Working on the project was a useful learning activity for topics in geology.	3.97	1.08
9	If I was asked about the course, I would say good things about it.	3.86	0.95
10	I am satisfied with my learning in the course.	3.81	0.94
11	I am satisfied with the content of the course.	3.86	0.94
12	Work put into this course was a good use of my time.	3.63	1.08
13	The course was useful.	3.72	1.08
14	The course was interesting.	3.89	1.08
15	Learning in the course was effective.	3.68	1.06
16	As a result of taking this course, I have more positive feelings about civil engineering.	3.66	1.07
17	I am satisfied with my overall experience in this course.	4.01	0.90
18	Experiences in the course were good.	3.97	1.00
19	The teaching methods in this course were effective.	3.57	1.10
20	The teaching methods in this course were useful.	3.57	1.05
21	I am satisfied with the teaching methods in this course.	3.52	1.12
22	The course was intellectually challenging.	3.4	1.06
23	The activities in the course were enjoyable.	4.09	0.87
24	The course enabled me to understand that I am interested in geology.	3.6	1.10
25	The course facilitated development and practice of my ability to communicate orally.	3.87	1.05
26	The course facilitated development and practice of my ability to communicate in writing.	3.68	1.05
27	The course contributed to my ability to reach an agreement with others.	3.74	1.04
28	The course contributed to my ability to solve problems creatively.	3.68	1.06
29	The course contributed to my ability to organize time effectively.	3.48	1.05
30	The course contributed to my ability to work autonomously.	3.6	1.09
31	The course contributed to my ability to plan and coordinate.	3.79	1.07
32	The course contributed to my ability to take the initiative.	3.84	0.97

*On a five-point Likert scale ranging between 1- strongly disagree and 5- strongly agree

the overall difference between the mean scores of statements is relatively small (0.85 between the highest and lowest, on a 5-point Likert scale).

The study also explored the differences in student perceptions according to their demographics, including gender, age, ethnicity, and the academic year the course was taken. For this analysis, responses

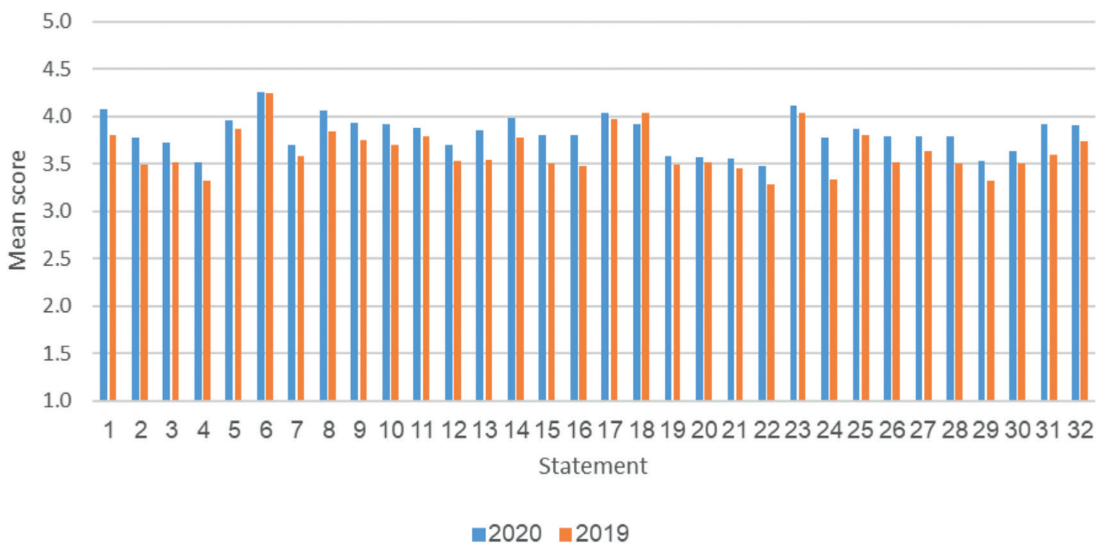

Figure 4. Mean of responses by year for each statement (see the list in Table 1).

of demographics categories indicated by only one or two students were removed (2 respondents with undefined gender and one respondent above age 31). On most statements under study, the differences between the genders and age groups were not statistically significant, as indicated by two-sided Mann-Whitney tests for gender and Kruskal-Wallis tests for age (out of 32 items, only 2 and 6 showed significant differences for gender and age group, respectively. The detailed results are presented in Appendix C).

Figure 4 presents the average scores of each statement for 2020–201 academic year students (who responded to the questionnaire after the course ended) and 2019–2020 academic year students (who responded to the questionnaire a full year after they finished the course). Though most averages are higher for the year 2020–2021 compared to 2019–2020, one-sided Mann-Whitney tests indicated that on most statements, these differences are not statistically significant (see Appendix C).

Ethnic minority students perceived the course's contribution and the pedagogy employed to be positive more than students belonging to the ethnic majority group (see Figure 5). A one-sided Mann-Whitney test indicated that this difference was statistically significant for 27 of 32 items in the instrument (see Appendix C). Two of the four statements with the highest significance of difference between the ethnic groups were concerned with soft skills- "The course contributed to my ability to plan and coordinate" (item 31) and "The course contributed to my ability to organize time effectively" (item 29). The other two statements with the highest difference are focused on interest in the discipline- "As a result of taking this course, I have more positive feelings about civil engineering" (item 16) and "The course enabled me to understand that I am interested in geology" (item 24).

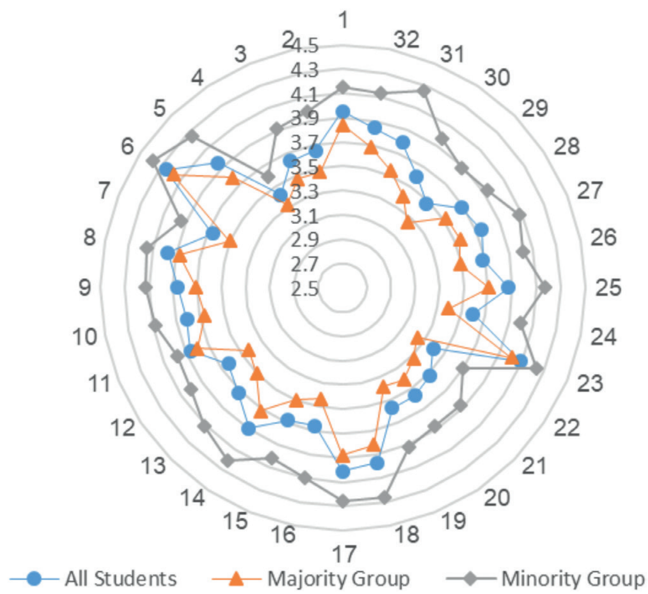

Figure 5. Means of responses by ethnic group for each statement (see the list in Table 1).

On the optional open-ended question regarding other skills that the course contributed to the respondents' development, 46 (27%) of the students replied. The most common comment themes were teamwork (44.4% of the comments) and presenting in front of an audience (24.4%). Other comments were focused on creativity (8.9% of the comments), learning to conduct research, and learning new things (6.7% each), expressing ideas orally (4.4%), and time management, developing one's personality, and interpersonal relationships among students (each was indicated by one student). Some of the comments indicated that the course contributed to students in a way the teaching staff did not anticipate. For example, one student mentioned that the course helped him develop the ability to "think outside the box and make the best of a given setting," while another indicated that the course "improved the relationships among the students", and a third mentioned the skills of "managing a budget and dividing tasks among friends."

DISCUSSION

This study provides strong evidence for the contribution of PBL in a sophomore theoretical course focused on basic knowledge of geological phenomena in civil engineering. Inferential statistics were used in this study to analyze data collected using a previously validated questionnaire with an adequate sample and response rate, something not often found in literature about PBL in civil engineering. Specifically, its findings suggest that students perceive the PBL pedagogy as satisfactory and enjoyable, positively contributing to developing their soft skills.

The pedagogy in the course was carefully chosen based on course context, best PBL practices, and inhibitors indicated in the literature. First, to support students' interest and sense of ownership (Chin and Chia 2004a), a list of topics is complied with the students, who are then asked to choose the one they wish to explore. Furthermore, there are no limitations presented regarding the design and implementation of the artifact. For example, students may choose to build a physical model or use multimedia (or both), to demonstrate the topic they picked.

Additionally, the course staff supplies scaffolding to students (Beagon, Niall, and Ní Fhloinn 2019) by conducting guidance meetings and several events of formative assessment (Chin and Chia 2006). Two major sources of resistance identified in the literature are also addressed via the course design. The first is the workload generated by the project (McKenna, Gibney, and Richardson 2018). To balance that workload, the time that is conventionally devoted to attending course lectures is directed, instead, to time used for teamwork on the project, with only short sessions with the teaching assistant held during the semester.

A second major concern of students found in the literature is they will not attain coverage of all the essential material of the subject (Warnock and Mohammadi-Aragh 2016). This concern is addressed by the short sessions at the beginning of the semester, the peer instruction, and the teaching assistant's sessions throughout the semester. The design choices described in this paper may also provide some remedy to the Mills & Treagust (2003) assertion that integrating PBL into engineering education may be problematic due to its hierarchical nature. Mills & Treagust (2003) suggest that missing some of the knowledge, which may occur in PBL, could hinder the learning of more advanced material. Thus, providing the students with an overview of the essential materials of the discipline may provide a solution.

The results indicate a high degree of satisfaction with the pedagogy and the experience it generated for the students. The highest agreement with questionnaire statements suggests that students perceive the new format as enjoyable (statement 23, see Appendix A) and that it supports learning (statements 5 and 6). Respondents' answers indicate that they are generally satisfied with the course (statements 17 and 18) and found the project to be a helpful activity (statements 6 and 8). High satisfaction is also recorded among students who took the course in the 2019–2020 academic year. These students took advanced courses that built on what they learned in the 2019–2020 PBL introductory geology course. As indicated by their responses to the survey, it seems that those 2019 students did not feel, in 2020, that they lacked knowledge in any follow-on courses. This suggests that, one year later, they felt the learning in the PBL-based introductory geology course was sufficient.

The findings indicate that the ethnic minority group perceived that the pedagogy was even more beneficial, as statistically significant response differences between the ethnic majority and minority groups were found in 27 of the 32 questionnaire statements. The most significant differences between ethnic majority and minority groups were regarding statements dealing with soft skills (one of the most-cited benefits of PBL), the subject's attractiveness and the discipline. These findings suggest that PBL should be considered when aiming to promote equality. Moreover, PBL may support enhanced passion for the subject, specifically for members of the ethnic minority group whose profession choices are often based more on practical considerations than on interest (Popper-Giveon and Keshet 2016).

Previous research on the effects of PBL on minorities and students from communities with low socio-economic status has focused on younger students (i.e., primary and secondary education) (e.g., Gordon et al. 2001). Most of these studies explored the impact of PBL on low socio- economic students compared to a control group (Leggett and Harrington 2019), rather than students' perception of PBL. Studies that examined differences between minority and majority groups in the perception of higher education teaching were focused mainly on the ethnicity of the instructor (e.g., Ali and Al Ajmi 2013; Wang and Gonzalez 2020), which, in our study, belongs to the country's ethnic majority. Some indications suggest that students from lower socio-economic backgrounds perceive teaching to be worse than students from higher socio economic background (Ye 2016). Thus, suggesting that finding in the current study concerning the differences between the perception of minority and majority students are of value.

Thus, future research should further explore this study's findings, which deal with the perception of college students. Specifically, it would be interesting to examine diverse ethnic minority groups and explore the processes that lead to these outcomes. Further research may also explore the relevance of the finding for older adults, as most of the respondents in this research were under thirty. Additionally, the results and conclusions of the research are based on a sample collected in one course in one civil engineering department. Although the methodology employed does not suggest limitations on their generality, this, too, should be further explored.

This study makes four contributions to the body of knowledge of PBL in engineering in higher education, specifically in civil engineering. First, rigorously exploring multiple aspects of the perception of PBL by students in a civil engineering. Such exploration in this context has been limited in past research (Chen, Kolmos, and Du 2021; Ulger 2018). Second, the study highlights a methodology found satisfactory by the students by offering the students an active learning experience in a theoretical course while supporting the development of required soft skills. The high evaluations by the respondents on multiple items, including satisfaction, perceived learning, skill development, and enjoyment suggests that the design of the course was successful in both achieving the required outcome and avoiding negative aspects of BPL identified in the literature.

The third contribution of this study to the body of knowledge regarding PBL in civil engineering is its exploration of, among other things, the emotional reaction of students to PBL (study findings indicated that student perceptions were highly favorable toward the PBL method of instruction, and that they enjoyed learning in the PBL environment). While research about PBL in higher education focuses on performances and perceived benefits, its emotional impact is rarely explored. In those studies where emotional impact emerges, it appears to do so when students are asked to provide their perception in writing, rather than simply indicating their agreement by selecting numbers on a scale (e.g., Beagon et al., 2019). Because feelings significantly impact how students learn and perform (Antonacopoulou and Gabriel 2001; Love and Love 1995), exploring students' emotional reactions to PBL is of value. Finally, this study highlights PBL as a potential means of promoting equality between ethnic majority and minority groups of engineering students. This potential is an issue that has not been the subject of significant research in higher education, and it should be considered for further exploration.

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APPENDIX A

List of Topics for the PBL (2020–2021 Academic Year)

- Solar system
- Earth's internal structure
- The moon's structure
- Earth's crust
- Metamorphic rocks
- Igneous rocks
- Gravity
- Erosion processes
- Plate tectonics
- The creation of islands
- The formation of the Rocky Mountains
- Mount Everest: uplifting and erosion
- Volcanism
- Seismology
- The impact of earthquakes on structures
- Tsunami
- The hydrology cycle
- Civil engineering aspects of underground water
- The influence of underground water pumping
- Soil settlement
- Foundation systems
- Sinkholes
- Oil formation
- Soils in the country
- Geotechnical site investigation.

APPENDIX B

Descriptive Statistics of Respondents

		Frequency	Percent
Course year	2019	71	42.8
	2020	95	57.2
Age	18–20	7	4.2
	21–23	49	29.5
	24–26	75	45.2
	27–29	31	18.7
	29–31	3	1.8
	31 or more	1	0.6
Gender	Female	33	19.9
	Male	131	78.9
	Not indicated	2	1.2
Ethnicity	Majority	89	59.0
	Minority	53	31.9
	Not indicated	15	9
Total		166	100.00%

APPENDIX C

Means and Statistical Test results by Respondents' Demographics

The detailed results for Kruskal-Wallis tests for age, two-sided Mann-Whitney tests for gender, one-sided Mann-Whitney tests for the academic year, and for comparing ethnic minority and majority perceptions are presented in the following table.

		Age	Gender			Year			Ethnic Group		
	Item	U-statistic (p-value)	Mean Female	Mean Male	U-statistic (p-value)	Mean 2020	Mean 2019	U-statistic (p-value)	Mean Majority	Mean Minority	U-statistic (p-value)
1	The course enabled me to better understand the subject of geology.	5.853 (0.21)	3.82	4.02	1987 (0.439)	4.07	3.80	2724.5* (0.022)	3.84	4.15	3059* (0.0259)
2	I learned more in the course than I anticipated.	9.89 (0.042)	3.33	3.75	1742.5 (0.071)	3.78	3.49	2707.5* (0.022)	3.47	3.98	3276** (0.0027)
3	I learned skills in the area of geology.	5.383 (0.25)	3.55	3.68	1986 (0.451)	3.73	3.52	2836.5 (0.066)	3.47	3.92	3280.5** (0.0025)
4	I learned skills that will help me in the future	2.498 (0.645)	3.33	3.47	2012 (0.526)	3.52	3.32	2951 (0.154)	3.32	3.6	2970 (0.0657)
5	The learning activities (learning by yourself, presentation in front of the class, writing an abstract, and making a display) promoted learning.	4.601 (0.331)	3.70	3.99	1885 (0.231)	3.96	3.87	2974 (0.17)	3.78	4.26	3195** (0.007)
6	I learned a lot from the project.	5.46 (0.243)	4.03	4.30	1898.5 (0.238)	4.25	4.24	3068 (0.277)	4.18	4.38	2797 (0.196)
7	I learned a lot in this course.	5.948 (0.203)	3.42	3.70	1810.5 (0.124)	3.69	3.58	2986 (0.177)	3.51	3.94	3171.5** (0.008)
8	Working on the project was a useful learning activity for topics in geology.	4.132 (0.388)	3.73	4.03	1888 (0.236)	4.06	3.85	2778.5* (0.04)	3.87	4.15	2903 (0.104)
9	If I was asked about the course, I would say good things about it.	7.265 (0.123)	3.70	3.89	1945 (0.341)	3.94	3.75	2788.5* (0.041)	3.71	4.13	3241.5** (0.004)
10	I am satisfied with my learning in the course.	5.02 (0.285)	3.45	3.93	1643.5* (0.022)	3.93	3.70	2787.5* (0.039)	3.66	4.08	3143.5* (0.011)
11	I am satisfied with the content of the course.	5.844 (0.211)	3.73	3.87	2043.5 (0.61)	3.88	3.79	2987.5 (0.183)	3.8	3.98	2785 (0.219)
12	Work put into this course was a good use of my time.	5.854 (0.21)	3.39	3.69	1885.5 (0.237)	3.69	3.54	2926.5 (0.128)	3.43	4	3287** (0.002)
13	The course was useful.	9.256 (0.055)	3.33	3.82	1686.5* (0.041)	3.85	3.55	2701.5* (0.021)	3.5	4.11	3328** (0.001)
14	The course was interesting.	8.656 (0.07)	3.58	3.97	1852 (0.183)	3.98	3.77	2930 (0.129)	3.72	4.21	3139* (0.013)
15	Learning in the course was effective.	6.198 (0.185)	3.36	3.75	1858 (0.19)	3.80	3.51	2824.5 (0.059)	3.5	4.02	3246.5** (0.004)

	Item	Age	Gender			Year			Ethnic Group		
		U-statistic (p-value)	Mean Female	Mean Male	U-statistic (p-value)	Mean 2020	Mean 2019	U-statistic (p-value)	Mean Majority	Mean Minority	U-statistic (p-value)
16	As a result of taking this course, I have more positive feelings about civil engineering.	10.773 (0.029)	3.33	3.74	1733 (0.067)	3.80	3.48	2668.5* (0.016)	3.43	4.09	3440*** (<0.001)
17	I am satisfied with my overall experience in this course.	6.721 (0.151)	3.76	4.08	1909.5 (0.257)	4.03	3.97	3129 (0.384)	3.88	4.26	3113* (0.014)
18	Experiences in the course were good.	8.136 (0.087)	3.85	4.00	2053.5 (0.639)	3.92	4.04	3467.5 (0.743)	3.82	4.26	3132* (0.013)
19	The teaching methods in this course were effective.	4.452 (0.348)	3.45	3.56	2069.5 (0.688)	3.58	3.49	3077 (0.303)	3.38	3.92	3268** (0.003)
20	The teaching methods in this course were useful.	3.589 (0.465)	3.48	3.56	2069.5 (0.691)	3.57	3.52	3137 (0.416)	3.41	3.87	3165.5** (0.009)
21	I am satisfied with the teaching methods in this course.	5.869 (0.209)	3.45	3.53	2070.5 (0.698)	3.56	3.45	3076.5 (0.314)	3.33	3.87	3243** (0.004)
22	The course was intellectually challenging.	3.31 (0.507)	3.45	3.37	2289.5 (0.585)	3.47	3.28	2964 (0.164)	3.24	3.7	3161* (0.011)
23	The activities in the course were enjoyable.	3.334 (0.504)	4.00	4.11	2134.5 (0.904)	4.12	4.04	3006.5 (0.187)	4.01	4.23	2880.5 (0.111)
24	The course enabled me to understand that I am interested in geology.	11.315 (0.023)	3.61	3.60	2164 (0.993)	3.78	3.34	2518.5** (0.004)	3.39	4	3363*** (<0.001)
25	The course facilitated development and practice of my ability to communicate orally.	9.378 (0.052)	4.03	3.79	2484.5 (0.163)	3.87	3.80	3156.5 (0.458)	3.71	4.17	3058* (0.029)
26	The course facilitated development and practice of my ability to communicate in writing.	7.319 (0.12)	3.67	3.66	2143 (0.938)	3.79	3.52	2851.5 (0.074)	3.49	4.02	3252.5** (0.004)
27	The course contributed to my ability to reach an agreement with others.	13.769 (0.008)	3.70	3.73	2156.5 (0.984)	3.79	3.63	3068 (0.288)	3.55	4.08	3296** (0.002)
28	The course contributed to my ability to solve problems creatively.	6.283 (0.179)	3.70	3.67	2180.5 (0.936)	3.79	3.51	2877.5 (0.09)	3.53	3.94	3138* (0.013)
29	The course contributed to my ability to organize time effectively.	11.462 (0.022)	3.64	3.39	2428.5 (0.252)	3.54	3.32	2984 (0.184)	3.26	3.89	3445.5*** (<0.001)
30	The course contributed to my ability to work autonomously.	5.805 (0.214)	3.58	3.56	2215 (0.821)	3.63	3.51	3099 (0.353)	3.4	3.98	3344.5** (0.001)
31	The course contributed to my ability to plan and coordinate.	12.558 (0.014)	3.67	3.80	2098 (0.786)	3.92	3.59	2710.5* (0.023)	3.54	4.26	3533.5*** (<0.001)
32	The course contributed to my ability to take the initiative.	3.897 (0.42)	3.88	3.82	2190 (0.902)	3.91	3.73	2936.5 (0.128)	3.68	4.13	3165** (0.009)

* p-value < 0.05; ** p-value < 0.01; *** p-value < 0.001