# Personal Epistemology: The Impact of Project-based Learning

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# Personal Epistemology: The Impact of Project-based Learning

**Abstract:** Project-based learning (PBL) has been widely adopted in engineering education because of its proved effectiveness in improving students' problem-solving ability, collaboration skills, and academic achievement. Moreover, it has been reported that students' participation in PBL activities could be beneficial for their epistemological development. Nevertheless, it remains unclear what aspects of epistemological thinking were impacted via PBL and the relationship between epistemology and learning. In this research, we set out to understand the impact of PBL on engineering students' epistemological thinking in the context of Perry's theory, which depicts students' epistemological development from dualistic thinking to a contextual constructive manner of thinking in four stages, that is, Dualism, Multiplicity, Relativism and Commitment (within Relativism). This study explored the demonstrations of students' contextual constructivist thinking in PBL in a qualitative manner and analyzed the associated factors. This would help us better understand the epistemological development of engineering students in PBL activities and give suggestions to facilitate the implementation of PBL activities.

**Keywords:** Project-based Learning; Epistemological Development; Impact Factors

## Introduction

The major responsibility of practicing engineers lies in solving uncertain, complicated, open-ended workplace problems. Because of this demand, project-based learning (PBL) has been proposed to be widely adopted in engineering education because prior research have suggested its effectiveness in improving students' problem-solving skills, collaboration skills, and academic achievement [1]. By converting lecture-based courses into a project-based learning environment, students learn to collaboratively solve multidisciplinary, complex problems.

Moreover, it has been reported that students' participation in PBL activities could be beneficial for their epistemological development [2]. Personal epistemology refers to students' reflections on "the limits of knowledge", "the certainty of knowledge", and the "criteria for knowing" [3]. Expert engineers demonstrated higher level of epistemological development than novices [4]. Prior research suggested that engaging in PBL is associated with engineering students' epistemological development toward advanced level of thinking [5]. Hmelo et al (1997) also suggested that through the teachers' meaningful guidance in the process of students' problem-solving, students can better develop higher order thinking skills. Nevertheless, it remains unclear how students' personal epistemology was impacted via PBL [6].

In this research, we set out to understand the impact of PBL on engineering students' personal epistemology in the context of Perry's theory, which depicts students' epistemological development from dualistic thinking to a contextual, constructive manner of thinking in four stages, that is, Dualism, Multiplicity, Relativism and Commitment (within Relativism) [7].

## Literature Review

Research on the development of epistemological theories has been going on over forty years since the first publication of Perry's work [7]. The ongoing refinement of Perry's model summarized the young adults' epistemological development in four stages, Dualism, Multiplicity, Relativism, and Commitment (within Relativism) [8]. A person in the stage of Dualism is characterized by holding a dualistic, right-or-wrong view of the world. A person in the stage of Multiplicity is aware of diversity of ideas and opinions and the uncertainty of knowledge. When an individual reaches the stage of Relativism, he/she moves from a dualistic view of the world to a view of contextual constructivism, in which he or she perceives knowledge as relative, contingent, and develops his or her own opinions via critical reasoning. The stage of Commitment within Relativism refers to a commitment to a relativistic view. In this stage, individuals claim a contextual and relativistic view in different areas of life in addition to one's study or one's pursuit of knowledge. By taking a contextual constructivist view, individuals carefully go through factors and examine related information in decision-making processes. Individuals confirm their commitments to carefully thought-through values, careers, relationships, and personal identity while recognizing the limitation of reasoning, and thus assuming major responsibilities in different areas of life.

Since the first proposal of Perry's model, subsequent theoretical frameworks and models were developed as related to young adults' epistemological development. These models or frameworks manifested further expansions and exploration of students' epistemological development, such as Belenky et al. 's work in the Women's Way of Knowing [9] [10], King and Kitchener's Reflective Judgement Model[11] and Kuhn's Argumentative Thinking[12]. In spite of the unique features of each theoretical model and framework, they all demonstrated a similar developmental trend which was first delineated in Perry's theory [13] [14], that is, from a dualistic, right-or wrong vintage point to a contextual, relativistic understanding.

In engineering education, quite a number of researchers have tried to explore students' epistemological thinking in their development towards competent engineers [4] [15]-[19]. Marra, Palmer and Litzinger (2000) assessed students' intellectual growth through a longitudinal study of students' intellectual development based upon Perry's model [16]. Their analysis showed that students' design experiences had positive relationship with students' intellectual development. Likewise, with the application of Perry's theory, Pavelich and Moore (1996) argued that engineering curriculum with extensive experiential components positively influenced students' intellectual growth [20]. Compared with traditional learning approach, PBL, as an innovative learning approach in engineering education, can better help engineering students develop problem-solving skills, improving students' abilities of combining theory and practice and communication skills [21]. With the increased use of PBL in engineering education, however, the impact of PBL on students' epistemological thinking is yet to be scrutinized.

## Methods

This report is part of a larger project in which an explanatory mixed-methods design was adopted. Quantitative data and results were first collected to depict a general picture of students' epistemic thinking, and then a qualitative study was conducted to refine the results by providing in-depth interviews. A link to an online survey was distributed to approximately 2,600 engineering students in fall semester of 2014 at the School of Mechanical Engineering, University H, which is a leading research university in China. Two hundreds and five complete responses were collected, which represents a response rate of about 7.9%. Considering the length of the survey, which has a total of 50 items, a response rate lower than 20% is common according the current literature [23]. This report focuses on exploring students' epistemological thinking in PBL activities in a qualitative manner.

For the qualitative portion, which this report focuses on, twenty-two students agreed to be interviewed in one-on-one manner. Among the 22 students interviewed, twenty-one were identified as being in the Relativism or Commitment stage based on their survey responses. The one student whose predominant thinking stage was Multiplicity was not included in this report because our focus on contextual constructivist thinking. All twenty-one interviews were transcribed, and ATLAS.ti 7 was used to analyze transcripts. Open coding procedure was used. Themes and patterns were summarized through the analyses. We focused on these students' demonstrations of contextual constructivist thinking in their PBL experiences to understand the impact of PBL on their thinking.

## Results

### *Prior Research*

First, the overall profile of engineering students' prominent epistemological developmental stages is mapped using the survey results. Students' demonstrations of thinking in each stage of Perry's model can be measured using separated scales [5] [24]. Students' epistemological development level was determined by identifying the most prominent thinking stage across the four dimensions in Perry's theory [5] [24]. Among 205 students, one hundred and eighty-eight students' overall levels of epistemological development were identified by using their prominent epistemological stage (Figure 1). Because of the complexity of personal epistemology, the ones with two stages at the same time means a student's prominent thinking shows the characteristics of both stages.

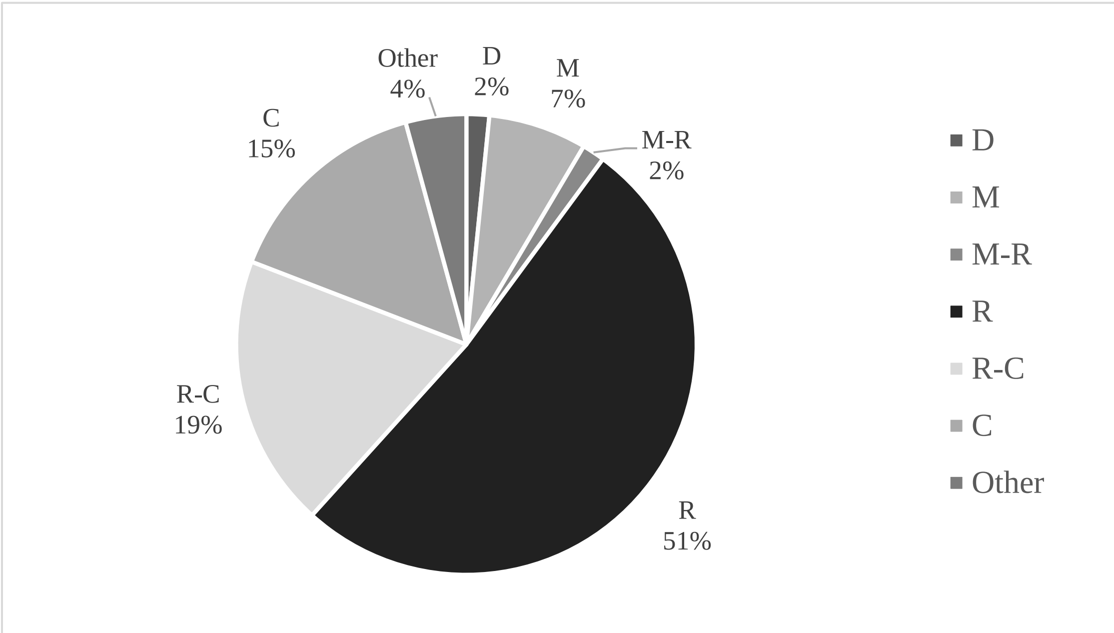

Figure 1. Distribution of the number of students among different groups (n=188)

Note: “other” includes D-M, D-R, M-C, with less than two persons in each group. Abbreviations: D-Dualism, M-Multiplicity, R-Relativism, C-Commitment (within Relativism).

Built upon our prior findings, we interviewed and analyzed twenty-one students whose predominant thinking style fell into the higher levels of Perry’s theory (Relativism and Commitment). As a work-in-progress, we finished analyzing sixteen transcripts. Specifically, we explored the relationships between engineering students’ personal epistemology and their engagement in PBL activities in a qualitative manner.

Table 1 Demographic information of interviewees

| | Name | Most Prominent Epistemological Thinking Stage(s) | Gender | Education background |
|---|---|---|---|---|
| **1** | Linda | Relativism | Female | graduate |
| **2** | Gary | Relativism | Male | graduate |
| **3** | William | Relativism | Male | graduate |
| **4** | John | Relativism | Male | graduate |
| **5** | Jack | Relativism | Male | graduate |
| **6** | Kevin | Relativism | Male | undergraduate |
| **7** | Tom | Relativism | Male | undergraduate |
| **8** | Peter | Relativism | Male | undergraduate |
| **9** | Bill | Relativism | Male | undergraduate |
| **10** | David | Relativism | Male | undergraduate |
| **11** | Nick | Relativism | Male | undergraduate |
| **12** | Sam | Relativism | Male | undergraduate |
| **13** | Carl | Relativism | Male | undergraduate |
| **14** | Paul | Relativism | Male | undergraduate |
| **15** | Richard | Relativism -Commitment | Male | graduate |
| **16** | Scott | Commitment | Male | undergraduate |

### *Demonstrations of Students' Contextual Constructivist Thinking in PBL Activities*

Based on Perry's theory**,** we first explored the demonstrations of students' contextual constructivist thinking in PBL in a qualitative manner. Students' advanced epistemological thinking was demonstrated in different aspects during the PBL activities. Specifically, they were able to solve problems within constraints, including the cost, the needs of consumers, the profitability of the product and so on, which represents the core of engineering thinking. Also, students actively conducted feasibility analyses, trying multiple solutions in the problem-solving process. Throughout the PBL actives, students intentionally reflected about the process to summarize lessons learnt from the project. Many students expressed that they realized the limits of their own thinking and experienced broadened thinking through collaborations with teammates, communication with instructors/professors, and their active learning by collecting and reading relevant literature or materials. By engaging in the PBL activities, they realized the distinctions between theory and practice. Therefore, they demonstrated an awareness to connect theory to practice. For example, they would set extra time aside just in case for unexpected problems in feasibility tests, taking into account the gap between theory and practice. What's more, the experience of project-based learning can help students know more about the process of research.

Based on these experiences, some students started to make plans for their future. Students reflect on the meaning of their major and the emphasis of their research orientation. Some students wonder about whether they are going to receive further education or not. The thoughts about future plans reflected that students started to undertake major responsibilities in life, which represents characteristics of the Commitment stage as in Perry's theory.

**Solving Problems within Constraints**

When trying to solve the problems, some of the students demonstrated an awareness of solving problems within constraints, such as cost, time and other factors. Within the given constraints, students tried to make good use of the resources to the greatest extent and actively took into consideration the practical requirements. Such manner of thinking reflects the characteristics of a contextual constructivist way of thinking in the Perry model, which also matches very well with the core of engineering thinking. For example,

*"**We needed to use limited resource within limited time to solve the problem**. Resources were around us, the things we could buy or find in the shortest time. We just had four days to solve the problem and we need to plan how we could utilize within the limited time. Basically, we had to think about what we were going to do on the first day, if it was successfully implemented, then what's next; if not, then what we would do. There were many things we had to think about, like what resources could be utilized, how we could exploit resources around us, how long it would take to buy the needed and to use the resources to solve the problem…We need to figure out to what extent we could solve the problem…like, there were five requirement (for the project), after a quick analysis, we realized that we can only accomplished three of them."—Richard*

As can be seen from the quote, this student along with his team members actively took consideration of multiple constraints into the problem-solving process. With limited time, they were able to plan ahead about each step and also prepare themselves for unexpected failures. In addition to constraints such as time and the availability of resources, students also took into considerations of the financial aspects of projects. For instance,

*"During the problem-solving implementation process, you can't go against the basic principles of professional knowledge, moreover, you need to **analyze the feasibility of the solution**. Sometimes the idea to solve the problem is feasible but the cost is too high or it is not economic and without a prospect. As an engineering student, when solving engineering problems, in addition to the professional knowledge, **you also need to take into consideration other aspects like the cost of the solution, profitability of the product, the needs of consumers.** I believe after the whole process, I have learned a lot."—John*

**Commercial Awareness**

As can be seen from John's case, in addition to considerations of the technological aspects of problem-solving, students showed the awareness to estimate the cost of the solutions, to understand the needs of consumers, and even the profitability of engineering products. Such awareness of the commercial aspects of engineering projects were further demonstrated in other students' PBL learning activities, *"**You needed to put forward something new, something that hasn't been produced before, new product, very innovative**. If there was any company that thought of the plan as recommendable, then it could be put into production. It's an Innovation and Entrepreneurship Contest, so for it be put into production, we needed to write the business plan in the start-up part, the final proposal was a commercial proposal."—Linda*

*"When we finished the product…we had to change our thinking into, just as our teacher said, **project management thinking**, how we can better sell our product, presenting it to the audience, how we can introduce the product to those experts to catch their interests and how to present its functions in a better way. Different ways of presenting can have very different effects."—David*

**Feasibility Analysis**

Throughout the PBL activities, a repeated theme can be observed across most students was that they often conducted feasibility analyses in the process. Along the multiple steps in the process, they performed rounds and rounds of feasibility tests, taking into considerations of the feasibility of methods, schedules and procedures. For instances, Paul mentioned the experiences of their group as related to market analysis in a course project.

*"**We would take many different things into consideration**, like the advantages, disadvantages of the questionnaire. Questions like the feasibility of the questionnaire, the effectiveness of the questionnaire, whether the questionnaire could reflect most people's thinking, and, whether people would be willing to fill in the questionnaire was also considered. These considerations had helped me a lot in the following work, at least they helped me realize that there was a rational process in doing the project. "—Paul*

In solving problems, in particular, during students' conducting feasibility analyses, one major characteristics was to figure out multiple approaches, weighing the pros and cons of each approach, in order to find an optimal way to the problem, which again represents the thinking patterns of Relativism

*"When I had that thought, I analyzed my ideas with the knowledge I learned from the class about mechanical parts, and tried to figure out what kind of construction could satisfy the function. **I had listed many different approaches, and finally got a relatively more feasible approach.**"—Peter*

**Broadened Thinking**

In the process of PBL, the students were able to realize the limit of their own thinking by actively collecting and reading relevant materials (e.g. literature), by the guidance of an instructor or through communications with team members or others. By breaking one's own thinking patterns, students often reported broadened or deepened thinking:

*"We had a lot discussions. One's perspectives are not comprehensive. During our discussion process, **we can combine other people's thinking, and have a deeper understanding about the problem, many times, even your wrong ideas can be corrected, and that is a very cheerful situation**."—Richard*

*"In terms of the participation of the project…sometimes,* ***there were ideas from others, that you think, you never would have thought of****."—Bill*

In addition to communications with classmates and team members, many students mentioned the guidance of the instructors/professors in helping them realize the limit of their thinking. For example, Scott mentioned the experience of a course design project:

*"So, for course design, in the question-and-answer part of the course project,* ***our teachers gave us some suggestions and pointed out the weakness of our solution. During that process, I realized the limit in our thinking****…If I am an engineer in the future and going to design something like a car, or a part of a car, if we did not do well in one part, then it could lead to severe consequences. So, in the beginning stage of the course project, there were many things that we hadn't take into consideration, or, say it was superficial, we did take into account, say, some other factors, so the thinking wasn't very thorough."—Scott*

*"****People's thinking can be different and during discussion process, you would get some other angles and perspectives to view the problem and these things are something you wouldn't think about.*** *I enjoyed discussions. During the self-test, our teacher would give us some questions to think about, and these questions helped us to reflect, what were the aspects that you were not very clear about… in particular, some comprehensive kinds of questions. I think this kind of communication and discussion is very informative to you."—Bill*

**Self-directed Learning**

Students' advanced thinking patterns were also demonstrated in their abilities to conduct a lot of self-directed learning. They actively searched for information online or literature to solve the problems. These experiences, along with the constant trial-and-error process and feasibility analyses have in part helped the development of the independent learning skills. Students realized the importance to be a master of the learning process. To solve the problem, students need to learn relevant knowledge first, to learn to use new software or new machines, new operational methods, all of which can be a self-directed process.

*"In fact, I think the self-exploration process is a very straightforward process. For example, if what we need is a microcontroller, which is a small program, you need to make it so that it can achieve certain results…You need to learn relative knowledge first, after learning, you make it, so it's a process in which you search the knowledge yourself, you learn the knowledge yourself, and you apply the knowledge yourself."—David*

**Linking Theory with Practice**

In applying what they have learnt, most students also actively linked theory with practice. On the one hand, students were aware of the differences between theory and practice; on the other hand, they emphasized the importance of linking theory with practice. Because of such awareness, students consciously allowed extra time to be prepared for unexpected problems.

*"Although there are different projects, what I have learned from project participation is that in practice we need to do schedule planning. In the actual operation process,* ***there are definitely***

***differences between the scheme that we designed and the practical process.*** *We need to plan ahead for these expected conditions, setting aside enough time." —Kevin*

*"**I think the course design acts as a bridge between theory and practice. What teachers teach in the class are just theory and there may be not so many things that need to be considered.** So during the course project…you need to consider the errors and the like, these thing only happen during the processing or in the finishing stage of the product, there is no need for such things in theory, but we need to consider these factors in our course design… So this is a process of turning theory into practice." —Scott*

**Devoted Effort**

Students' demonstrations of advanced level of thinking were often accompanied by their high degree of engagement in the project.

*"After we became a team, all of us kept thinking about what we were going to do. We thought about this in class, during lunch time. When we were together, we would think together." —Linda*

**Planning for the Future**

During the participation of PBL, some students became familiar with the process of engineering problem solving and get acquainted with the reality of engineers' work. As they reported, such experiences allowed them to be more informative in planning for their own future.

*"Through the whole process, I understood what it would be like to do the research in graduate studies, and whether it could help me or not. According to employment situation of my senior schoolmates, they told me that doing the research wasn't helpful if I wanted to go to foreign companies or other private enterprises, since our projects were mainly connected with state-owned enterprises and research institutes. After knowing this information, I held different attitudes towards these projects. Before implementing this project, I actively wanted to participate. However, after experiencing this, I found that it was just like this. Then I just did what my supervisor asked me to do. **I had my own life plan and I wouldn't do these kinds of projects for my supervisor for ever.**" —John*

## *Factors*

As summarized in the last section, students' patterns of contextual, constructivist thinking can be observed in various aspects of the PBL activities. We further investigated the factors that were related to such advanced thinking patterns. It should be noted that, the formats of PBL activities in which students self-reported included their course design or course projects, capstone projects, undergraduate research projects, and some competitive activities (e.g. Innovative Practice Program for university students, a program that focuses on promoting innovative design and practice among undergraduate students). By analyses of transcripts, we identified multiple factors, such as guidance from their professors/instructors, collaborations with peers, communications with other stakeholders and their active collections, and digestion of relevant materials (e.g. literature). Also, the difficulty level of the projects can also play a role in improving their thinking.

**Guidance by Professors**

According to the interviewees, professors have played a very important role in the process of problem-solving. They often pointed out directions for students, broadened their thinking by bringing up alternative solutions or commenting on the limit in students' thinking, provided timely feedback to students' design, facilitated students' progress in the project by regular meetings, and offered support and encouragement. In the process of students' self-directed problem-solving, professors often acted as a "guide" or a "coach" by providing suggestions or ideas as needed.

*"Interviewer: What roles did your professor play in this research or patent specifically?*

*Linda***：*A guide****, to point directions, it is very important. Without this guidance, I don't really know what to do."*

*"**Our supervisor would point out the directions for me**, and he would not actively ask whether I had a question or whether I knew how to do it. Instead, I need to take initiatives to ask him whenever I had any questions. Most supervisors are experienced. Since he have met all the problems that I run into, he is able to help me solve the engineering problems. His role? To help you solve the difficult engineering problem."—Kevin*

**Communications with Peers**

In addition to the guidance from instructors or professors, most students mentioned the importance of communicating with their classmates or teammates. These discussions helped them be aware of their own set of thinking, and realize the distinctions of thinking styles across different people. Communications with teammates with different thoughts allowed students to be exposed to different perspectives to a question, or multiple solutions to a problem.

*"After reading the same paper, **different people may have different ideas**. He may think in this way and you may think in that way. Maybe these two people's thinking is both limited, and by discussion, we could be closer to what the author wanted to express. **It's a process of discussion, mutual help and mutual progress.**" —Linda*

**Communications with Multiple Stakeholders**

Moreover, some students also mentioned the importance to communicate with multiple stakeholders, such as staff from factories, audiences in product exhibitions, or the representatives from companies.

*"Then you had to print the circuit boards, you had to communicate with the factory. We would draw it and gave it to the factory. It's a process of communicating with the factory. About buying components, sometimes we went to electronics factories or buy online. We need to communicate with others about the parameters and performance of the component. **I had gained a lot through these communications outside of classes**."—Linda*

**Collecting and Digesting Relevant Information**

Besides the communications with professors, teammates and other stakeholders, almost all students talked about the importance of actively researching and digesting relevant information, including literature. Students need to figure out what they need to learn and how they can solve the problem in a self-directed manner. Therefore, to search relevant literature or materials became an essential task. Through this process, most students reported their improvement in searching related literature and gained a deeper understanding of prior knowledge learnt from their classes.

*"**For example, in order to know what you need know, you have to search information by yourself and organize the materials in a self-directed manner.** Sometimes you may need to present what you find via PowerPoint, and through this process, you may learn a lot through the process of collecting information. And the process of collecting information or materials is a study process itself."—Bill*

**Difficulty Level of the Projects**

In addition, some students reported that the difficulty level of the problem can also make a difference in their learning.

*"In the process of PRP (Participation in Research Program for undergraduate students) activity, we used software in ways that was more difficult than what we used in our course design. It had some complicated functions and would let you analyze different operating conditions. It's a systematic process and you need to do modeling analysis and analyze different types of problems. It was a very big project, not like the easy construction we usually designed. **I think these two projects (PRP and Innovative Practice Program for university students) are difficult. After finishing the difficult projects, I felt I gained more.**" —Kevin*

**Individual Factors**

Several students also mentioned individual factors, such as the degree of one's interest towards the project, which could directly influence their level of engagement within the project. With high interest, students would be more self-directed to participate in the project and gain more.

*"Some students around me paid little attention to the capstone project, and said that we just need to spend some time and finish it before deadline. However, I didn't think so. **I had interest in my project and I wanted to do it well.** During the process of completing the project, I tried my best and exerted much effort to finish it day and night. I got up at 7 o'clock, and was the first one to go to the lab. I would do the project the whole day, usually got back to dormitory at 10 pm."—Richard*

## Discussions

This paper explored students' epistemological thinking in the process of PBL activities. By analyzing the demonstrations of advanced epistemological thinking, we summarized the patterns of students' thinking during the PBL process. Also, we explored the factors that were related with students' advanced thinking in the PBL process.

Researchers have found that engineering students' epistemological development is closely linked to their engineering capabilities and those who demonstrate higher levels of epistemological development tend to display expert engineers' thinking patterns [4][19]. Using qualitative data, this paper presented the demonstrations of the contextual, constructivist way of thinking, the advanced level of thinking as described in Perry's theory, in the PBL activities. Students demonstrated characteristics such as analyzing problems from different aspects, analyzing and comparing the feasibilities of multiple solutions, linking theory with practice and so on. These thinking patterns are exactly what students need during practical engineering problem-solving. During the problem-solving process, engineering students also displayed commercial awareness. They took into consideration factors such as the needs of consumers, the cost of the product, the ways to effectively present the product and so on. This awareness also lies in the core of engineering thinking [25].

Prior research have pointed out the positive impact of PBL on students' epistemological thinking, nevertheless, the detailed factors remain to be investigated [21]. This paper reports multiple impact factors in the PBL process as related to students' advanced thinking. First, professors were found to play an important role in students' PBL activities. Pointing a general direction for students was conceived as a very important way for students' progress. Moreover, using timely feedback and structured reflective activities for students can also help them in the problem-solving process. The importance of collaborations with peers was stressed by nearly every student. They commented on the help from being exposed to different thinking styles of students from different majors. Such collaborations often helped them to realize the limit in their own thinking. Communications with other stakeholders were also informative in broadening their thinking. Finally, appropriately scaffolding the complexity level of a project can provide additional opportunities for students to challenge themselves.

## Conclusion

This study has explored the demonstration of students' contextual, constructivist thinking in the PBL activities and summarized the factors that were associated with such thinking by analyzing interviews with twenty-one students. Our preliminary data suggested through factors like guidance from their professors/instructors, collaborations with peers, communications with other stakeholders and their active reading and digesting of relevant materials (e.g. literature), students could realize the limits of their own thinking and experienced broadened thinking. Considering the limitation of having only one female in this study, we expect to include more gender diversity in our future effort. An understanding of these and other relevant factors and how they have affected students' epistemological development can help improve the organization and implementations of PBL activities.

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