Understanding First-year Engineering Students' Perceptions of Working with Real Stakeholders on a Design Project: A PBL Approach

Homero Murzi
Department of Engineering Education
Virginia Polytechnic Institute and State University
Blacksburg, United States
hmurzi@vt.edu

Lydia Fielding
Department of Civil Engineering
Virginia Polytechnic Institute and State University
Blacksburg, United States
lf253@vt.edu

Mark Huerta
Department of Engineering Education
Virginia Polytechnic Institute and State University
Blacksburg, United States
markhuerta@vt.edu

Juan Ortega Alvarez
Department of Engineering Education
Virginia Polytechnic Institute and State University
Blacksburg, United States
jdortegaa@vt.edu

Matthew James
Department of Engineering Education
Virginia Polytechnic Institute and State University
Blacksburg, United States
mjames@vt.edu

Andrew Katz
Department of Engineering Education
Virginia Polytechnic Institute and State University
Blacksburg, United States
akatz4@vt.edu

Jacob Grohs
Department of Engineering Education
Virginia Polytechnic Institute and State University
Blacksburg, United States
jrgrohs@vt.edu

***Abstract*—This full paper reports on students' experiences after working on a first-year engineering design project with a real client. The instructors partnered with a Children's Museum in the local area, and students were tasked with developing prototypes of potential exhibits. The purpose of this paper is to present results on students' perceptions of their experience working with a real client, developing a prototype, and having to interact with project stakeholders (e.g., children). The course design was based on problem-based learning (PBL) and data were collected from 169 first-year engineering students who anonymously filled out an exit survey. Responses were coded and emerging themes are presented. Natural processing language techniques were also used to analyze the open-ended responses.**

***Keywords*—design, PBL, first-year engineering, NLP**

I. Introduction

First-year general engineering programs are common in large research universities in the U.S. These programs are focused on introducing new engineering students to some foundational aspects of the discipline, providing support with the transition from high school into college, and introducing students to the different options they have when selecting an engineering major [1], [2]. This study was conducted in a course that is part of a first-year general engineering program. Students complete a two-course sequence throughout their first year before matriculating into discipline-specific degree-granting programs: the first course focuses on an introduction to the discipline and engineering problem-solving strategies, and the subsequent course focuses on the engineering design process through a semester-long project. This is similar to other first-year general engineering programs in the U.S, which generally focus on a wide variety of learning outcomes that go beyond understanding the engineering profession and the different options the students have in terms of majors, including some professional skills (e.g., teamwork, communication), introduction to engineering tools (e.g., CAD or MATLAB), and probably the most important, introduction to engineering design [3]–[6].

This study takes place in the second design-focused course. In the semester of data collection, there were several different design project options that instructors could follow. Most course sections followed an approach that was more traditional at the study institution in which students were given projects with hypothetical real-world clients and applications [7]. In contrast, several instructors took part in a project that partnered with a local children's museum so that student teams could directly interact with project stakeholders [8]. This paper focuses on students' perceptions of their experiences taking part in this project

Problem based learning is a method of teaching which incorporates real-world problems in order to enhance student learning of certain concepts. This is in contrast to the "direct presentation of facts and concepts" [9]. This problem-based learning environment allows students to gain critical thinking and communication skills. For example, in teaching engineering design, PBL provides students with a focus on the process rather than the final product, something that engineers in industry learn to value but engineering students are more reluctant to accept. One aspect of PBL that is crucial in this process, is the importance of students having several interactions with real stakeholders. In these contexts, students are able to receive feedback during each unique interaction and have the opportunity to continuously improve their designs. This feedback from groups such as real users and clients can be used to expand upon the student's preconceptions and original perspectives of their work. The interaction between the student and the client is often part of the value in PBL courses and can help create a more fruitful first-year engineering design project experience.

Our research explores students' perceptions of their experiences after being involved in a first-year design course developed following a PBL approach with a real client. Our research question is "What did students learn from a PBL first-year experience working for a real, external client?"

This paper examines students' experiences after having an introductory design course with a PBL approach paired with real problems from external clients.

II. Guiding Theoretical Framework: Problem Based Learning

Bonwell & Eison [10] define active learning as an instructional method that engages students -beyond passive listening- in the learning process. Active learning is presented in the literature as the opposite of a traditional lecture because students reflect on what they are doing after engaging in several learning activities introduced in the classroom. First-year engineering programs have been structured to promote several active-learning activities, especially around an introduction to engineering design. According to Bonwell & Eison [10], the amount of information retained by students declines considerably after ten minutes of listening. The hands-on and reflection promoted in active learning has been proven to be more effective in engineering students. By actively participating they have been able to obtain the desired learning outcomes offering itself as a more effective strategy in engineering education [10]–[12].

One active learning approach that is particularly well suited for teaching engineering design is problem-based learning (PBL). In PBL, students receive a relevant, real problem to solve during a class for an entire semester. According to Prince and Felder [13], open-ended, ill-structured, authentic problems are more similar to what students will encounter in real-world situations in the workplace. Students usually work in teams that have to identify learning needs to solve the problem and develop a viable solution. Instructors using this approach work as facilitators and key sources of information [11], [13][14]. The participants are involved in a self-directed and contextual environment that promotes learning. A PBL instructional strategy has several steps. *Naming* is defined as the identification of the main issues in the problem. One aspect that PBL emphasizes is the importance of fully understanding the problem -and obtaining as much data on it as possible- before even trying to solve it. *Framing* is considered to be the establishment of the limits of the problem. *Moving* refers to the experimental action taken to solve the problem, and reflecting is evaluating and criticizing the move. The learning will be obtained after this process is fully developed [15]. In addition, Roselli and Brophy [16] state that a PBL environment needs to be student-centered and when possible, allow for students to have interactions with experts on the problem topic or real stakeholders. The role of the facilitator is to introduce the concepts and the problem-solving skills required to solve the problem.

PBL has been widely implemented in engineering education as an approach that promotes critical thinking and problem-solving skills for students. PBL has been proven to be effective among engineering students to develop both technical and professional competencies. Problem-based learning (PBL) approach has been used in various undergraduate engineering courses such as engineering design, capstone, introduction to electrical engineering courses, material science, and laboratory courses [17]–[23]. Research conducted by Atman et al., [19] suggested PBL offers adaptable and accurate practical context to develop designing skills, while Yadav et al., [23] implied PBL offers students an appreciation of the applicability of their academic field on real-world problems. Atman et al., [19] illustrated how to connect design research and design education by presenting two examples where the first one focused on bringing into the classroom research findings from a laboratory, and the second one elucidates a PBL developed and operated in the classroom including instructor intervention based on activity observations. They concluded PBL approaches need to be accompanied by intervention and assessments that account for the development of the activities in the classroom including learning distinctiveness and specific objectives [19]. In the specific context of electrical engineering, Yadav et al. [23] focused on understanding learning transferability from PBL versus a traditional lecture. The research took place in a Midwest university and had 55 participants, using within-subjects A-B-A-B research, a pre and post-test, and an assessment of their learning. Their findings suggested students' experience with PBL provided a good learning experience that many students considered different from the traditional lecture. They considered PBL was close to having a hands-on real engineering experience and provided a lot of practical knowledge while still recognizing the technical knowledge that some lectures provided [23].

In this sense, Yadav et al., [23] suggested that PBL comes with benefits and challenges, and faculty need to provide support to scaffold the experience and conduct assessments that align with this approach. As can be seen, not only the PBL pedagogical approach can have an impact on students' learning but also setting up the experience as an iterative process where students can receive real feedback will be ideal. Hence for this study, we developed a PBL approach by providing the students with a real problem in a real context. To further improve the experience of the students, we partnered with the Children Museum of Blacksburg (CMB) and allowed students to have real interactions with the main stakeholders of the project. More details about the course and the context of the project are provided in the following section.

III. Course Context

The course where this research was conducted is the Foundations of Engineering II which is a required course for first-year engineering students. Typically, students take this course in their second semester after successfully completing the Foundations of Engineering I in their first semester. The goal of this two-course sequence is to expose students to engineering disciplines, the engineering design process, modeling engineering systems, exposure to contemporary software tools such as MATLAB and CAD, and professional practices and expectations (e.g., communication, teamwork, and ethics). The second course focuses on a semester-long team design project that provides the context to achieve this goal. Data for this paper were collected during the Spring 2018 semester. During that semester, the sections participating in this research had the course structured around 3 modules. Module 1 aimed at helping students understand the fundamentals of engineering design. Module 2 discussed modeling, testing, and communicating engineering ideas. Module 3 focused on unpacking engineering problems. A notable aspect of the course was the semester-long design project that students completed working in teams of 4-6 students. There were 5 sections and each section had approximately 33 students. Each section had approximately 7 teams.

In the Spring 2018 semester, three instructors decided to take a different approach than had been used in past course iterations by partnering with CMB with the goal of developing prototypes for children to play and learn. The objective of the final prototype was not only that it was interactive and fun for the kids to play with, but also that the exhibit was able to help them develop skills and knowledge in line with the Virginia standards of learning for different age groups (6 – 10 years old). The instructors took a PBL approach and provided students with a set of requirements and constraints. We explained to students that learning the engineering design process requires an understanding of products, materials, constraints, and criteria, and also requires an understanding of context, stakeholders, and implications of the things we design. Hence, the Museum was highly involved as a real client and the Museum Director was willing to interact with the students. The three faculty members involved with the project had initial meetings with the Museum Director and developed a plan to work with them during the semester. The plan included a commitment from the Director to attend a pitch session mid-semester with all the sections involved, and attend the final design fair. The CMB director attended all sections at least once and was able to individually interact with all teams and provide feedback on their initial pitch. Similarly, the instructors committed to bringing the students to one of the Museum's open house events and to ensuring that all teams were visiting the museum facilities at least once to obtain an understanding of the layout and the existing prototypes.

The project required them to create and produce an interactive product (e.g., physical artifact, software interface) for the museum. Students started by doing individual brainstorming, then team discussions about their ideas, and were required to select an idea to pitch to the Museum director and the instructor of the course. They then had several rounds of peer interactions where they received continuous feedback. The project involved at least two rounds of prototyping and at the end students participated in a design fair where they brought their prototypes and presented them to all the students enrolled in these sections. Students were also required to do a final presentation and submit a final report.

IV. METHODS

Data were collected using an anonymous survey that was distributed electronically as a class exit survey for the students at the end of the semester. In the survey, we asked students about their experience during the course, about what they learned about design, about how they thought their experience was different when compared to the other sections, and about how the experience was of working with a real client. The specific questions are provided in table 1.

TABLE I. SURVEY QUESTIONS

Questions	
1	Describe your personal interaction with the design project client (The Children's Museum of Blacksburg Director)
2	Describe your team's interaction with the design project client (The Children's Museum of Blacksburg Director)
3	How was your design experience different because your worked with an actual client to produce a design to be used in the Children's Museum?
4	Would you recommend this type of project be continued in the future? Please briefly explain your answer.
5	Describe some elements that were present this semester that you felt were valuable for student learning and success in the engineering design project
6	What are some specific elements from this semester that you would change for the future in order to better enable student learning and success in the engineering design project?
7	What did you learn about engineering design this semester?
8	How would you rate your team's execution of the design process in comparison to the other products you saw displayed.
9	Please identify two or three factors that contributed to the result indicated in the previous question and explain how each contributed.

Students responded to the open-ended questions and were provided time in class to fill out the survey. In total, 169 students' responses were used in this study. The study secured ethical clearance from the Virginia Tech Institutional Review Board.

To facilitate theme identification in students' responses, we used a human-in-the-loop (HITL) natural language processing (NLP) approach. The general motivation for this approach was to allow the research team to handle the data volume more efficiently and consistently highlight the themes across responses.

The HITL NLP workflow starts with the raw text from students' responses. We then embedded that raw text in a high-dimensional vector space using pre-trained transformers [24]. These kinds of language models are a kind of modern neural network architecture that enables consideration of context and abstract representation of semantic meaning such that phrases like "I had a great time" and "I enjoyed the experience" would be more similar than "I disliked the trip." After two dimension reduction steps to bring those embeddings down to a lower-dimensional vector space, the low-dimensional representations were clustered. In theory, assuming not too much information was lost in these steps, these clusters should represent thematically similar student responses. Measures of the exact amount of information lost from the original embedding are difficult to calculate due to the nonlinearity in the second dimension reduction step, but the first dimension reduction step loses ~10% of the original variance in the data. This roughly corresponds to losing 10% of the information with that step.

V. RESULTS

Our results provide an understanding of the perceptions of students' learning while participating in our first-year PBL engineering design approach. Our data processing through HITL NLP resulted in several emergent themes: (i) understanding the design process, (ii) the importance of defining design constraints, (iii) having an awareness of the client's needs, and (iv) the importance of communication. We will discuss the themes in detail in this section.

In general, the overarching premise of most of the student's responses was that using a PBL approach that had a real client during their first-year engineering experience helped them better **understand the design process**. They expressed that the design process is an interactive, non-linear, and iterative process. Creating a final product that meets the design goals by the scheduled deadline requires an understanding of these interactions. For example, one student mentioned that there are "many factors you need to take into consideration during the engineering design process." Similarly, another participant mentioned that "there is so much more that goes into a project before you start building it." These important factors to deal with before creating a product were explored intentionally throughout the PBL learning experience. Students also recognized that understanding the design process meant understanding and accepting the frustrating aspects of the process. Two participants commented on this: "I learned that iterations and improvements are, at times, frustrating, but critically important to the success of a design," and "I learned that you have to take critique well, and leave frustration out it." Finally, in terms of their learning about the design process, students also commented on their awareness that design is a collaborative process rather than an individual effort.

Several students also commented on the importance of **understanding and establishing design constraints or criteria** as one of the main factors that limit engineering design. Multiple students emphasized its importance by mentioning why constraints are necessary parts of the design process and planning. One student stated that constraints are important "to keep…in mind when designing [a] product, as well [as] the criteria that our stakeholders have." One salient aspect of constraints and criteria is that students could make the connections on how they should be defined or at least highly informed by the real clients and stakeholders. Students commented on the importance of listening to their clients and having continuous interactions with them to understand better how they were fulfilling and understanding their design criteria and constraints. The students mentioned the criteria set by clients and stakeholders to be arguably the most important aspect in order to shape their design. In one case, it was said that "the client's opinion is the only opinion that matters." Being required to meet a client's constraints for a design project is an important lesson for young engineers because all real-world design projects will be for a client with certain needs.

Another emergent theme in the data was around the significance of the **interaction between client and human needs and the design process**. The students learned that it is important to design with the stakeholders in mind because they significantly impact the project. One student stated, "almost everything you do within your design process revolves around the stakeholder." This shows that the students understood that the client has different needs than that of the design group, and it is essential to find the best way to include their desires along with doing what the design team thinks is necessary. Furthermore, they understood that those needs could change and evolve, hence, the importance of continuous interactions. For example, a student mentioned, "You need to be able to engage with the client and ask appropriate questions in order to figure out exactly what you need to produce from the client." Another important aspect of these interactions was mentioned by several students who explained that they learned how to create a balance between their needs and the team needs, the course requirements, and the stakeholders' needs. They recognized that in engineering problems, there is not a "one solution fits all" and that instead, there are a series of trade-offs when balancing the different actors, expectations, and requirements. Client and human needs were the most mentioned emergent theme by the students, and they considered that this theme could be easily incorporated into all the other themes as a transactional component.

Finally, students learned the importance of **communication and planning** as part of the engineering design process. Students realized that interacting with real clients and stakeholders was not an easy task. Understanding clients' and stakeholders' expectations was challenging because they were often difficult to please, and in many cases, they did not know what they wanted. This demonstrates the importance of learning effective communication in engineering as it is one of the most important skills identified by students in the design process. Interacting with the client involves a conversation on expectations and being able to ask good questions, having continuous interactions, understanding feedback, and presenting ideas effectively. For example, one student said it best when they stated, "you need to be able to engage with the client and ask appropriate questions in order to figure out exactly what you need to produce." Another student stated, "a great deal of engineering design stems from clear and constant communication with the stakeholder." After discussion with the client about their needs, the students learned how to take feedback from a client and implement it into their design; they also understood that this was an ongoing process of continuous feedback and improvement. One of the students stated it as "a process that requires examination and reexamination, constant improvement and communication." It is evident that this demonstrates their understanding that the design process is constantly evolving. Their designs will end up going through iterations and improvements based on multiple client meetings. Students recognize that learning about engineering design is all about the process and less about the final product.

Students were also asked how they considered their experience to be different from that of their peers (doing a more traditional project approach, e.g., building a wind turbine for a hypothetical client with some given constraints). Students mentioned that they consider their experience a better and more round educational experience to really understand what design is. For example, a student commented:

> I can't even imagine getting the same sort of actual experience from doing any other project offered in [ENGE1216]. This project was much more motivating because I felt like I had a real obligation to the client. I was exposed to the real world instead of theoretical scenarios and I got to experiment with budget/time

constraints. With the other projects (Turbine/Drone), I doubt I would be anywhere close to the level I am at now when it comes to the engineering design process.

One aspect that impacted the students' perceptions of design and a real project was receiving feedback on their first prototype from a real client. They were all sure that their prototype was going to work and they had thought about all the possible weaknesses, to realize that they were not close to understanding the context of the Museum. A student mentioned: "It gave me a lot of information on human-centered design because there was live feedback from a client. It also taught me how not all ideas are going to be perceived the way I perceive them. Some are going to be rejected." This process really made the students take a step back, and most of the teams radically changed their initial approach/idea. However, that was not seen as something negative but rather provided the students with more commitment to the project. As two students explained:

> I think that this was the best design project for me. I really liked working with an actual client. It made it exciting and the project worthwhile. I feel that working with a real client drove my team to work harder and more efficiently. This class was very practical in relation to real-world engineering. I liked being introduced to this concept as a freshman because now I can use what I have learned for my future at Virginia Tech.

> I definitely felt more of the real pressure and motivation to do a good job, and the pitch we made was a lot more real, with us actively trying to 'sell' our idea to her… … [it was] different from the other classes, we did not simply design our project to work or for a grade, but we designed for a person for a purpose, which is what real engineers do.

VI. DISCUSSION

The findings overall indicate that integrating a real client in a first-year design project can support student learning outcomes and a deeper, more nuanced understanding of the design process in a real context. Students described how the interactions with their clients contributed to their understanding and appreciation of the iterative nature of the design process. Throughout the semester, students communicated and obtained feedback from their client resulting in design changes. They noted the importance of refining their constraints and criteria based on client feedback to ensure they meet their needs. Several students describe that the experience of working on a real project with a client provided more authenticity than theoretical projects and helped them better understand the importance of taking a "human-centered" approach. There is also evidence that working with a client provided a more meaningful, purposeful experience as there was a realistic opportunity for their end solution to be utilized by their client. This seemed to support students' motivation as they were designing a solution not just for a good grade but to actually fulfill a client's need.

The study thus provides some insight into some of the value-added of introducing a real-world project with a real client into general engineering courses. The findings here suggest these projects increased students' understanding of the importance of communication, particularly with stakeholders and clients, and the importance of design interactions as a means to get feedback from them. They also understood the importance of being open-minded to fulfill stakeholders' expectations. Similarly, they were engaged and motivated by having a real project and a real client. Using ill-defined projects without a step-by-step procedure and a prescribed solution is more representative of real-world problems students will encounter in the workplace. These projects force students to apply project management tools more authentically and navigate the design process to develop a solution. Evidence within PBL literature indicates that projects are more effective when anchored into real-world situations that learners find meaningful and important [25], [26]. In contrast, overly defined cookbook-recipe style projects in which students follow a prescriptive, linear procedure that is not well-connected to real-world applications can lead to a superficial learning [27].

While the results here suggest there is value in engaging a real-world client, there is additional preparation, and work instructors must arrange and scope these types of projects. Instructors need to continuously identify projects each semester and clients that are invested in the project and willing to take the time to connect and provide feedback to students. Instructors need to plan with the client and set reasonable expectations for the end products based on the course's expectations and the students' current capabilities. Depending on the project's scope, one semester may not be enough time to produce meaningful end products for clients. Still, it may be sufficient for at least crowdsourcing some new, potentially innovative conceptual designs and rough prototypes. Scaling these projects across many courses thus poses significant challenges. It perhaps would need to involve additional personnel (i.e., project managers) to help identify and scope these projects to appropriate classroom contexts.

VII. CONCLUSION AND FUTURE WORK

This work provides a better understanding of the experiences of first-year engineering students going through a PBL design experience with a real client and delivering an actual project. We used NPL to analyze open-ended responses to an anonymous exit survey. We want to recognize the importance of this methodological approach to processing a relatively big data set of open-ended responses. Our results demonstrate that students valued the experience and understood the importance of understanding the design process, establishing design constraints and criteria, working with an actual client, and communicating and planning. Based on our experience teaching this course, we consider one of the most important results was students' recognizing the uniqueness of having an actual client to communicate with; they always appreciate feedback and clear instructions. However, they seemed to be more engaged by having the input coming from an external stakeholder. Similarly, having several interactions with the client and understanding that the design process is iterative and the process is more important than the final product was an outcome that we really appreciated as this has been one of the intentions of this course.

We consider that future work of this research should focus on making a more intentional comparison of the different types of projects students can go through when learning introductory design in first-year engineering. We have data available that will be used to create these comparisons and contribute to our understanding of how the type of project influences students' perceptions and knowledge of design in first-year engineering programs.

ACKNOWLEDGMENT

We want to recognize the Children Museum of Blacksburg's involvement in this course as they were a crucial aspect in the success of this initiative by not only opening the door for the students but also by continuously interacting with them in the course.

This material is based upon work supported by the National Science Foundation under Grant No. EEC2107008. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1] C. E. Brawner, X. Chen, M. W. Ohland, and M. K. Orr, "The effect of matriculation practices and first-year engineering courses on engineering major selection," in *2013 IEEE Frontiers in Education Conference (FIE)*, Oct. 2013, pp. 1217–1223. doi: 10.1109/FIE.2013.6685023.

[2] H. Murzi, J. Jurkiewicz, K. Reid, and R. Rosenbaum, "First-year Engineering Program Evaluation: Understanding Senior Students' Perceptions About Their First-year Experience," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Oct. 04, 2020. [Online]. Available: https://peer.asee.org/first-year-engineering-program-evaluation-understanding-senior-students-perceptions-about-their-first-year-experience

[3] M. C. Paretti and K. J. Cross, "Assessing first-year programs: Outcomes, methods, and findings," 2011.

[4] M. J. Mohammadi-Aragh and R. L. Kajfez, "Comparing common and discipline-specific first-year engineering programs: Examining the need and explaining the study," in *2015 IEEE Frontiers in Education Conference (FIE)*, Oct. 2015, pp. 1–4. doi: 10.1109/FIE.2015.7344026.

[5] H. M. Matusovich, H. Murzi, D. Gray, B. D. Chambers, and M. B. James, "An Autoethnography: Outcomes from Faculty Engagement in Course Development in a Large First-year Engineering Program," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Oct. 04, 2020. [Online]. Available: https://peer.asee.org/an-autoethnography-outcomes-from-faculty-engagement-in-course-development-in-a-large-first-year-engineering-program

[6] M. B. James, H. Murzi, J. Forsyth, L. Virguez, and P. L. Dickrell, "Exploring Perceptions of Disciplines Using Arts-informed Methods," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Oct. 04, 2020. [Online]. Available: https://peer.asee.org/exploring-perceptions-of-disciplines-using-arts-informed-methods

[7] J. Jessop and T. Peeples, "Engineering Problem Solving Design Project: Emergency/Homeless Shelter Design," in *2005 Annual Conference*, 2005, pp. 10–555.

[8] J. Marshall, "A Laboratory/Design Based, Problem Solving Capstone Helps Engineering Technologists Hit The Job Market!," in *2010 Annual Conference & Exposition*, 2010, pp. 15–44.

[9] "Problem-Based Learning (PBL)." https://citl.illinois.edu/citl-101/teaching-learning/resources/teaching-strategies/problem-based-learning-(pbl) (accessed Apr. 06, 2022).

[10] C. C. Bonwell and J. A. Eison, *Active learning: Creating excitement in the classroom. 1991 ASHE-ERIC higher education reports.* ERIC, 1991.

[11] M. Prince, "Does active learning work? A review of the research," *Journal of engineering education*, vol. 93, no. 3, pp. 223–231, 2004.

[12] P. T. Terenzini, A. F. Cabrera, C. L. Colbeck, J. M. Parente, and S. A. Bjorklund, "Collaborative learning vs. lecture/discussion: Students' reported learning gains," *Journal of Engineering Education*, vol. 90, no. 1, pp. 123–130, 2001.

[13] M. J. Prince and R. M. Felder, "Inductive teaching and learning methods: Definitions, comparisons, and research bases," *Journal of engineering education*, vol. 95, no. 2, pp. 123–138, 2006.

[14] J. S. Lamancusa, J. L. Zayas, A. L. Soyster, L. Morell, and J. Jorgensen, "2006 Bernard M. Gordon Prize Lecture*: The Learning Factory: Industry-Partnered Active Learning," *Journal of engineering education*, vol. 97, no. 1, pp. 5–11, 2008.

[15] G. Ellmers and M. Foley, "Introducing reflective strategies informed by problem-based learning to enhance cognitive participation and knowledge transference in graphic design education," 2007.

[16] R. J. Roselli and S. P. Brophy, "Redesigning a biomechanics course using challenge-based instruction," *IEEE Engineering in Medicine and Biology Magazine*, vol. 22, no. 4, pp. 66–70, 2003.

[17] W. Akili, "How Engineering Design Learning May be Improved: Thoughts, Practices, and Recommendations," presented at the 2018 ASEE Annual Conference & Exposition, Jun. 2018. Accessed: Apr. 19, 2022. [Online]. Available: https://peer.asee.org/how-engineering-design-learning-may-be-improved-thoughts-practices-and-recommendations

[18] W. Akili, "On Engineering Design Learning: Thoughts, Challenges, and Realities," presented at the 2019 ASEE Annual Conference & Exposition, Jun. 2019. Accessed: Apr. 19, 2022. [Online]. Available: https://peer.asee.org/on-engineering-design-learning-thoughts-challenges-and-realities

[19] C. Atman, J. Borgford-Parnell, J. McDonnell, O. Eris, and M. Cardella, "Engineering Design Education: Research, Practice, and Examples that Link the Two," A. Johri and B. Olds, Eds. Cambridge, UK: Cambridge University Press, 2014, pp. 201–228. Accessed: Apr. 19, 2022. [Online]. Available: http://www.cambridge.org/gb/academic/subjects/engineering/engineering-general-interest/cambridge-handbook-engineering-education-research

[20] J. Dong and N. Warter-Perez, "Collaborative Project Based Learning To Enhance Freshman Design Experience In Digital Engineering," Jun. 2009, p. 14.337.1-14.337.11. Accessed: Apr. 19, 2022. [Online]. Available: https://peer.asee.org/collaborative-project-based-learning-to-enhance-freshman-design-experience-in-digital-engineering

[21] H. Henry, D. H. Jonassen, R. A. Winholtz, and S. K. Khanna, "Introducing Problem Based Learning in a Materials Science Course in the Undergraduate Engineering Curriculum," Apr. 2012, pp. 395–403. doi: 10.1115/IMECE2010-39049.

[22] B. B. Terranova *et al.*, "Work in Progress: Curriculum Revision and Classroom Environment Restructuring to Support Blended Project-Based Learning in First-Year General Engineering Laboratory Courses," presented at the 2017 ASEE Annual Conference & Exposition, Jun. 2017. Accessed: Apr. 19, 2022. [Online]. Available: https://peer.asee.org/work-in-progress-curriculum-revision-and-classroom-environment-restructuring-to-support-blended-project-based-learning-in-first-year-general-engineering-laboratory-courses

[23] A. Yadav, D. Subedi, M. A. Lundeberg, and C. F. Bunting, "Problem-based learning: Influence on students' learning in an electrical engineering course," *Journal of Engineering Education*, vol. 100, no. 2, pp. 253–280, 2011.

[24] K. R. Bokka, S. Hora, T. Jain, and M. Wambugu, *Deep Learning for Natural Language Processing: Solve your natural language processing problems with smart deep neural networks*. Packt Publishing Ltd, 2019.

[25] P. C. Blumenfeld, E. Soloway, R. W. Marx, J. S. Krajcik, M. Guzdial, and A. Palincsar, "Motivating project-based learning: Sustaining the doing, supporting the learning," *Educational psychologist*, vol. 26, no. 3–4, pp. 369–398, 1991.

[26] D. Fortus, R. C. Dershimer, J. Krajcik, R. W. Marx, and R. Mamlok-Naaman, "Design-based science and student learning," *Journal of Research in Science Teaching*, vol. 41, no. 10, pp. 1081–1110, 2004, doi: 10.1002/tea.20040.

[27] N. Shin, J. Bowers, J. Krajcik, and D. Damelin, "Promoting computational thinking through project-based learning," *Disciplinary and Interdisciplinary Science Education Research*, vol. 3, no. 1, pp. 1–15, 2021.