The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #41296

# Student Epistemic Beliefs in Engineering Laboratories

**Dr. Michael Robinson, Saint Vincent College**

Michael Robinson received his Ph.D. in Mechanical Engineering from The Pennsylvania State University. He is currently an Assistant Professor of Engineering at Saint Vincent College in Latrobe, Pennsylvania. His academic experience includes positions as an Assistant Professor of Engineering at Messiah College, and as a Visiting Lecturer at Ashesi University in Ghana. His research interests include autonomous vehicle pedestrian avoidance algorithms and engineering epistemology.

**Mr. Brian E. Faulkner, Milwaukee School of Engineering**

Brian Faulkner's interests include teaching of modeling, engineering mathematics, textbook design, and engineering epistemology.

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## Abstract

Engineering laboratories require different kinds of thinking than typical engineering theory courses. Laboratories often require students to correctly recall theory and gain practical knowledge of how to perform experiments related to that theory. The results of such experiments are frequently inconclusive, which requires students to practice judgement in interpreting results. These factors make the engineering laboratory an epistemically rich environment; however, experience suggests that students may not be adequately aware of such factors. This paper investigates student epistemic beliefs by adapting and extending survey instruments like the Engineering Related Beliefs Questionnaire and the Need for Cognitive Closure Scale to the laboratory setting. A survey instrument was developed which included a combination of quantitative and qualitative methods to measure students' epistemic cognition and epistemic motivation. Results from an undergraduate laboratory will be presented to advance understanding of how students view knowledge in laboratory settings. Suggestions for future advances in laboratory pedagogy will be presented based on these findings.

## Introduction

Engineering education recognizes the importance of epistemology as is seen in the 2006 document produced by a group of leading educators titled *The Research Agenda for the New Discipline of Engineering Education* where "engineering epistemologies" is one of five research directions listed [1]. That document defines epistemology as "research on what constitutes engineering thinking and knowledge within social contexts now and into the future" [1, p. 259]. While there is no precise agreement in engineering education literature about what constitutes epistemology as Beddoes found by reviewing literature since the 2006 agenda [2], the concept of epistemology as a viewpoint toward the nature of engineering knowledge will act as a definition for the current work. One framework for coarsely evaluating student progress is the development of epistemic understanding framework, where learners mature through stages of realist, absolutist, multiplist, and evaluativist [3].

Epistemic beliefs are dynamic and context dependent and develop over the course of a student's studies [4]. For example, Gainsburg studied the development of the mathematical epistemology of engineering students over the course of their studies and categorize the students views as falling into dualism, integrating, and relativism but did not find evidence that students advanced through these stages. Faber and Benson related students' epistemic beliefs to their performance on an open-ended biomedical-engineering problem [5]. Students without epistemic goals (i.e., students with goals like finishing quickly and getting the question right) spent less time on the assignment and showed ineffective problem-solving strategies such as seizing on their first idea and freezing on that solution even when asked to review their work.

This paper investigates students' epistemic beliefs in a lab setting. Laboratory study is an important part of many engineering courses. Laboratory instruction has many purposes as summarized in Feisel and Rosa's seminal paper [6]. Laboratory instruction has undergone many changes in response to changes in social and technological factors. Though most programs require laboratory instruction and 95% of faculty strongly believe laboratories are an essential part of engineering education, there is no consensus among faculty on the actual purpose of laboratory [7] [8]. At present, most students have access to laboratory equipment only during scheduled lab times for 2-3 hours per week and laboratory experiments are one-off procedure "cook-book" modules rather than extended projects [8]. Increases in computing power have enabled new types of remote-control laboratory equipment accessed from home, small inexpensive kits that can be shipped to students, and advanced simulation software rather than hardware experimentation [8] [6].

Laboratories have been relatively less studied in the literature than other parts of the engineering curriculum and what results exist suggest a potentially negative impact of laboratories on student epistemology. For example, some laboratory experiences may cause regression in students' epistemic views, in particular their view that mathematics and the physical world are deeply connected [9]. Students' epistemological beliefs in a laboratory setting have been investigated in other disciplines outside of engineering. Epistemology is context dependent, even to the extent that *science* laboratories and *engineering* laboratories have different epistemic standpoints [10]. The objective of an experiment in a science lab class setting is generally to validate or discover, but in an engineering setting it may be to design or test [11]. Physics education has more robust literature on student epistemology in a lab setting. For example, Zwickl et al. present an instrument known as the Colorado Learning Attitudes about Science Survey for Experimental Physics (E-CLASS) [12]. Their data from a range of institutions shows a small decrease in agreement between student epistemic responses and expert-like responses over the course of an introductory Physics lab. These data indicate that students' epistemic beliefs become less expert-like over the course of a semester.

## Context and methodology

Data were collected from students in a one-credit course which includes experiments from several engineering courses including statics, dynamics, circuits, and thermodynamics. The course is typically taken by juniors, but seniors may also take the course if their schedules did not permit them to do so junior year. Data were collected in the spring of 2023 when eleven students were enrolled in the course. All eleven students (six juniors and five seniors) chose to participate in this study, so these data represent the range of opinions present in the course. This course is part of a Bachelor of Science in Engineering degree. Students declare concentrations within the general engineering degree, and for the students represented in these data, nine were mechanical concentration while two were materials concentration. As this is the final laboratory course in the curriculum, students are expected to demonstrate independence in applying content knowledge from previous courses and the ability to use experimental equipment. The latter is facilitated by the design of the curriculum where all needed lab equipment has been used by students at least once, and often multiple times in previous courses.

Since this paper investigates students' epistemology, it will be helpful to review the epistemic goals of the faculty in the course used for data collection. The integrated nature of this course is intended to develop an epistemology that engineering knowledge cannot be easily separated. Solving a problem almost always involves thinking across disciplines. In this way the course provides some correction to a view of engineering knowledge which is somewhat inevitable given that students progress through courses which seem to be largely isolated from one another. In addition to the connectedness of engineering knowledge, this course aims to deepen students' understanding of the relationship between engineering theory and practice. Students are expected to give detailed accounts of how theory predicts their results and why a particular theory may fail to predict their results. The data below confirms the experience of the course faculty that current these goals are only achieved to a small extent. This is not entirely surprising given that the goals above in a sense contradict experiences students have had elsewhere in their education. As noted above, the nature of discrete courses seems to suggest that engineering knowledge can be separated. Also, students' past lab experiences often give the impression that a well-executed lab should confirm a given theory, or only deviate in highly predictable ways. Faculty are considering ways to incorporate the goals of this laboratory into earlier courses to better prepare students for their junior-year laboratory.

To provide further context for this course, an example lab assignment is presented in the appendix. This assignment is typical of the assignment for this course in length and expectation. Students are expected to make decisions on how to best complete the assignment including what content to use from previous courses, what instruments to use, how to verify their measurements and how to justify the validity of their experiments. A main objective of this course is that students will practice problem solving and learn from failure. To facilitate that objective, six lab assignments are scaffolded such that students are given more help with the first three labs and expected to work independently on the last three labs.

| | | | Number of student responses at each Likert level | | | | |
|---|---|---|---|---|---|---|---|
| Item # | Items from Faber and Benson | Mean | 1 | 2 | 3 | 4 | 5 |
| 1 | When thinking about a problem, I consider as many different solutions as possible. | 3.9 | 1 | 0 | 2 | 3 | 4 |
| 2 | I don't like situations that are uncertain. | 3.6 | 0 | 2 | 2 | 4 | 2 |
| 3 | I dislike questions which could be answered in different ways | 2.0 | 5 | 1 | 2 | 0 | 1 |
| 4 | Engineering problems have only one right answer. | 1.8 | 6 | 2 | 2 | 1 | 0 |
| 5 | All engineering experts understand engineering problems in the same way. | 1.8 | 8 | 0 | 1 | 1 | 1 |
| 6 | If your personal experience conflicts with the "big ideas" in a book, the book is probably right. | 2.9 | 2 | 2 | 3 | 3 | 1 |
| 7 | First-hand knowledge is the best way of knowing something in engineering | 3.3 | 1 | 2 | 3 | 3 | 2 |
| 8 | New engineering knowledge is produced as a result of controlled experimentation. | 3.0 | 1 | 2 | 6 | 0 | 2 |
| 9 | Engineers can solve engineering problems by just following a step-by-step procedure. | 2.1 | 5 | 1 | 3 | 0 | 1 |

| Item # | Original items | Mean | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| 10 | I consider it a waste of time when there is an equipment problem in the lab | 2.2 | 3 | 3 | 3 | 1 | 0 |
| 11 | I do not know how to decide which is correct when an experiment disagrees with theory | 2.8 | 0 | 5 | 3 | 1 | 1 |
| 12 | I like using intuition to solve problems | 3.9 | 1 | 1 | 0 | 3 | 4 |

**Table 1:** Questions used with Likert scale responses along with the mean and number of student responses at each level of the Likert scale. Questions 1 though 9 come from Faber and Benson [5], but questions 1 and 7 received minor wording changes.

Students completed a questionnaire which included open-ended questions about epistemic goals, problem solving, and engineering judgement. Students were also given twelve items with Likert-scale responses as seen in Table 1. Nine of these items were based on the instrument presented in Faber and Benson [5]. The remaining questions were developed by the authors to gauge students' epistemic beliefs.

## Results and discussion

This instrument began with questions about students' epistemic goals including "what were your goals, if any, for these labs?" and "what, if anything, did you hope to gain by completing these labs?" Responses were coded by the authors to determine whether students listed epistemic goals, meaning some specific knowledge they hoped to gain, for their labs. If the response did not mention knowledge, learning, or understanding, it was coded as a zero. If the response mentioned knowledge, learning, or understanding but was not specific, it was coded as a one, and specific responses that mentioned knowledge, learning, or understanding were coded as a two. For example, the response "A goal for me in this lab was to be able to solve complex problems on my own by thinking creatively and forming solutions to struggles that I would face doing such labs." would be coded as a zero because it did not mention goals in terms of knowledge. The response "My goal for these labs were to learn as much as I can. I want to be able to apply the knowledge and skills learned to the work I may do after I graduate." would be coded as a one because it lacks any specific statement of what is hoped to be learned. On the other hand, the response "I wanted to pass, learn about how engineers conduct experiments and report on them." would be coded as a two since the student expects the lab to help them learn how engineers conduct experiments. Both authors independently rated the student responses and agreed in roughly half the cases. The differences resulted from different expectations about the specificity need for a score of 2. It was agreed that any specificity on what the student wanted to learn would be coded as a 2. The authors conferred on all discrepancies and agreed on a single set of results. As a point of comparison to the students' epistemic goals, the epistemic goals of the faculty are reviewed in the section on context and methodology.

The data on epistemic goals is shown in Table 2. About half of the responses did not list a specific epistemic goal. While the number of responses in these studies is small to make definitive conclusions, comparing this result to Faber and Benson where half of the students listed an epistemic aim indicates that this group was similarly disposed to epistemic aims.

|  | Number | Percent of total |
|---|---|---|
| Responses coded as 0 | 5 | 0.23 |
| Responses coded as 1 | 5 | 0.23 |
| Responses coded as 2 | 12 | 0.55 |

**Table 2**: Results for student epistemic goal questions coded as 0, 1, or 2.

The quantitative results with low scores are questions 4 and 5 which indicates that students do not agree that engineering problems have one right answer or one right interpretation. This seems to indicate that students have moved somewhat beyond the lowest level of epistemic belief where there is always one right answer; however, many students explanation of their response shows they are using a relativistic framework. For example, many students strongly disagreed that all engineering experts understand engineering problems in the same way. A common explanation for students with this response was “Everyone has their own way of understanding a problem, and that’s in everything, not just engineering.” Only three of the eleven students were neutral or in agreement with this statement. A common response for these students was “Engineering experts most likely have the same initial approach or ideas about engineering problems, but they have their own method of solving them.” This shows more nuance in this group of students’ understanding of engineering knowledge.

The questions with the most variance in results were 6 and 7 which deal with discrepancies between students’ experiences and the expert knowledge found in books and elsewhere. There appears to be some tension between students answers to these questions and their answers to questions 4 and 5 as just reviewed. Some students reported difficulty understanding these questions. For example, one student who strongly disagreed with question 6 (dealing with differences between personal experience and book knowledge) said “I don’t know if I fully understand this question. But I would say neither is more right than the other. I think in many cases, both can be right where your personal experiences say one thing, but the book says another. I think it really comes down to how the problem is define and the premises set by the situation. Many times a book can set up ideal situations that just don’t exist in the real world.” From the explanation, it seems that this student is not preferencing personal experience or expert knowledge but suggesting that the knowledge in the textbook may imperfectly reflect the experiment being performed.

The quantitative results with the highest scores are questions 1 and 12. Students agree that they consider as many different solutions as possible and that they like to use their intuition to solve problems. Most students strongly agreed that they consider as many different solutions as possible to problems with a common response being “There are always multiple ways to get to an answer in engineering, you just have to be creative enough to find that route.” A student who agreed with this question showed more reflection in the response “I feel like I am getting better at trying to diversify my thoughts when I problem solve however there are still times where I convince myself that there is only one type of solution to a problem.” The only student who strongly disagreed to this prompt explained their response as “Being honest, I definitely don’t spend enough time in the “every idea” phase. I do think that I consider few ideas in my head, but they often aren’t very thought out and generally go with the one I think will work out the best.” This student recognizes that they have been taught to consider diverse ideas, but also recognizes that they do not generally apply this approach showing a deeper level of reflection than many of the students who agreed with this question but provided a generic response.

The responses to item 10 which states “I consider it a waste of time when there is an equipment problem in the lab” contrast interestingly with previous work on troubleshooting [13]. Surveyed instructors of electronics consider troubleshooting a malfunctioning circuit one of the most important learning outcomes in a circuits class. Students have a mixed response, expressing both appreciation for learning about the real-world complexities and frustration at the loss of class time that does not contribute to their grade. A nuanced response was “Sometimes I believe this can be a waste of time since it can delay someone from getting their work done. However sometimes fixing the equipment can lead to a good learning experience.” The students’ epistemological stance on problems is situated by the classroom context: the goals of achieving higher grades by finishing work and the goal of learning are in conflict when evaluating whether equipment problems are a waste of time.

## Conclusions

This paper has presented results from a survey instrument design to measure students’ epistemic beliefs in a lab setting. While students’ quantitative answers to Likert-scale questions point toward development along levels of epistemic maturity, many of their responses indicate a lack of adequate reflection. This may indicate that students have a sense of the “right answer” to the Likert-scale questions, but have a limited understanding of why that answer is appropriate.

The results presented above confirm findings from other aspects of engineering education. As observed in [5], roughly half of the students set an epistemic goal in the data above. Students’ explanations to the Likert-scale questions rarely mention things they experienced in the lab course where this instrument was administered. This may be explained by the fact that these questions were adapted from an instrument designed for a general engineering context, but it seems likely that this result is similar to what is observed elsewhere (for example in [12]) in the literature; namely, that student epistemic beliefs do not change significantly as a result of laboratory instruction.

Future research should focus particularly on student perceptions of what (if anything) has changed in a student’s way of thinking about engineering knowledge throughout a lab course. Identifying the factors that lead to different ways of thinking would be highly valuable in developing future laboratory assignments.

It may also be helpful to develop laboratory assignments specifically targeted at developing students’ epistemology in particular areas. For example, in the results above students tended to strongly disagree with prompts like “engineering problems have only one right answer” but provided generic explanations of their results that did not show a nuanced understanding about how engineers reach an understanding of a situation. In the lab assignments these students completed during the semester evaluated above all the groups attained similar results, indicating at least a range of expected values to the engineering problems. Perhaps in answering this question students did not consider problems like those completed in the lab genuine engineering problems which they anticipate do not have one right answer. This should be explored in future research. It is anticipated that providing formal opportunities for students to compare their results to others may help them better understand regularities in engineering problems. It seems that if other epistemic development opportunities are identified by instruments like the one above, similar interventions could be created to address those opportunities.

## References

[1] R. Adams *et al.*, “The research agenda for the new discipline of engineering education,” *Journal of Engineering Education*, vol. 95, no. 4, pp. 259–261, 2006.

[2] K. D. Beddoes and C. T. Schimpf, “Undisciplined epistemology: Conceptual heterogeneity in a field in the making,” in *2015 ASEE Annual Conference & Exposition*, 2015, pp. 26–1630.

[3] D. Kuhn, R. Cheney, and M. Weinstock, “The development of epistemological understanding,” *Cogn Dev*, vol. 15, pp. 309–328, Jan. 2000.

[4] J. Gainsburg, “Developing skeptical reverence for mathematics,” in *ASEE Annual Conference and Exposition*, 2012.

[5] C. Faber and L. C. Benson, “Engineering students’ epistemic cognition in the context of problem solving,” *Journal of Engineering Education*, vol. 106, no. 4, pp. 677–709, 2017.

[6] L. D. Feisel and A. J. Rosa, “The Role of the Laboratory in Undergraduate Engineering Education,” *Journal of Engineering Education*, vol. 94, no. 1, pp. 121–130, 2005.

[7] M. K. Seery, “Establishing the laboratory as the place to learn how to do chemistry,” *J Chem Educ*, vol. 97, no. 6, pp. 1511–1514, 2020.

[8] T. Kotulski and S. Murray, “The National Engineering Laboratory Survey,” 2010.

[9] T. D. Taganahan, “Changing Students’ Epistemological Beliefs and Understanding of Basic Concepts on Electric Circuits,” *Journal of Multidisciplinary Studies*, vol. 3, no. 2, Jan. 2014, doi: 10.7828/jmds.v4i1.631.

[10] S. Zwart, “Engineering Epistemology: Between Theory and Practice,” *Engineering Studies*, vol. 14, no. 2. Routledge, pp. 79–86, 2022. doi: 10.1080/19378629.2022.2124025.

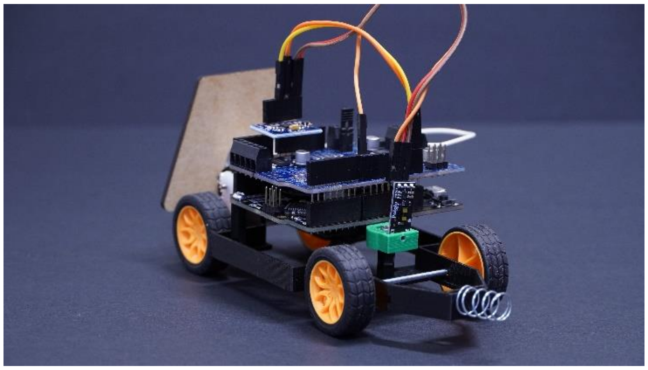
[11] R. Havdala and G. Ashkenazi, “Coordination of theory and evidence: Effect of epistemological theories on students’ laboratory practice,” *J Res Sci Teach*, vol. 44, no. 8, pp. 1134–1159, Jan. 2007, doi: 10.1002/tea.20215.

[12] B. M. Zwickl, T. Hirokawa, N. Finkelstein, and H. J. Lewandowski, “Epistemology and expectations survey about experimental physics: Development and initial results,” *Physical Review Special Topics - Physics Education Research*, vol. 10, no. 1, p. 010120, Jun. 2014, doi: 10.1103/PhysRevSTPER.10.010120.

[13] D. R. Dounas-Frazer and H. J. Lewandowski, “Electronics lab instructors’ approaches to troubleshooting instruction,” *Phys Rev Phys Educ Res*, vol. 13, no. 1, Jan. 2017, doi: 10.1103/PhysRevPhysEducRes.13.010102.

## Appendix: Example lab on vehicle modeling

Below is an example lab assignment used in the course where the data above were collected. It is provided to give context to the results above.



**Goal:** Measure the force and resulting acceleration of a small vehicle and compare to theoretical values.

### Background

The vehicle to the right is a control systems experiment named Terrae. It has a small motor driving the rear wheels. It also has an accelerometer and a distance sensor.

### Experiments

1. The motor on Terrae is the same type as was used in Lab 3. Use the torque values from Lab 3 to predict the force that this vehicle will produce at different input voltages. Perform an experiment to measure the force at different voltages.
2. Predict the maximum acceleration of this vehicle and perform an experiment to measure the acceleration.

| **Performance Indicators** | **Meets Expectations**<br>2 | **Developing**<br>1 |
|---|---|---|
| **Develops experimentation**<br>*Creates effective experimental plan* | Experimental plan includes ways to verify measurements | Creates a reasonable experimental plan |
| **Analyzes data**<br>*Performs necessary calculations* | Calculations are correct or contain only minor errors | Calculations contain significant errors |
| **Interprets data**<br>*Presents and explains information* | Data presentation and explanations are adequately complete and facilitate comprehension | Data presentation and explanations are incomplete or difficult to interpret or follow |
| **Uses engineering judgment to draw conclusions**<br>*Evaluates experimental validity* | Provides adequate assessment of experimental validity | Provides minimal assessment of experimental validity |