Investigating Student Perceptions of Engineering Judgment through Experiential Learning

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ABSTRACT

As a result of the increasingly complex and interconnected problems facing the world, civil (and all) engineers entering the workforce require a more mature sense of engineering judgment at an early stage in their career. The world can no longer afford to wait fifteen years for engineers, civil especially, to reach their prime decision-making ability. At the same time, and likely for the same reasons, ABET-aware faculty are grappling with how to develop and assess engineering judgment at the undergraduate level. The goal of our project is to develop and implement various learning strategies and instructional tools to improve student outcomes related to engineering judgment. To begin to address this, a second-year cohort of civil engineering students at Rensselaer Polytechnic Institute, a medium sized R1 institution which has been producing prominent engineers such as Ralph Peck since the early 19th century, participated in several activities in a required geotechnical engineering course aimed at assessing student understanding of engineering judgment. Open coding qualitative analysis was performed on gathered student definitions of engineering judgment to identify themes within student responses prior to undergoing a design project. Subsequent student submissions to the design project were qualitatively analyzed for employment of these themes within their prepared solutions. Findings suggest that while students included certain subskills in their definitions of engineering judgment, they struggled to demonstrate them within their design submissions. Additionally, analysis of reflection prompts after completion of the design project indicated that students

prefer application-based problems to traditional theoretical problem solving. This creates tension with another emerging theme from the reflection prompts: students wished they had more guidance for the open-ended design project. The general nature of application-based design problems, and ultimately experiential learning, is that the learner has limited guidance to fully allow for the individual exploration of the solution space. This work-in-progress paper briefly addresses this tension in student responses, while focusing on the evolution of engineering judgment development in second-year civil engineering students over the course of eight weeks during a required introductory civil engineering course.

LITERATURE REVIEW

According to Helle et al. (2006), ever-changing and -developing educational pedagogies tend to peak "every forty years or so". While the peak of Project-based Learning (PjBL) may have come and gone, numerous tertiary institutions are yet to employ its methods. Despite its mixed levels of use, PjBL's positive impacts have been thoroughly examined and documented (Servant-Miklos and Kolmos 2022; Kolmos et al. 2004). Across these studies, PjBL has been shown to increase communication skills in students. Koehn (2000) concluded that the heightening of students' communication skills arises from the groupwork aspects of many PjBL assignments, as well as the increased correspondence with course staff resulting from the heightened complexity of PjBL assignments.

Improving communication skills in students can be useful in the documentation of ABET student outcomes (Esche 2002). In addition to providing data for institutional authorities like ABET, communication is widely accepted as a critical component of engineering judgment (Bennett et al. 2022; Francis et al. 2021).

Since this study involves the investigation of student perceptions, a brief insight into existing literature on student perceptions is included herein. From an achievement point of view, positive student perceptions on a topic can be tied to higher performance (Ferreira and Santoso 2008). However, this glosses over a step between the learners' experiences, which shape their perceptions, and their achievement. Student perceptions are a window into what learners think of the education being presented to them. Each student is a unique person with a different personality, educational background, and upbringing. As such, the way they interact with learning materials will vary immensely (Lizzio et al. 2002). By assessing and documenting student perceptions and conceptions, we can inform our educational methods, potentially enabling higher quality learning.

METHODS

The study population for this analysis is fifty-seven students enrolled in a required introductory geotechnical engineering course at Rensselaer Polytechnic Institute, a medium-sized R1 research STEM-focused institution for higher education located in the Northeast of the United States. The students in the course are generally enrolled in a 4-year ABET accredited Bachelor of Science in civil engineering curriculum. Additionally, the majority of students in the course would have only taken general engineering and science courses prior to this semester. This course, along with introductory courses to structural, transportation, and environmental engineering typically taken in the same semester, would be their first exposure to civil engineering specific coursework as well as true engineering design work. The course instructional team estimates that the population consists of 56% male-identifying and 44% female-identifying students. Demographic information was not collected, and no exclusion criteria were employed.

The deployment of PjBL in this study was performed using the Goals, Activities, Products, and Assessments (GAPA) framework (Stolk and Martello 2018). The GAPA framework serves to support project goals during course revision. Also, the GAPA components are non-directional; they are often exchanged and even repeated in the interest of achieving desired student outcomes. The first component of the PjBL implementation utilized in this study was a Proctor compaction laboratory experiment in which pre-assigned student groups of 3-4 students performed the ASTM Standard Proctor compaction laboratory test according to a modified version of ASTM (2021). The goal of this activity is to plot a dry unit weight versus water content curve. This deliverable would be needed for a subsequent activity. During the lab session, instructional staff took great care to discuss the applications of the proctor results on design decisions. This was done to plant the seeds of engineering judgment. In the week after all students completed the experiment, the students participated in a facilitated in-class discussion. They answered three prompts in stages:

> "1.) What does 'engineering judgment' mean to you? Leverage examples and stories about where you have observed engineering judgment or engineering judgment development in the classroom, internships, or general life experiences.
> 2.) What are the indicators for engineering judgment? Leverage examples and stories about where you have observed these indicators or development of these indicators in the classroom, internships, or general life experiences.
> 3.) How would you demonstrate your development of engineering judgment in your undergraduate coursework? Consider speaking to future opportunities to demonstrate use/development of engineering judgment" (Carkin 2023).

After the students answered each question individually, they were invited to discuss and combine their responses into a group response. These groups were self-selected and comprised of 3 to 4 students, each different than those used to perform the Proctor compaction laboratory experiment.

After completion of the engineering judgment defining activity, students received the design project assignment (to be completed independently) and the engineering judgment rubric with which their assignments would be assessed. The engineering judgment framework that is the foundation for the rubric is defined in Richtarek (2021) and Bennett et al. (2022). This framework was developed by identifying commonalities and differentiators between concepts in the early conceptualization of engineering judgment, such as that by Ralph Peck (DiBiagio and Flaate 2000), with the current educational frameworks in engineering and the dense literature on critical thinking. This synthesis yielded a preliminary set of competencies that comprise engineering judgment and may be individually targeted in the classroom.

The design project consisted of the design an earthen structure to serve as a detention pond in accordance with the 2021 King County Surface Water Design Manual. This manual is readily available online and contains design criteria for detention ponds, including geometry and compaction specifications. While the details of stormwater design were deemed out of scope, the students were given the total 100-yr storm runoff to detrain and full agency to alter the geometry of the pond within the constraints of the provided site. The assignment also required them to appropriately specify compaction of the berms with the assumption that the material was identical to that with which they performed their Proctor experiments. Students were initially given four weeks to complete the design project.

After the project was initially submitted, the course staff asked students to complete a self-assessment of their submissions using the rubric. Following the self-assessment, students participated in a self-selected group reflection activity called "*I like, I wish, What if*" to collect feedback on their perceptions of the design project. These three prompts are an established method of collecting and assessing student takeaways without instilling as much anxiety as a formal assignment. The first prompt solicits positive responses from students to gain an understanding of well-received project components. This prompt also serves to shift their mindsets in favor of providing constructive feedback, which colors their subsequent responses. The second prompt allows students to criticize the project, revealing the project's less-favorable attributes. The final prompt gathers potential alternatives to the activity being assessed. Students initially responded to each prompt individually; they were then asked to generate group responses similar to the engineering judgment defining activity. After completion of the reflection activity, the students were given assessments of their design project submissions by the course instructional staff (consisting of a professor and two graduate assistants). At this time, students were invited to prepare a resubmission of the design project. Results and discussion of the student design project submissions were the subject of Carkin et al. (2023).

A timeline depicting the order of activities utilized in this GAPA implementation is shown in Figure 1.

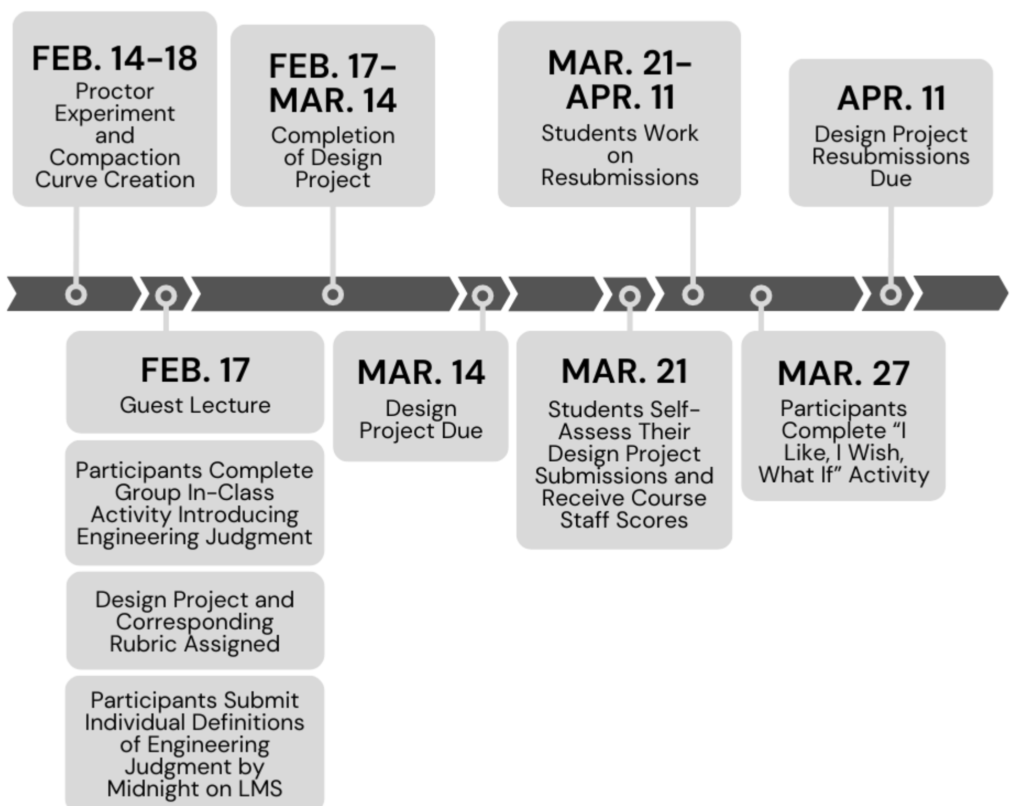

Figure 1. Timeline Depicting Implementation Activities (Adapted from Carkin, 2023).

Sources of data analyzed for this study include the student responses to the engineering judgment defining activity and student responses to the “I like, I wish, What if?” reflection activity. The students responded individually and collaboratively in self-selected groups of three to four for both activities. Only the collaborative group responses were analyzed in this study. This study used grounded theory and thematic analyses to identify themes of interest (Glaser and Strauss 1967; Nowell et al. 2017). The application of grounded theories allows the researcher to generate new theories and hypotheses while staying rooted in the source content (Glaser and Strauss 1967; Nowell et al. 2017). During the analyses, reflexive practices were employed: these are vital for deep and rich qualitative analyses (Crabtree and Miller 1999). In this particular study, several iterations of analyses were taken. Initially, researchers performed a data familiarization phase during which the responses from a Microsoft PowerPoint format (as submitted by the participants) were converted to Microsoft Excel for easier manipulation. Then, each response was reviewed several times to generate discussion amongst the research team about potential themes to explore. At this stage and throughout the process, memos were written to help document the process and keep track of how iterations changed the emergent themes (Braun and Clarke 2006).

After the initial data familiarization period, open coding was performed utilizing the constant comparative method (Glaser and Strauss 1967). In this application of the constant comparative method, “In Vivo” coding was utilized, which “places emphasis on the actual spoken words of the participants” (Manning 2017; Saldana 2012). As a result, most of the codes in this study stem from a common phrase used by the participants. After a code was defined, which is the act of explicitly describing the criteria which qualifies a response to be coded as a particular code, the constant comparative method was used to refine the code. In this process, each phrase found to fall within the defined code is compared to the previous. If the researcher is content that both incidents are similar and grouped in an intuitive manner the definition is unchanged, if the incidents appear to be dissimilar, the definition is altered and the process is repeated (Glaser 1965). In this highly iterative process, the researcher aims to ensure a robust, replicable study. Given the resultant code definitions, any qualitative researcher should be able to replicate the results. Upon the generation of multiple codes, the relationships between codes were examined. In this phase, similar codes can be grouped into categories, and similar categories into themes (Glaser 1965). One example of this within this study was the joining of the codes term-listing and decision-making into the emergent theme of “multi-factor decision making,” which will be further explored in the results and discussion section.

RESULTS AND DISCUSSION

One emergent theme identified in the student responses to the engineering judgment defining activity is multi-factor decision making. This theme encapsulates the idea that engineering judgment is demonstrated when multiple factors go into making a decision. These factors included “safety”, “cost”, and “ethics”, and some responses even acknowledged that these factors may conflict. For instance:

> “[Engineering judgment is] Being moral and ethically grounded. Being cost effective and taking into account safety/potential conflicts. Making educated decisions while approaching obstacles by connecting them to past experiences or learned concepts.”
> -Anonymous

This theme of multi-factor decision making is quite similar to the engineering judgment competency defined by Richtarek (2021) "Application of Judgment", which is defined as "Application of Judgment (Evaluation and Inference Implications and Consequences + Definitive Conclusion): The learner understands how to apply inferences from these results toward a solution to the task at hand. The learner identifies the most significant and probable implications and thoroughly considers the potential consequences of the proposed solution from all stakeholders' points of view. The learner clearly forms a logical and empathetic conclusion and provides justification for the conclusion."

Another competency from the Richtarek (2021) Engineering Judgment framework is "Global Engineer"; this is defined as "The learner understands that engineering challenges may have multiple effective solutions and can look at the challenge from many points of view in order to assess the benefits for ALL stakeholders. The learner approaches the engineering challenge in the context of optimizing societal wellbeing from all perspectives (ethics, economic feasibility, environmental sustainability, community, region and culture)." This ties into the identification of ethics, cost, and sustainability as factors in the emergent theme of multi-factor decision making.

In the analyses of the student responses to the engineering judgment defining activity, another emergent theme identified is "traditional education". This theme is defined as "participants identifying laboratory experiments, exams, homework, or lecture as a method to demonstrate development of engineering judgment" (Carkin 2023). There are very few citations of traditional education in student responses to the engineering judgment defining prompts. In contrast to this, many students cited cooperation and collaboration, which are grouped into a third emergent theme, "classroom collaboration". This third theme is defined as "Participants identifying asking for help, or group work, as a method for demonstrating development of engineering judgment" (Carkin 2023). Given the significantly larger number of students identifying collaboration over traditional methods, this could suggest that students perceive that engineering judgment cannot be demonstrated using traditional methods, but can be in a PjBL learning space. In students' post PjBL reflection, they cited enjoying (even preferring) the design project to assignments such as lab reports.

> "I liked that this was an alternative to the lab reports because this allowed me to better see what we do in the lab as a real life application" –Anonymous

It is promising for students to think engineering judgment can be demonstrated in collaborative PjBL settings; PjBL has been shown to be more effective for student learning outcomes (Servant-Miklos and Kolmos 2022). If students can embrace the PjBL approach with excitement and a positive attitude, this may lessen the workload of instructors as well as fuel intrinsic motivation in students. However, while students claim to like the assignment, their feedback creates tension, as they adamantly cited that they wished they had more guidance. For Instance:

> "I wish there was some more guidance on this project through either a more specific rubric or maybe an in-class example of a scope of work" –Anonymous

> "I wish I had more strict instructions giving me a guidance upon what specifically is being asked from me" –Anonymous

This is interesting because when students claim to enjoy PjBL, that could imply that they enjoy the open-endedness, which is a critical component of the PjBL process. This discontinuity could suggest that although students think they like PjBL, when faced with what they perceive as a lack of guidance, they revert towards preference for traditional methods with which they are more comfortable. This point of view of the students is not uncommon and was found in a similar study by Esche (2000). Esche (2000) also notes “there needs to be a balance between the amount of guidance given and the freedom that should be allowed for creativity in an open-ended project.” This idea is present and reinforced in this study. Too much guidance detracts from the agency PjBL gives the learner and does not allow for the creative exploration of a solution space.

In contrast, a quote showing the positive embrace of the openness of the PjBL assignment is:

> “I liked how the project gave us free liberty of how to tackle the problem at hand” -Anonymous

Their use of the word liberty is a beautiful connection to Self Determination Theory, which when applied to pedagogy provides a method to focus teaching and learning around students’ individual interests and capabilities (Ryan and Deci 2000; Pérez et al. 2022). This supports the existing narrative that PjBL can promote agency and intrinsic motivation in students.

It is important to note that PjBL deployment in this study was in the form of an individual assignment. While we acknowledge there are distinct benefits to group work, such as its resemblance to post-collegiate workforce conditions, there are also drawbacks, such as inequitable group member contributions and increased efforts required of instructional staff. However, the students in this study did wish to have the collaborative benefits of group work.

> “I wish we would have been in groups working on this project and more throughout the class itself.” -Anonymous

> “I wish that I could have been with peers while working on this instead of by myself over break.” -Anonymous

Given the recurring theme that engineering students (and students in general) want more guidance for PjBL, the question must be asked: how much guidance is the proper amount? Perhaps the ideal amount has already been found and students just do not like it. This could mean that we as educators need to do a better job communicating to students what is important within their education (Bennett et al. 2022).

CONCLUSION

A quality engineering education is marked by hands-on learning, ‘do-learn’ environments, interdisciplinary and teamwork experiences, integrated learning opportunities, design, and many other components. The effectiveness of these components with respect to student learning outcomes has been studied to varying degrees. However, there is a dearth of research investigating student perceptions and conceptions of this ‘innovative’ pedagogy. This exploration of the student experience is foundational to creating an educational environment that is resilient and relevant to Gen Z learners. We have noted the importance of clearly communicated expectations while struggling to find the balance between the creative potential of open-endedness and the maturity/expectations of our students.

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