Lessons Learned about Engineering Reasoning through Project-Based Learning: An Ongoing Action Research Investigation

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ABSTRACT: In this paper, we report on the third cycle of an ongoing action research project, the purpose of which is to develop engineering students' skills regarding judgement and reasoning. Students were required to develop a solution to an open-ended problem, and perform a series of analyses in order to propose a safe and viable solution to the given problem. The results of the study suggest that the students found it challenging to handle such an open-ended design problem, and required greater guidance on the part of the lecturer.

Keywords: Action research, student engagement, teaching methods, education research methods

1 Introduction

Geotechnical engineering requires extensive reasoning, judgement and evaluation, which rests on a dual base of technical knowledge and experience. Traditionally, geotechnical engineering curricula at universities have focused on the development of the first base, namely technical knowledge. More recently, however, there has been increasing focus on introducing students to the kinds of practices (particularly in terms of reasoning and judgement) that are required from geotechnical engineering professionals.

This paper presents the results of a third cycle of action research aimed at developing civil engineering students' engagement with geotechnical engineering. In particular, it aims to investigate the extent to which a geotechnical engineering design project allowed students to develop the kinds of reasoning, evaluation and judgement processes required in geotechnical engineering practice. The paper begins with a review of the literature pertaining to the development of engineering reasoning and judgement, both at university and in practice, prior to providing a description of the methods deployed in this study. Thereafter, the results obtained are discussed and conclusions drawn.

2 Engineering judgment and reasoning: In practice and in education

The importance of engineering judgement and reasoning is made clear in empirical research as well as in the prescribed outcomes required of engineering programmes in countries aligned with the Washington Accord (IEA, 2019). For example, in the United States, engineering graduates are required to "use engineering judgment to draw conclusions" [Accreditation Board for Engineering and Technology (ABET), 2018] and, in South Africa, they are required to "exercise judgment and take responsibility within own limits of competence" (Engineering Council of South Africa, 2019: 14). Empirical research further reinforces this need. A study undertaken at Massachusetts Institute of Technology (MIT, cited in Crawley et al., 2007: 66-69) found that engineering reasoning was rated as the most important skill required of engineering graduates amongst all groups of participants, including faculty, industry, recent alumni and experienced alumni. This MIT study was replicated in Sweden, and similar findings were obtained.

As such, though the importance of engineering judgement and reasoning is relatively clear, the definition of these terms is somewhat less clear. A search of EBSCOhost Research Platform (EBSCO, 2019) using the Boolean phrase [(judgment OR reasoning OR judgement) AND "geotechnical engineering"] yielded 40 search results. Of these, four articles could be excluded as they did not actually deal with geotechnical engineering-related topics or, in one instance, it was a brief editor's note about another of the articles in the search results. Of the remaining 36 articles, three (O'Kelly et al., 2009; Pierce et al., 2013; Bourne and Baxter, 2014) dealt with engineering education, albeit one of them (O'Kelly et al., 2009) was a brief piece about the history of the geotechnical engineering programme at Trinity College Dublin, which was thus excluded from further analysis. Another four (Christian, 2004; Bea, 2006; Marr, 2006; Muszynski, 2009) dealt with the topic of engineering judgement in geotechnical engineering in a meta-reflective manner. The remaining 29 articles were technical works that mentioned engineering judgement or reasoning in their abstracts, but were not specifically about engineering judgment.

In the six articles that explored engineering judgement and reasoning, either in geotechnical engineering education or practice, perhaps the strongest rationale for its importance is that provided by Christian (2004: 1001):

> "It is clear that our knowledge of the geological and environmental factors affecting geotechnical engineering is imperfect and that it will remain so. Although modern developments in remote sensing and information technology promise to ameliorate this situation, we are not likely ever to have as much or as reliable information as we would like to have. However, we have to proceed with our projects. The first step is to recognize the extent of our ignorance and to understand whence it arises. We can reduce uncertainty by obtaining more information, especially when the search for more information is guided by a rational understanding of the nature of uncertainty and its impact on our decisions. "

Given the importance placed on engineering judgment and reasoning in engineering practice, considerable attention has been given to these topics in the engineering education literature. All of the major engineering education journals include multiple articles that reference this point. These studies have been undertaken, inter alia, in the context of project-based learning (Jaeger & Adair, 2015), engineering ethics (Harding et al., 2012; Berdanier et al., 2018; Hess et al., 2019), conceptual understanding and reasoning (Van Meter et al., 2016; Brown et al., 2018; Goncher & Boles, 2019), assessment (Leite et al., 2011; El-Maaddawy, 2017) and engineering design (Campbell et al., 2019; Dasgupta, 2019).

One way of developing engineering judgement and reasoning on the part of university students is through implementing problem-based learning (PBL). PBL is an approach to teaching and learning that focuses primarily on the learning process, that is, on *how* students should learn rather than what they should learn. De Graaff & Kolmos (2003; 2007) suggest that problem-based learning begins with analysis of problems, which can range from open-ended to well-defined. Generally, PBL also involves team-based learning, in which learning, as a social act, takes place through dialogue and communication with peers (de Graaff & Kolmos, 2003; 2007).

3 Methodology

The present paper reports on the results of the third cycle of an ongoing action research project. Action research is an iterative approach to research characterised by consecutive cycles of planning, implementation and reflection with respect to an identified problem (Christie & de Graaff, 2017; Bevins et al., 2011). This is depicted in Figure 1. Action research is widely used in educational research albeit less so in engineering education research. Nonetheless, Christie and de Graaff (2017) argue that action research is "a suitable research model for engineering educators who wish to do research on active learning in engineering education".

In this ongoing action research project, the initial problem identified was lack of engagement on the part of students within a geotechnical engineering course. This course forms part of a general degree in civil engineering, and is the second of three consecutive semester courses that the students undertake on geotechnical engineering.

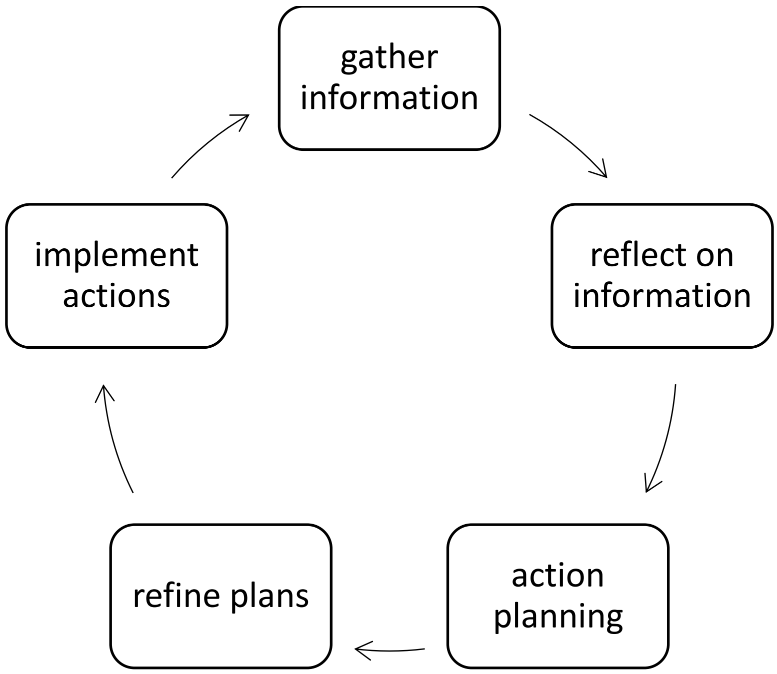

Figure 1: The action research cycle (adapted from Bevins et al., 2011: 404)

3.1 First cycle

In the first cycle of the research, conducted in 2017 (see Ferentinou & Simpson, 2019a), a number of changes in the module were implemented, such as the introduction of a guest lecture by an industry professional, greater interaction during class activities, weekly quizzes and increased use of software applications such as Slide 2018 within the classroom.

3.2 Second cycle

Despite the fact that the first cycle yielded greater student satisfaction with the course – and improved engagement with the course material as a result – it was observed that students continued to struggle to link the course materials and activities to the demands of geotechnical engineering practice. This necessitated a second cycle of research, which aimed to link student learning to engineering practice through project-based learning. As part of a second cycle, conducted in 2018 and described in Ferentinou & Simpson (2019b), students were tasked with a design project that required them to offer geotechnical engineering solutions for a commercial development founded on problematic geotechnical conditions. Although the design project was, in large part, successful, the researchers nonetheless identified a need to unpack the students' engagement with the project to examine the kinds of reasoning, evaluation and judgement practices developed through participation in these activities. This is the focus of the present paper.

3.3 Third cycle

In the current cycle, students were again required to undertake a design project. The lecturer (the second author of this paper), in an attempt to simulate real-world practice, acted as the project manager on the students' projects, which were conducted in groups of four students. The lecturer met with each group individually four times during the semester. In preparation for these meetings, the student groups were required to submit questions or preliminary designs for discussion. The project culminated in the submission of a report and delivery of a presentation, both aimed at proposing a safe and viable design solution and explaining the reasoning behind the proposed design. Moreover, the design needed to be in accordance with relevant standards as well as include consideration of financial viability, the environment, and questions of sustainability. The presentations delivered by the students were co-assessed by an industry professional, who also provided the case study on which the project was based. The aim of these decisions was to develop the course as an integrated learning experience, where students simultaneously develop disciplinary knowledge and professional engineering skills (Crawley et al., 2007).

In order to evaluate the success of the designed intervention, three types of data were collected. First, the group meetings held with each group were observed (by the first author of this paper) and the questions and preliminary designs submitted by the groups were collected and analysed. The focus of this analysis was on categorising the questions submitted in terms of focus, as well as on categorising the groups' proposed design solutions and identifying misconceptions in the students' design proposals. These questions – and observation of the meetings – were used to understand the student-participants' process regarding developing a design solution (these data are discussed in Section 3.1). Second, the students' final presentations were observed and their final technical design reports collected. In this regard, the focus of the analysis was on classifying the groups' design solutions and identifying the strategies used to display their reasoning and judgement (these data are discussed in Section 3.2). Finally, in order to validate the findings obtained, the industry-based co-assessor was also asked to produce written commentary on the work produced by the student groups (these data are discussed in Section 3.3). The focus of this input was on the quality of the reasoning and judgement displayed by the students during the presentations, and how this accorded with the kinds of reasoning and judgement demanded in geotechnical engineering practice. The intention of gathering this input was to support, or deepen, the observations and findings obtained from the first two sets of data.

3.4 Ethical considerations

All students – as well as the industry participant – gave informed consent to participate in the present study. All participants were given the option of not participating and had the right to withdraw from the research at any time. Their privacy and confidentiality were guaranteed and have been preserved in the present paper.

4 Student engagement in project-based learning

4.1 Focus on process

The problem given to the students introduced a typical road embankment that showed signs of pavement cracking and severe erosion, indicating the possibility of a slip failure. The causal factors identified by the lecturer were a lack of maintenance of the storm water drainage system and poor fill material. In addition to this, water was seeping under the embankment from a pond in which storm water was collected. The critical parameters were given as part of the problem definition. The students were required to present a design solution that would protect the slope from further erosion and ultimate failure. As part of their analysis, the students needed to perform (a) a deterministic analysis under Ultimate Limit State condition, (b) a probabilistic analysis, (c) a Serviceability Limit State analysis to evaluate long term settlement of the embankment, and also (d) consider practicalities, such as revegetation of the slope, drainage (or storm water system), and environmental aspects. As already mentioned, students had to submit a final report and make a 10-minute oral presentation

For their analysis, students could use Slide 2018 (RocScience, 2018). The students were introduced to the software during the course and were able to ask the course tutor for assistance during scheduled tutorials and practicals. In addition, probabilistic analysis is not a stated outcome of the course and students were expected to self-study this. This was required in order to ascertain their ability to solve problems without having all the required information easily available. Admittedly, therefore, the expectations of this course were particularly high, aimed at the level of a “capstone” design course, rather than a third year module. However, the researchers felt that students might benefit from being introduced to project-based learning earlier so as to be more adequately prepared for the capstone design course they were to face the following year.

The site conditions and relevant contextual information were provided as part of the design brief, which was prepared by the lecturer in consultation with the industry representative. The design brief was intentionally open-ended so that students were able to explore any solutions they deemed suitable. The project took place over an entire semester, during which time the students had four formally-scheduled opportunities to meet with the lecturer, who acted as project manager, as already mentioned. To this end, the students were able to ask questions and present ideas – but the lecturer intentionally avoided providing direction for the groups' individual designs, a decision that, in retrospect, was problematic, as the students required more direction than was initially assumed.

4.1.1 Findings from initial meetings

There were definite shifts in the students' thinking over the course of the meetings with the lecturer. During their initial meeting, held early in the semester, the student groups largely focused on site conditions and contextual information. Initially, the observational data collected – as well as analysis of the actual questions posed by the students – revealed four key themes. These pertained to i) misidentification of the central design problem, ii) difficulties understanding the geometry of the design problem, iii) cost and environmental considerations, and iv) the need for assumptions. Each of these themes is explored, in turn, in the paragraphs that follow.

Many of the questions asked by the student groups reflected a misidentification of the central problem underpinning the design solution. For example, many students asked for rainfall data, which reflected a misunderstanding of the seepage problem – which was due to the presence of a pond, rather than excessive precipitation. Moreover, the embankment that failed was constructed in order to carry a road, and many groups asked about the bearing capacity of the road and the materials used in the design of the road pavement. Again, this reflected a misidentification of the core problem – in that the road had not failed, but the embankment on which the road was constructed; the road was not the cause of the slope failure.

The students' misidentification of the problem at hand, in many instances, seemed to emerge from difficulties understanding the geometry of the problem. Many groups did not understand where the pond was located in relation to the embankment – and, despite the fact that an image of the failed slope was provided, many students did not understand the geometry of the slope itself, misrecognising the slope height, angle, road placement and so on. This led to some unworkable initial design solutions, such as construction of a bridge (this assumed that the road was crossing a ravine, which was not the case as the road was running parallel with the ravine – hence the embankment).

Another significant point in the students' initial ideas and questions related to consideration of economic and environmental factors. Several groups proposed bringing in entirely different materials and removing the in-situ material, which displayed a lack of consideration of the costs of such a solution, and ignored the fact that techniques exist to improve material parameters, such as geomaterials and the like. In addition, some groups asked about the local fauna and flora, both in terms of its role in causing the failure, but also in terms of the importance of considering this in the design solution.

Finally, several groups requested information that was unavailable or that needed to be assumed. In these cases, the groups were expected to make assumptions based on the information that was available, and to make these assumptions explicit in their design solution. For example, the exact dimensions and location of the pond were not given, and students were expected to make assumptions in this regard, possibly through developing a range of scenarios. Some groups also wanted more direction than the lecturer was willing to give. For example, some groups asked what factor of safety was to be achieved and others asked if they were expected to use geosynthetics in their solution. In these instances, students were advised to rely on their own judgment as well as on relevant standards, rather than relying on being told how to approach the design problem. Students had access to a number of relevant standards – and the purpose of the project was to expose them to problems in which the necessary information was not made explicit. Rather, they were expected to determine what information they would need and how to obtain it.

Overall, therefore, the initial project meetings with the various student groups revealed that very few groups were immediately able to identify the central design problem, with many student-groups initially focusing their effort on pavement design, geometric design of the road itself, or design of an altogether new slope – rather than rehabilitating the existing slope by addressing the seepage problem prevalent.

4.1.2 Findings from the final meetings

Fortunately, by the final group meetings, all the groups were able to propose a design solution that addressed the core problem of slope failure (but not always the underlying cause of the slope failure: seepage), albeit some groups continued to misunderstand the geometry of the slope. Analysis of the final meeting sessions yielded seven key themes: i) continued misidentification of the root cause of the design problem, ii) technical misconceptions pertaining to the critical slip surface, iii) inadequate attention given to boundary conditions, iv) continued lack of consideration of cost, v) lack of consideration given to constructability, vi) lack of consideration given to land use, and vii) frustration on the part of students with a perceived lack of guidance provided by the lecturer.

The first theme emerged from the fact that while most groups addressed the problem of slope stability, relatively few offered a solution to the seepage problem caused by the presence of the pond above the slope – which was the root cause of the slope failure. Moreover, many groups focused on one dimension (erosion, global stability, seepage) rather than all of these elements of the problem.

Themes (ii) and (iii) are primarily technical in nature. In the first instance, few groups were able to see the link between the critical slip surface and the need for soil reinforcement. Most of the groups included soil reinforcement in their proposed design, but only one or two groups (out of almost 25) extended this reinforcement (whether in the form of soil nails, geotextiles and the like) through the critical slip surface, thus doing little to enhance the tensile strength along this surface and failing to secure the global stability of the slope. In the second instance, many groups failed to accurately set the boundary conditions for their design models, which were produced on Slide 2018 (RocScience, 2018). This meant that groups' modelling of the seepage flow was often inaccurate and unreliable although the students had been given explicit instruction regarding the importance of setting correct boundary conditions.

The next three themes pertained to factors that students were required to give attention to in reaching design decisions. The first of these factors was cost. To this end, most of the student groups provided solutions that demonstrated significant over-design (though still failing to obtain adequate safety factors because of the aforementioned challenge with regard to the critical slip surface). The students also demonstrated a lack of consideration of constructability. For example, many groups proposed a solution involving placement of geomaterials to reinforce the embankment. However, many of these groups placed these geomaterials perpendicular to the slope surface, rather than horizontally – which would create significant challenges for construction and placement. Another problematic – but common – design proposal was to reduce the slope angle. This widens the amount of land needed which does not consider the extent to which this is possible, given questions of availability of land, as well as ownership of the land adjacent to the existing embankment. Moreover, it also increases costs due to the need for more materials. Finally, many groups reduced the slope angle, but still added reinforcement, which displayed a lack of understanding of the goal of the use of reinforcement: namely, to achieve steeper, more economical, slope angles.

Finally, what was also noticeable throughout the meetings with the groups was the fact that some students expressed a degree of frustration with the open-ended nature of the design problem. In one instance, some students became visibly upset at the lack of explicit guidance provided by the lecturer. For example, this group asked if vegetation would be sufficient to prevent erosion at the toe of the slope (also part of the initial design problem) and were irritated when the lecturer responded by suggesting that they need to decide for themselves if vegetation would be an appropriate solution and then justify their decision.

Overall, therefore, by the final project group meetings, most groups had developed an initial design solution, but they generally arrived at these solutions through trial and error using the software that was available (in their final presentations, many groups admitted to this fact). Very few of the groups were able to clearly articulate the assumptions they made and justify these assumptions, or to justify the design decisions they had made. Moreover, the groups struggled to balance the need to make assumptions based on incomplete information, while still paying attention to the competing demands of safety, cost, constructability and environmental impact. Unfortunately, many of these challenges persisted into the students' final project reports and presentations.

4.2 Focus on final product

Based on our analysis of the submitted reports, it was revealed that the students: i) reviewed the problem, which was open ended, ii) tried to clarify the meaning of terms, the geometry and the parameters that controlled the stability of the given embankment, and iii) analysed and defined the problem, with guidance from the lecturer.

All the groups managed to retrieve and organise pre-existing knowledge (for example, seepage analysis had been taught in the previous semester and was required in order to solve the problem). They also identified the knowledge (reinforcement, erosion protection) required. However very few groups attempted to design a drainage system, in order to control seepage.

The presentations were on time, and well prepared; however, the content contained several deficiencies that were also present in the reports submitted. Through this process, students developed professional engineering skills such as oral communication and collaborative work. As such, the learning objectives were partially met. However, the safety factor that was calculated by the majority of the groups was lower than what is expected in the relevant standards, to which the students had access. In many instances, seepage analysis was not performed correctly, as the boundary conditions of the problem were wrong for almost 50% of the projects.

Many reports focused primarily on problem definition, background and literature review, rather than methodology, analysis and presenting a solution. The editorial standard of the majority of the reports was not very high.

The concept of probabilistic analysis was not examined at all in a majority of the reports. Where it was included, it was not supported by sufficient support, explanation or reasoning. Limit state design and serviceability based design was not discussed by any of the groups, although the students had received instruction on these during the course of the semester, albeit in the context of retaining walls.

4.3 Industry perceptions of students reasoning, judgment and evaluation practices

The industry guest examiner felt that the lecturer needed to be stricter with the students regarding deadlines as this would demonstrate that students are able to manage their time, which is an important skill. The external examiner also identified problems in the students' identification of the failure mechanism, which suggested a lack of understanding of the basics of geotechnical design (i.e. loading and drainage calculations and criterion for acceptance) on the part of the students. While some groups understood this and correctly applied these using appropriate software, most of the groups simply targeted a safety factor without understanding the principles underlying the safety factor. Likewise, although it was required to perform deterministic, limit state (Ultimate Limit State and Serviceability Limit State) and probabilistic analyses, these were not all performed. When probabilistic analysis was performed, it was not accompanied by any reasoning; instead, the function was simply automated using the software, without trying to understand the underlying theory or purpose. Order of scale was also problematic on the part of the students. For example, the flow rates that were calculated during the seepage analysis were unrealistic and safety factors of 1.1 were considered adequate. This again suggests that students did not exercise judgement and reasoning regarding the results they obtained. Finally, regarding the use of geosynthetic materials, students demonstrated that they understood that geosynthetics provide tensile properties, albeit the parameters students used were not justified – and could not be explained (even when correct).

4.4 Reflections

Marr (2006: 98) argues that: "Judgment is critical thinking and reasoning. Judgment is arriving at a sound conclusion despite having had to sift through masses of conflicting, contradictory, erroneous, irrelevant information." Based on this definition, the majority of the students presented limited to low reasoning. Based on the outcomes of this third cycle of action research, there is a need to develop strategies to assist the learners with more guidance and scaffolding. One form of guidance could be worked examples, in order to provide the students with problem solving models (Chi et al., 1982). It might be more beneficial to teach the steps of problem solving, from visualisation to solution evaluation.

5 Conclusion

In this study, the authors sought to demonstrate that open-ended, problem-based learning activities could develop within students the kind of engineering judgement and reasoning practices required in geotechnical engineering practice. However, it was found that the students were quite resistant to the open-ended nature of this task, and they found it difficult to attend to all the competing requirements of this project. In retrospect, the researchers needed to do more to balance the need to encourage students to think, act and learn independently, with the need to provide explicit instruction, guidance and scaffolding. We had thought that the students would be in a position to work independently; however, it appears that Taber's (2010: 33) argument "that minimal guidance, almost letting the learners just get on with it, is seldom an appropriate educational strategy" holds true. This research, despite not achieving its original aim, demonstrates the challenge that students experience in moving from acquiring fundamental geotechnical engineering knowledge to applying this knowledge in more complicated real-life engineering design projects. If students are to acquire engineering judgement and reasoning skills, there needs to be more continuous formative feedback than was provided in the delivery of the module in its present form.

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References

Accreditation Board for Engineering and Technology (ABET). (2018). Criteria for Accrediting Engineering Programs, 2019 – 2020. [Web:] https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/#GC3 [Date of access: 1 November 2019].

Bea, R. (2006). Reliability and Human Factors in Geotechnical Engineering. Journal of Geotechnical and Geoenvironmental Engineering, 132(5), pp. 631-643.

Berdanier, C. G. P., Tang, X., Cox, M. F. (2018). Ethics and Sustainability in Global Contexts: Studying Engineering Student Perspectives through Photoelicitation. Journal of Engineering Education, 107(2), pp. 238-262.

Bevins, S., Jordan, J., Perry, E. (2011). Reflecting on Professional Development. Educational Action Research, 19(3), pp. 399-411.

Bourne, R., Baxter, S. C. (2014). Creating Environments for Fostering Effective Critical Thinking in Mathematics Education (Math-EFFECTs). Proceedings of the 121st American Society of Engineering Education Annual Conference and Exposition, ASEE, pp. 1-8, ASEE, Indianapolis, USA.

Brown, S., Montfort, D., Perova-Mello, N., Lutz, B., Berger, A., Streveler, R. (2018). Framework Theory of Conceptual Change to Interpret Undergraduate Engineering Students' Explanations about Mechanics of Materials Concepts. Journal of Engineering Education, 107(1), pp. 113-139.

Campbell, C., Roth, W-M., Jornet, A. (2019). Collaborative Design Decision-Making as Social Process. European Journal of Engineering Education, 44(3), pp. 294-311.

Chi, M. T. H., Glaser, R., Rees, E. (1982). Expertise in Problem Solving. In: Sternberg, R. J. (Ed.), Advances in the Psychology of Human Intelligence (vol. 1). Lawrence Erlbaum & Associates, Inc., Hillsdale, NJ, USA, pp. 7-76.

Christian, J. T. (2004). Geotechnical Engineering Reliability: How Well Do We Know What We Are Doing?. Journal of Geotechnical and Geoenvironmental Engineering, 130(10), pp. 985-1003.

Christie, M., de Graaff, E. (2017). The Philosophical and Pedagogical Underpinnings of Active Learning in Engineering Education. European Journal of Engineering Education, 42(1), pp. 5–16.

Crawley, E., Malmqvist, J., Ostlund, S., Brodeur, D. (2007). Rethinking Engineering Education: The CDIO Approach. Springer, New York, USA.

Dasgupta, C. (2019). Improvable Models as Scaffolds for Promoting Productive Disciplinary Engagement in an Engineering Design Activity. Journal of Engineering Education, 108(3), pp. 394-417.

De Graaff, E., Kolmos, A. (2003). Characteristics of Problem-based Learning. International Journal of Engineering Education, 19(5), pp. 657–662.

De Graaff, E., Kolmos, A. (2007). Management of Change Implementation of Problem-Based and Project-Based Learning in Engineering. Sense Publishers, Rotterdam, Netherlands.

EBSCO. (2019). EBSCOhost Research Platform. [Web:] https://www.ebsco.com/products/ebscohost-platform. [Date of access: 12 January 2020].

El-Maaddawy, T. (2017). Innovative Assessment Paradigm to Enhance Student Learning in Engineering Education. European Journal of Engineering Education, 42(6), pp. 1439-1454.

Engineering Council of South Africa (ECSA). (2019). Qualification Standard for Bachelor of Science in Engineering (BSc (Eng))/ Bachelors of Engineering (BEng): NQF Level 8". [Web:] https://www.ecsa.co.za/education/EducationDocs/E-02-PE%20Qualification%20Standard%20for%20Bachelor%20of%20Science%20in%20Engineering%20BSc-Eng_Bachelors%20of%20Engineering%20BEng_NQF%20Level%208.pdf. [Date of access: 1 November 2019].

Ferentinou, M., Simpson, Z. (2019a). Action Research to Enhance Student Engagement in Geotechnical Engineering. IAEG/AEG Annual Meeting Proceedings: Volume 6: Advances in Engineering Geology: Education, Soil and Rock Properties, Modelling, Shakoor, A., Cato, K. (Eds.), pp. 33-40, Springer, Cham, Switzerland.

Ferentinou, M., Simpson, Z. (2019b). Teaching Geotechnical Engineering for Practice-Readiness: An Action Research Project. Proceedings of the Eighth Research in Engineering Education Symposium (REES2019), Kloot, B. (Ed.), pp. 530-539, SASEE, Cape Town, South Africa.

Goncher, A. M., Boles, W. (2019). Enhancing the Effectiveness of Concept Inventories Using Textual Analysis: Investigations in an Electrical Engineering Subject. European Journal of Engineering Education, 44(1/2), pp. 222-233.

Harding, T. S., Carpenter, D. D., Finelli, C. J. (2012). An Exploratory Investigation of the Ethical Behaviour of Engineering Undergraduates. Journal of Engineering Education, 101(2), pp. 346-374.

Hess, J. L., Beever, J., Zoltowski, C. B., Kisselburgh, L., Brightman, A. O. (2019). Enhancing Engineering Students' Ethical Reasoning: Situating Reflexive Principlism within the SIRA Framework. Journal of Engineering Education, 108(1), pp. 82-102.

International Engineering Alliance (IEA). (2019). Washington Accord. [Web:] https://www.ieagreements.org/accords/washington/ [Date of access: 12 January 2020].

Jaeger, M., Adair, D. (2015). Using an Evidential Reasoning Approach for Portfolio Assessments in a Project-Based Learning Engineering Design Course. European Journal of Engineering Education, 40(6), pp. 638-652.

Leite, C., Mouraz, A., Trindade, R., Martins Ferreira, J., Faustino, A., Villate, J. (2011). A Place for Arguing in Engineering Education: A Study on Students' Assessments. European Journal of Engineering Education, 36(6), pp. 607-616.

Marr, W. A. (2006). Using Our Best Judgment. Civil Engineering, September, pp. 46-98.

Muszynski, M. R. (2009). Incorporating Reliability Methods into Geotechnical Engineering Practice. Journal of Performance of Constructed Facilities, 23(3), pp. 130-131.

O'Kelly, B., Orr, T., Farrell, E. (2009). Geotechnical Teaching and Research Reaches Fifty Years Milestone at TCD. Engineers Journal, 63(1), pp. 26-27.

Pierce, C. E., Gassman, S. L., Huffman, J. T. (2013). Environments for Fostering Effective Critical Thinking in Geotechnical Engineering Education (Geo-EFFECTs). European Journal of Engineering Education, 38(1), pp. 281-299.

RocScience. (2018). Getting Started - Slide 2018. [Web:] https://www.rocscience.com/help/slide2/#t=getting_started%2FGetting_Started.htm. [Date of access: 12 January 2020].

Taber, K. S. (2010). Constructivism and Direct Instruction as Competing Instructional Paradigms: An Essay Review of Tobias and Duffy's Constructivist Instruction: Success or Failure?". Education Review, 13(8). [Online:] http://www.edrev.info/essays/v13n8index.html [Date of access: 12 January 2020].

Van Meter, P. N., Firetto, C. M., Turns, S. R., Litzinger, T. A., Cameron, C. E., Shaw, C. W. (2016). Improving Students' Conceptual Reasoning by Prompting Cognitive Operations. Journal of Engineering Education, 105(2), pp. 245-277.

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