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Prioritizing Learning Outcomes for Chemical Engineering Laboratory Courses: Student Perspectives

Dr. Chris Barr, University of Michigan

Dr. Christopher Barr is the Instructional Laboratory Supervisor in the Chemical Engineering Department at University of Michigan. He obtained his Ph.D. at University of Toledo in 2013 and is a former Fellow in the N.S.F. GK-12 grant "Graduate Teaching Fellows in STEM High School Education: An Environmental Science Learning Community at the Land-Lake Ecosystem Interface". His main responsibilities are supervising and implementing improvements to the undergraduate labs. He also serves as secondary instructor for the CHE labs, the Departmental Safety Coordinator, and lead for the SAFEChE (Process Safety Across the CHE Curriculum) modules as well as the Visual Encyclopedia of Chemical Engineering Equipment. Currently, he serves as a Director for the ASEE ChE Division.

Dr. Sarah A Wilson, University of Kentucky

Sarah Wilson is an assistant professor in the Department of Chemical and Materials Engineering at the University of Kentucky. She completed her bachelor's degree at Rowan University in New Jersey before attending graduate school for her PhD at the University of Massachusetts.

Dr. Janie Brennan, Washington University in St. Louis

Janie Brennan is a Senior Lecturer of Energy, Environmental and Chemical Engineering at Washington University in St. Louis. She earned her BS in Agricultural and Biological Engineering from Purdue University in 2010, and her Ph.D. in Chemical Engineering (also from Purdue) in 2015. She teaches several core engineering courses, including thermodynamics, separations, unit operations lab, and zymurgy, and her research has focused on understanding best practices for teaching and learning in these courses.

Dr. Joanne Beckwith Maddock, Carnegie Mellon University

Joanne Beckwith Maddock is an assistant teaching professor in the Department of Chemical Engineering at Carnegie Mellon University. She earned her B.S. in chemical engineering from the University of Toledo in 2013, her M.S.E. from the University of Michigan in 2017, and her Ph.D. in chemical engineering from Michigan in 2021. Her research focus areas include laboratory courses, first year engineering, and engineering in rural communities.

Prof. Tracy L. Carter, Northeastern University

Tracy Carter is a faculty member in the Chemical Engineering Department at Northeastern University. She is also a faculty facilitator for the Industry/CCPS Faculty Workshops on process safety. She also has 9 years of R&D experience in industry. She has 15+ years of experience teaching unit operations laboratory and process safety to undergraduate and graduate students. She also has 5+ years mentoring graduate students on technical communications in the NU College of Engineering Communication Lab.

Prof. Samira Azarin Azarin,

Samira Azarin is an Assistant Professor of Chemical Engineering and Materials Science at the University of Minnesota. She earned her B.S. in chemical engineering from the Massachusetts Institute of Technology in 2006 and went on to receive a Ph.D. in chem

Amy J. Karlsson, University of Maryland

Amy J. Karlsson is an associate professor in the Department of Chemical and Biomolecular Engineering at the University of Maryland - College Park. She received her BS in chemical engineering from Iowa State University and her PhD in chemical engineering from the University of Wisconsin - Madison.

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Prioritizing learning outcomes for chemical engineering laboratory courses: Student perspectives

Abstract

Undergraduate laboratories are an integral component of most engineering programs, playing a pivotal role in integrating hands-on application of theory as well as building other skills for future engineers. Previous work by Feisel and Rosa [1] suggested thirteen learning outcomes that can be covered in engineering laboratory courses; however, two potential barriers make using these outcomes in chemical engineering laboratory courses challenging: (a) Feisel and Rosa's learning outcomes are not targeted specifically to chemical engineering or to the needs of stakeholders within the chemical engineering curriculum and (b) expecting laboratory instructors to assess thirteen different learning outcomes for student success is unrealistic.

Therefore, a survey was designed to gain an understanding of the outcomes most important to the various lab stakeholders (faculty, non-academic engineers, and students) and the current successes and gaps of chemical engineering laboratory curricula in addressing those outcomes. This paper describes responses received from chemical engineering students. Including the student voice is important in higher education curricular development and can have positive outcomes in terms of student perceptions of courses and their engagement in them [2]. Additionally, students are more intrinsically motivated by course attributes that are tied to their future careers [3]. Thus, incorporating the student perspective into chemical engineering laboratory course design is critical.

Thirty-one students responded to the survey. Survey responses included demographic and background information, which can be used to situate the survey responses in the context of the respondents' experiences. Additionally, respondents were asked to rank the five most important learning outcomes for laboratory-intensive chemical engineering courses, identify which outcomes respondents are weakest in, and which outcomes the chemical engineering curriculum should do a better job covering. Finally, open-ended questions were included to identify additional important learning outcomes and provide comments. The results provide insight into the prioritization of laboratory learning outcomes and allow the redesign of laboratory courses to better align with the skills and attributes desired from all three stakeholder groups.

Introduction

Over the last decade, many surveys and studies have considered the future of chemical engineering and its alignment with industry expectations [4], resulting in changes to ABET requirements [5] (specifically towards process safety education [6] and ethics and social responsibility [7]). A larger picture of chemical engineering modernization was the focus of a recent National Academies report entitled “New Directions for Chemical Engineering”, which explored research and undergraduate educational program updates [8].

Undergraduate chemical engineering laboratory instructors have begun to explore modernization, having been spurred by the aforementioned studies, as well as the need for flexibility within instruction and the continuing impact of illnesses and stress on student mental health [9, 10]. While the previous studies have been completed for the chemical engineering curriculum as a whole, very little focus has been placed on the purpose of the chemical engineering laboratory and what should be taught within it. The 2015 industry-academic alignment survey found that lab courses contribute to industry-desired outcomes such as safety, troubleshooting, teamwork, and critical thinking [4], while the National Academies' report underscored the importance of experiential learning but lacked specificity on crucial learning outcomes in chemical engineering labs [8]. The most recent examination of chemical engineering laboratories was a 2018 survey of 70 chemical engineering programs; in this survey, writing/communication and safety were identified as primary ABET outcomes assessed in labs [11]. However, this survey only examined what was currently taught and did not consider input from laboratory stakeholders other than faculty.

To more fully investigate the alignment of stakeholder needs and vision for chemical engineering laboratories, a survey was developed [12] and distributed to the three major stakeholders: chemical engineering faculty, chemical engineering alumni in fields outside of academia, and students within chemical engineering programs. This survey focused on Feisel and Rosa’s thirteen learning outcomes that can be covered in engineering laboratory courses [1]. Previous papers have explored the survey responses from faculty [13] and chemical engineering alumni in non-academic settings [14].

Many surveys, such as the 2015 survey from AICHE and the 2020 study from the National Academies, either utilize feedback from industry or include industry in the authorship, but they lack feedback from students even though many studies have found the importance of including the student voice within higher education curricular development [2, 15]. Including students in curricular development can lead to positive student perceptions of courses and high levels of student engagement in courses [2]. Additionally, students are more intrinsically motivated by course attributes that are tied to their future careers [3]. Thus, the authors of this paper found it imperative to include the student perspective in the survey, and this paper describes the responses received from chemical engineering students.

Methods

Survey Development and Distribution

The student-related components of the survey are provided in Appendix A. Initial development of the survey questions and content for each of the three stakeholder groups were previously described [12]. In the survey, respondents were asked about their demographics (gender identity, race/ethnicity) and then self-identified into a stakeholder group (undergraduate student in chemical engineering or related field, faculty member in chemical engineering or related field, non-academic/industry engineer, or other group). Respondents who selected "Other" for the stakeholder group were directed to the non-academic/industry branch of the survey.

Each stakeholder branch of the survey then asked additional demographic questions to allow the authors to situate the survey responses in the context of the respondents' experiences. The student branch asked for their institution name, expected graduation date, experience outside of the classroom (co-op, internship, research), and whether they had already taken a chemical engineering laboratory course.

Following the demographics questions, the survey provided a definition of learning outcomes in chemical engineering laboratory courses and asked the respondents to answer survey items related to **five** research questions:

1. What are the three most important learning outcomes for a laboratory-intensive chemical engineering course? [Open-ended Response]
2. How important are the following learning outcomes for a laboratory-intensive chemical engineering course? [Likert scale for level of importance and Top 5 of importance ranking]
3. What gaps exist in the thirteen learning outcomes identified by Feisel and Rosa? [Open-ended Response]
4. Which learning outcome(s) do you feel you have the most trouble with / are weakest in? [Select 3]
5. Which learning outcome(s) do you feel your overall chemical engineering curriculum should do a better job of covering? [Select 3]

The survey attempted to elicit an "unbiased" answer to the first question by asking respondents to list the three most important learning outcomes without providing any suggestions or commonly used outcomes as examples. The remaining research questions referred to the Feisel and Rosa outcomes (Table 1).

Respondents were asked to rate the overall importance of each of the thirteen outcomes on a Likert scale and to rank their top five outcomes from this list. Finally, respondents were asked via an open-ended text box to suggest any additional outcomes that were not already represented by the list from Feisel and Rosa.

Table 1. Thirteen important learning outcomes for engineering laboratories, as described by Feisel and Rosa [1], and the description provided in the survey.

#	Short name[a]	Learning outcome description as provided in the survey
1	Make measurement	Make measurements: Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.
2	Compare to theory	Compare theory to reality: Identify the strengths and limitations of theoretical models as predictors of real-world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.
3	Design experiment	Design an experiment and interpret the results: Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.
4	Analyze data	Analyze data: Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments and use measurement unit systems and conversions.
5	Design prototype	Design and/or prototype: Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.
6	Troubleshoot	Troubleshoot issues: Identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.
7	Problem solve	Independent real-world problem-solving: Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem-solving.
8	Select tools	Select appropriate tools and resources: Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.
9	Safety	Handle safety issues: Identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.
10	Communication	Oral and written communication: Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.
11	Teams	Work in teams: Work effectively in teams, including structure, individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.
12	Ethics	Behave ethically: Behave with highest ethical standards, including reporting information objectively and interacting with integrity.
13	Senses	Use human senses to gather information: Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.

[a] The "short name" indicates an abbreviated name of the outcome for use in the presentation of the data.

For the student survey, two additional reflective questions were included. These questions asked students to reflect on their weaknesses in the lab learning outcomes as well as any weaknesses they perceived in their departmental curriculum for these learning outcomes. These questions were included to get the views of students currently in the programs, as these views may differ from the views of faculty in the programs and alumni perceptions may be skewed by changes to curricula over time and time since graduation.

The survey design was approved by the Institutional Review Board (IRB) at University of Kentucky. The survey was encoded in Qualtrics survey software and was distributed by the author at the IRB institution through "snowball sampling," in which a survey advertisement and link are shared through appropriate listservs and social media, and others are asked to also share the link through their networks.

Data Analysis

Open-response answers were independently coded by two of the authors using the thirteen learning outcomes (Table 1). The applied codes were then compared, and disagreements were resolved. Learning outcomes that did not match the thirteen identified in Table 3 were labeled as "Other." Results were then quantified through counting of the codes across the qualitative responses collected.

For the Likert-scale responses, mean scores and standard deviations were calculated for the data set. For the ranking of the top five learning outcomes, all unranked learning outcomes were given a score of zero, and the rankings were reverse-scored (Rank 1 = 5, Rank 2 = 4, etc.). A mean score was then determined for each learning outcome, and the mean score was used to rank the outcomes with high scores indicating those outcomes that were most highly ranked.

Results

Participants

Thirty-one students completed the survey, with most completing the full survey. Data were included in the analysis if the respondent completed a response to that particular question. Exact response numbers are included with the relevant figures. The responding students were from eight different institutions and enrolled in chemical engineering or closely related fields. Of the responding students, 70% graduated in 2023 and 27% will graduate in 2024. To establish their positionality, the authors asked about two major educational experiences: (1) experiences outside of the core chemical engineering curriculum and (2) if they had taken a chemical engineering laboratory course yet. For experiences outside of the core curriculum, students could choose all that applied from internship (47%), co-op (17%), research (57%), or no experience (13%). Understanding if students' answers are predominantly expectations or could be based on their previous chemical engineering laboratory course experiences is important, and 67% of respondents reported previously taking a chemical engineering laboratory course.

Open response to most important learning outcomes

Thirty-one of the respondents provided answers to the open-ended question, “What are the most important learning outcomes for a laboratory-intensive chemical engineering course?” Responses were coded according to the thirteen learning outcomes listed in Table 1, and the number of mentions of each learning outcome was determined (Figure 1).

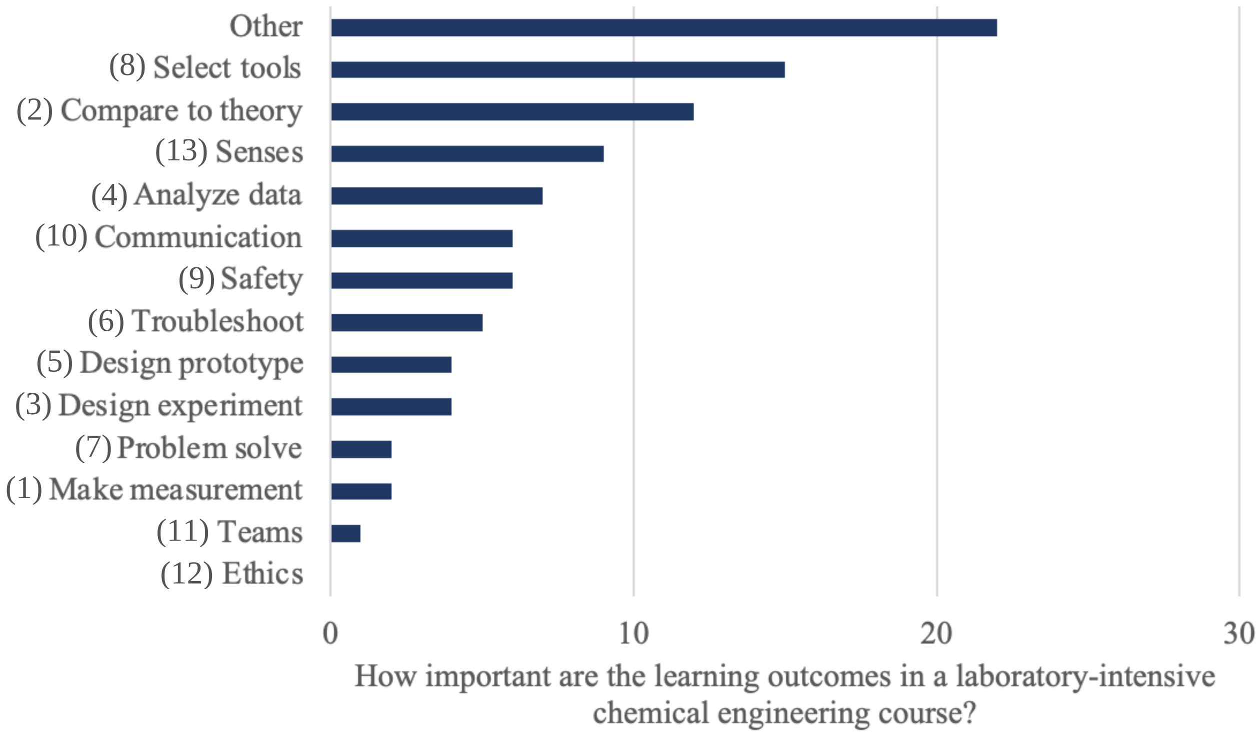

Figure 1. Number of times each of the thirteen outcomes was coded from responses to an open-ended question asking for the three most important outcomes in a laboratory-intensive chemical engineering course (n = 31). Numbers next to abbreviated name correlates to Table 1 and numbers in Feisel and Rosa.

In Figure 1, results are ordered from most responses (top) to least responses (bottom). The top two learning outcomes that aligned with Feisel and Rosa’s laboratory learning outcomes (each with over 10 mentions) were “Select tools” and “Compare to theory.” Six outcomes had fewer than five mentions: “Design experiment,” “Design prototype,” “Make measurement,” “Problem solve,” “Teams,” and “Ethics.” Unlike previously reported responses by faculty [12] and non-academics [13], many student responses did not directly code to the thirteen learning outcomes in Table 1; further learning outcomes that were identified were

- Real-world application: Outcome related to a "real" process or "real" equipment (n = 16)
- Scale-up: Outcome related to scaling up a process or equipment (n = 3)
- Time management: Outcome related to managing time (n = 2)
- Critical thinking: Outcome mentioned critical thinking (n = 1)

Evaluation of the importance of the thirteen different learning outcomes

Student respondents were asked to rate (on a Likert scale) the relative importance of each of the thirteen learning outcomes in a laboratory-intensive chemical engineering course (Figure 2). For student responses, all thirteen outcomes were given an average rating of "moderately important" (3) or higher. All thirteen outcomes were considered similarly important by student respondents.

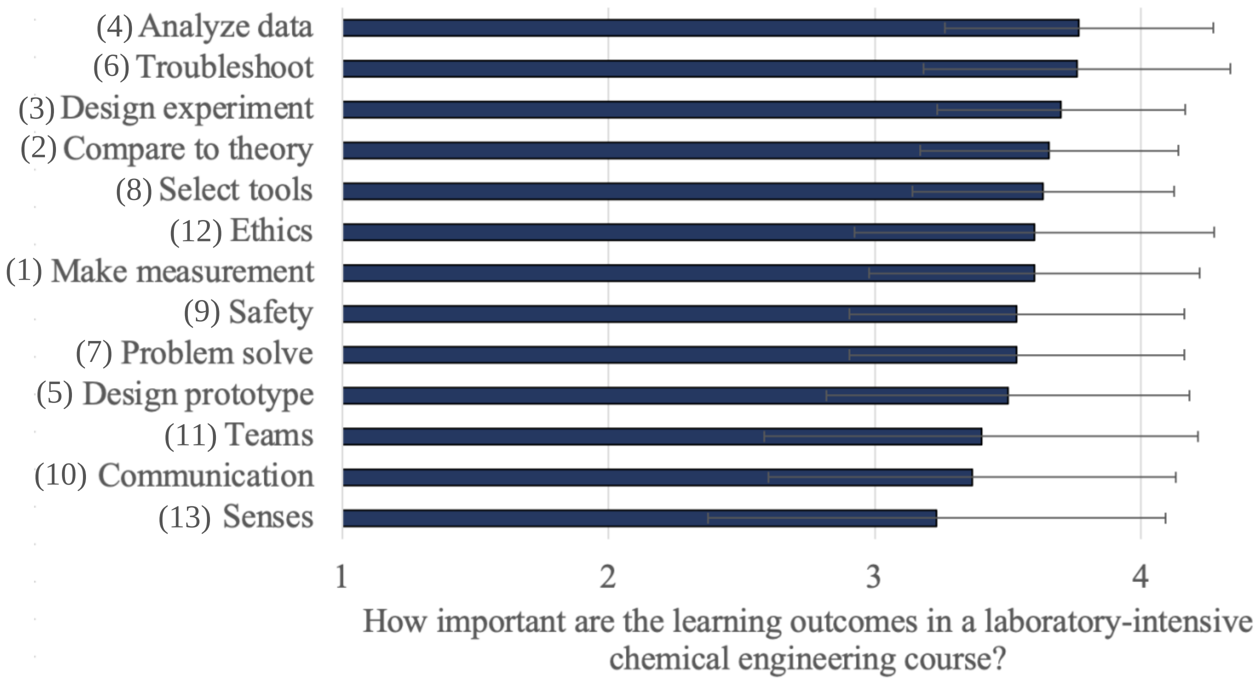

Figure 2. Mean value of a Likert-scale assessment of the relative importance of thirteen common learning outcomes in a laboratory-intensive chemical engineering course (1 = not at all important, 2 = slightly important, 3 = moderately important, 4 = very important) (*n* = 30). Outcomes are ordered from highest mean Likert-scale rating (top) to lowest mean Likert-scale rating (bottom). Error bars represent one standard deviation. Numbers next to abbreviated name correlates to Table 1 and numbers in Feisel and Rosa.

Ranking of the top five learning outcomes

Respondents were then asked to rank the top five most important learning outcomes from the list of thirteen in Table 1. The distribution of these rankings and the relative mean ranking of each outcome are shown in Figure 3.

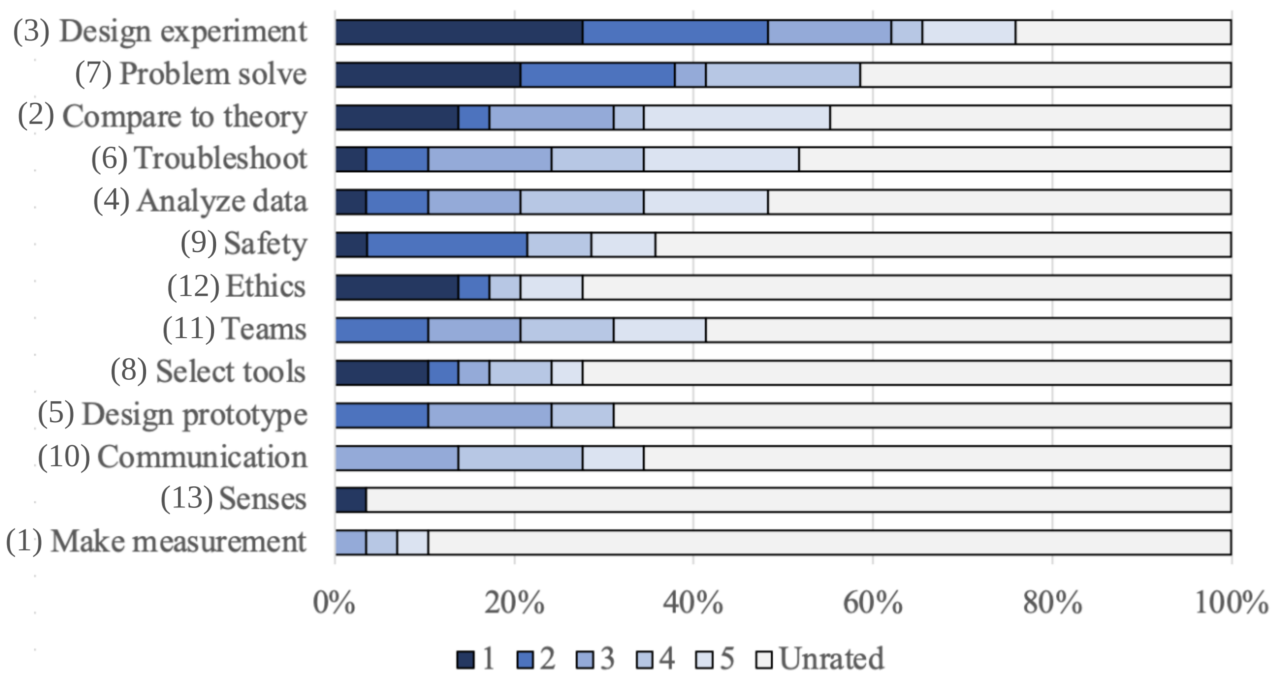

Figure 3. Distribution of rankings of the thirteen common learning outcomes when respondents were asked to select the top five most important outcomes for a chemical engineering laboratory-intensive course (n = 29). Outcomes are presented in order from highest to lowest mean ranking, and the distribution of the rankings for each outcome is indicated. Numbers next to abbreviated name correlates to Table 1 and numbers in Feisel and Rosa.

For this survey question, the top five learning outcomes based on mean ranking were "Design experiment," "Problem solve," "Compare to theory," "Troubleshoot," and "Analyze data." Of these five learning outcomes, only "Compare to theory" and "Analyze data" were listed in the top five of the open-ended responses (when excluding responses in the "Other" category). According to student responses, the four least important learning outcomes for laboratory courses were "Design prototype," "Communication," "Make measurements," and "Senses." Some outcomes (senses, ethics, and select tools) had bifurcated responses, with a high ranking from a small number of respondents and a low ranking or no ranking from a large number of respondents.

Missing learning outcomes

Similar to previous surveys for faculty and non-academic stakeholders, the survey asks respondents to list outcomes that they do not feel fall within the thirteen laboratory learning outcomes in Table 1. The authors identified three responses that were unique and stood out from the learning outcomes in Table 1. The first, "specific translations to industry roles," aligns well with the "Real-world application" outcome mentioned in the first open-ended response. The other two, "Realization that there is more than one way to accomplish the goal" and "Utilize creativity in a technical project," focus on critical-thinking skills, which were also – mentioned in the open-ended responses.

Self-reported gaps in student understanding and curriculum coverage

In the final set of questions, students were asked to self-report gaps in their understanding and what topics the chemical engineering curriculum overall should do a better job of covering. In both questions, students were asked to select their top three from the list of thirteen lab learning outcomes, and the percentage of respondents that chose each learning outcome was quantified.

In terms of self-reported weaknesses (Figure 4), over 40% of students selected "Design prototype" and "Compare to theory" as their greatest weaknesses. "Design experiment" and "Troubleshoot" were also commonly chosen. Of these four outcomes, only "Design prototype" was *not* highly ranked in terms of its importance (Figure 3). The outcomes about which students did not feel weak were "Make measurement," "Safety," "Ethics," and "Analyze data." "Safety," "Ethics," and "Analyze data" had moderate levels of importance to students (Figure 3), but "Make measurement" was the lowest ranked in terms of importance.

The outcomes that students felt should be better covered by their curriculum (Figure 5) largely mirrored their personal areas of weakness, with a couple of exceptions. Although only ~20% of students felt a weakness in the "Select tools" outcome, nearly 40% of students felt that their curriculum should cover it more. Conversely, "Compare to theory" was the highest-rated weakness by students, but fewer than 20% felt that their curriculum should cover it more.

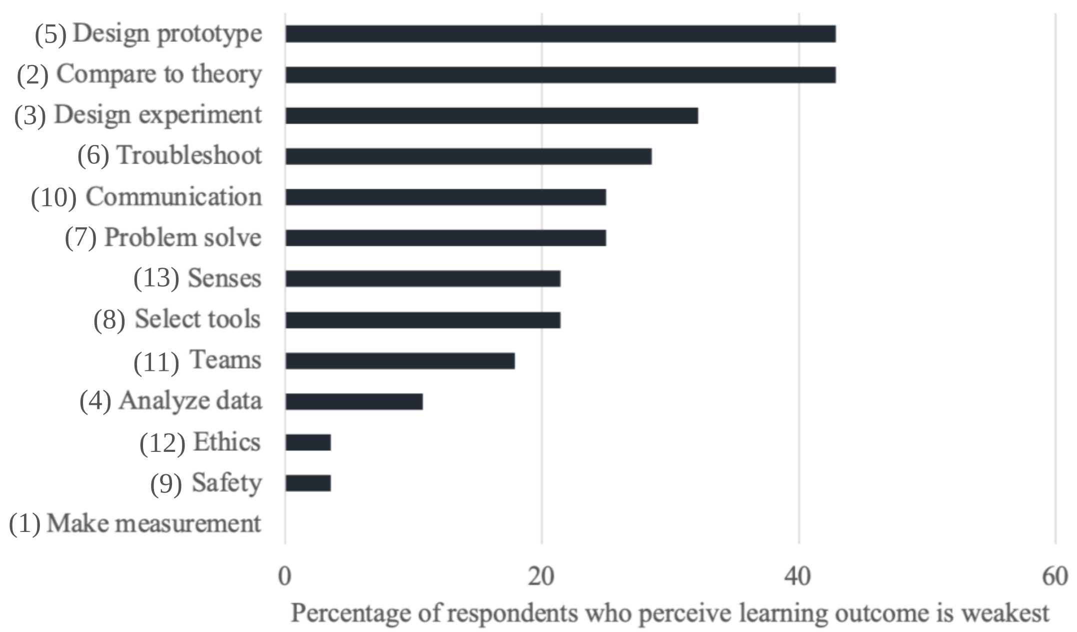

Figure 4. Responses to prompt "Which learning outcome(s) do you feel you have the most trouble with / are weakest in?" [Select 3] (n = 28). Numbers next to abbreviated name correlates to Table 1 and numbers in Feisel and Rosa.

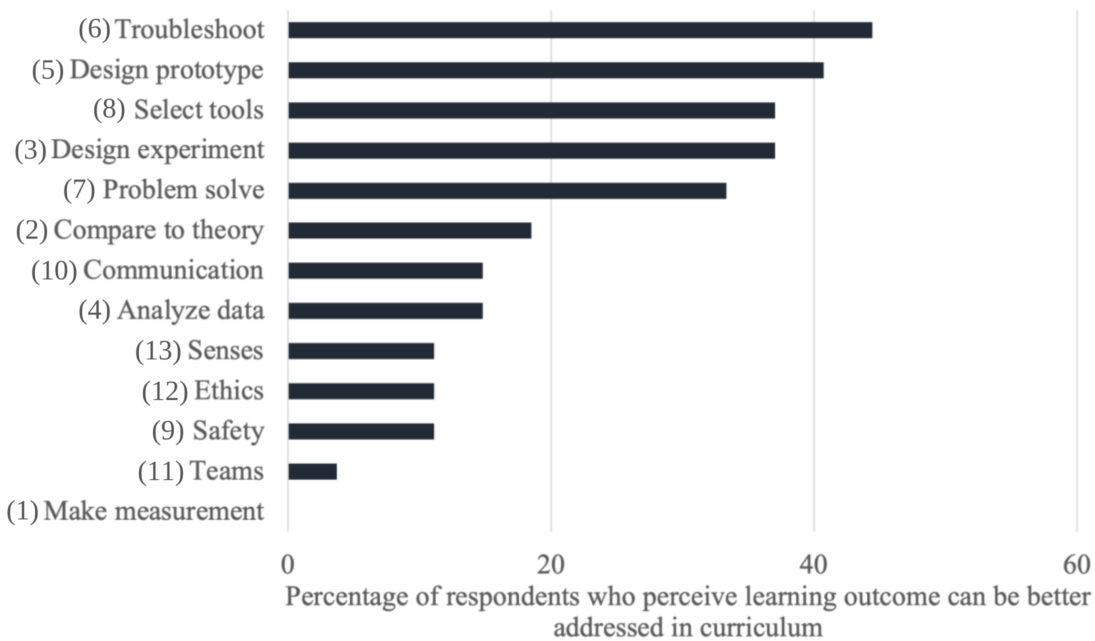

Figure 5. Responses to prompt "Which learning outcome(s) do you feel your overall chemical engineering curriculum should do a better job of covering?" [Select 3] (n = 27). Numbers next to abbreviated name correlates to Table 1 and numbers in Feisel and Rosa.

Discussion

Students' perceptions of the importance of learning outcomes had some similarities with the perceptions of faculty and non-academic stakeholders and some differences. Compared to previous surveys with faculty [13] and industrial/non-academic stakeholders [14], less consensus on the top four learning outcomes was apparent for the students. "Compare to theory" was the only learning outcome appearing in the top four of all three stakeholder groups. The perception of students that all learning outcomes are equally important continued is a perception that was shared with the faculty stakeholders. For students, all thirteen outcomes were ranked between moderately and very important and had statistically the same importance. This is even more pronounced than the findings for the faculty survey, which showed the top eleven out of thirteen outcomes as "moderately important (3)" or higher and the top 8 as statistically similar [13]. This is somewhat concerning, considering chemical engineering laboratory courses are already often tasked with assessing many outcomes because of the experimental nature of the curriculum. Adequately covering all thirteen learning objectives in a single lab course is clearly unrealistic. The notion that students perceive the pressure to incorporate all learning outcomes into the lab course highlights the importance for departments to consider what outcomes are best suited for their laboratory courses and to identify opportunities for the remaining outcomes to be incorporated elsewhere in the curriculum.

Several outcomes that students felt were less important (in the lower half of Figure 3) were highly covered in lab courses as reported in the 2018 study "How We Teach: Unit Operations" [11]. In this study, 98.4% of courses covered teamwork, 98.4% covered ethics, and 67.2% covered communication. In particular, the student response data showed a slight consensus around the lack of perceived importance of teaming in a chemical engineering lab course. "Teams" appeared in the bottom three of the open response and importance measures, and ranked seventh in the top five ranking. This result is particularly surprising given that over 98% of chemical engineering lab courses are taught using teams, 80% directly assess teamwork as a learning outcome of the course, and teamwork influences the laboratory grade of 62% of courses [11]. Since teaming is standard practice in chemical engineering lab courses and one of the seven student outcomes established by ABET [5], it is surprising that students do not acknowledge it as an important learning outcome of the course. This indicates a disconnect between what students are doing in the course and what they perceive as meaningful learning, and understanding why students do not perceive teaming as important will help shape course changes. For example, students may have found teaming either easy or unenjoyable and discounted its importance. Alternatively, as team-based projects are becoming more prevalent throughout the curriculum, students may have felt that teamwork was not unique to the chemical engineering lab and thus was not as important as some of the other learning outcomes specific to the lab course. It is also possible that instructional content on the importance of teamwork and effective strategies for navigating teams was lacking, leaving students unclear as to the extent teamwork was a learning objective for the course.

A similar disconnect between which of the Feisel and Rosa lab course outcomes the faculty and non-academic/industrial respondents felt were most important to a chemical engineering lab course and what students felt they were weakest at and should be covered more strongly in the overall curriculum. The top three outcomes students wanted to be covered more strongly were "Troubleshoot," "Design prototype," and "Select tools"; all three of these outcomes were in the bottom five least important to the faculty respondents [13] and were in the bottom half of ranked importance for non-academic respondents [14]. Another dissimilarity was that students did not feel safety was an area of weakness for themselves and that it did not need to be covered more strongly in the curriculum, while it was a top-five ranked outcome for both faculty [13] and non-academic engineers [14].

Overall, these data suggest that faculty may improve the experience of students in chemical engineering laboratory courses by being more explicit about what they are teaching in laboratory courses and what they are expecting students to learn (and why the learning outcomes are important). Having a better understanding of the motivations students have while taking a chemical engineering lab course could help align faculty and student expectations. When asked to openly suggest the learning outcomes of the lab course, the most reported answer from students was “Real-world applications.” With $n = 16$ out of 31 responses, “real-world applications” had more responses than any of the thirteen Feisel and Rosa outcomes [1]. Real-world applications had been mentioned in previous surveys with faculty and industry partners but to a much lesser extent than with the student survey. While faculty and non-academic stakeholders may understand how the other thirteen outcomes relate to “real-world” experiences, students have comparatively less experience outside the classroom. Faculty may need to do a better job of helping students make the connection between what they are doing in the laboratory and how that relates to what they will encounter post-graduation.

Conclusion

This paper examines student perceptions of the relative importance of learning outcomes in chemical engineering laboratory courses. Students were also asked about gaps in their learning and the curriculum with regard to these outcomes. Although students felt that all thirteen of Feisel and Rosa’s learning outcomes were generally important, “Design experiment,” “Problem solve,” “Troubleshoot,” and “Compare to theory” were most often chosen in a top-five ranking. In open-ended responses, a majority of students indicated that “Real-world applications” was a key learning outcome, although that outcome is not represented in Feisel and Rosa’s list. Students felt that they had weaknesses in the “Troubleshoot,” “Design experiment,” and “Design prototype” learning outcomes and that curricula should cover these more. Interestingly, students also felt weak in the “Compare to theory” outcome but did *not* think their curricula should emphasize it to a greater extent. In this early analysis, it appears there may be a disconnect between what students and other stakeholders feel is important, with students perhaps lacking an understanding of the importance of some outcomes for the “real world”. Future work will focus on a comprehensive comparison of the three stakeholder surveys (faculty, non-academic/industry, and students) and generating recommendations that will help instructors prioritize learning outcomes in their laboratory courses.

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Appendix A: Student-Related Questions from the Qualtrics Survey

By clicking "I AGREE" below, you agree that you have read the information provided and are voluntarily agreeing to let your responses be used in this research study. If you do not agree and do not want to participate in the research study, please click "I DO NOT AGREE."

- o I AGREE
- o I DO NOT AGREE

How do you describe your gender (please select all that apply)?

- ▢ Female
- ▢ Male
- ▢ Agender (e.g., non-gender, neutrois)
- ▢ Cisgender
- ▢ Genderqueer
- ▢ Gender Fluid
- ▢ Gender Non-conforming
- ▢ Indigenous/Other Culturally-Specific Gender (e.g., two-spirit, hijra, etc.)
- ▢ Non-binary
- ▢ Polygender
- ▢ Transgender
- ▢ Gender not listed here (please specify): ____
- ▢ Prefer not to say

How do you describe your race/ethnicity (please select all that apply)?

- ▢ American Indian, Native American, or Alaskan Native (please specify nation or band, if applicable): ____
- ▢ Arab or Arab American
- ▢ Asian or Asian American
- ▢ Biracial or Multiracial
- ▢ Black or African American

▢ Jewish

▢ Latino/a/x/e or Hispanic

▢ Pacific Islander or Native Hawaiian

▢ White or Caucasian

▢ Race/ethnicity not listed here (please specify):
____

▢ Prefer not to answer

Which option best describes you?

o Undergraduate student in chemical engineering or related field

o Faculty member in chemical engineering or related field

o Non-academic/industry

o Other (please describe) ____

What university do you attend?

____

What is the name of your major/degree program?

o Chemical Engineering or closely related field (e.g., Biochemical Engineering)

o Other (please specify): (2) ____

What is your estimated year of graduation?

____

Have you had any ***engineering*** experience outside of academia? Please select all that apply.

▢ Yes - Internship

- ☐ Yes - Co-op
- ☐ Yes - Research
- ☐ No

Have you taken a chemical engineering laboratory course? This might include Unit Operations Laboratory, Mass Transfer Lab, or similar. It should NOT include general science laboratories (e.g., chemistry, biology, physics) or general engineering laboratories.

- o Yes
- o No

The Chemical Engineering laboratory seeks to expose students to the type and scale of equipment they are likely to see in industry and to equip them with the ability to analyze the behavior of these systems as well as have a true “feel” for how they work (or don’t work quite as expected) [1]. In this survey, we are exploring the unit operations (typically senior-level) laboratory and are NOT including general science laboratories (e.g., chemistry, biology, physics) or general engineering laboratories.

<u>Definition of Chemical Engineering Laboratory Courses</u>

The Chemical Engineering laboratory seeks to expose students to the type and scale of equipment they are likely to see in industry and to equip them with the ability to analyze the behavior of these systems as well as have a true “feel” for how they work (or don’t work quite as expected) [1]. In this survey, we are exploring the unit operations (typically senior-level) laboratory and are NOT including general science laboratories (e.g., chemistry, biology, physics) or general engineering laboratories.

<u>Definition of learning outcomes</u>

Learning outcomes are measurable statements that concretely formally state what students are expected to learn in a course [2].

1: Vigeant, M. A., Silverstein, D. L., Dahm, K. D., Ford, L. P., Cole, J., & Landherr, L. J. (2018, June). How we teach: Unit operations laboratory. In 2018 ASEE Annual Conference & Exposition

2: Northeastern University's Center for Advancing Teaching and Learning through Research. Teaching Strategies: Course Learning Outcomes. https://learning.northeastern.edu/course-learning-outcomes/

What are the three most important learning outcomes for a laboratory-intensive chemical engineering course?

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How important are the following learning outcomes for a laboratory-intensive chemical engineering course? (Likert scale: 1: Not at all important, 2: Slightly important, 3: Moderately important, 4: Very important)

1. Make measurements: Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.

2. Compare theory to reality: Identify the strengths and limitations of theoretical models as predictors of real-world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.

3. Design an experiment and interpret the results: Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.

4. Analyze data: Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments and use measurement unit systems and conversions.

5. Design and/or prototype: Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system

specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.

6. Troubleshoot issues: Identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.

7. Independent real-world problem-solving: Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.

8. Select appropriate tools and resources: Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.

9. Handle safety issues: Identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.

10. Oral and written communication: Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.

11. Work in teams: Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.

12. Behave ethically: Behave with highest ethical standards, including reporting information objectively and interacting with integrity.

13. Use human senses to gather information: Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.

Please rank your top 5 most important learning outcomes for a chemical engineering laboratory-intensive course: (Drag the items to the box on the right)

Five most important learning outcomes (1 = most important, 5 = least important)
______ Make measurements
______ Compare theory to reality
______ Design an experiment and interpret the results

_______ Analyze data

_______ Design and/or prototype

_______ Troubleshoot issues

_______ Independent real-world problem-solving

_______ Select appropriate tools and resources

_______ Handle safety issues

_______ Oral and written communication

_______ Work in teams

_______ Behave ethically

_______ Use human sense to gather information

Are there any important learning outcomes for a chemical engineering laboratory-intensive course not listed above? If so, please list them here:

____

____

____

At this time, which learning outcome(s) do you feel you **have the most trouble with / are weakest in**? Select up to 3.

- ☐ Make measurements
- ☐ Compare theory to reality
- ☐ Design an experiment and interpret the results
- ☐ Analyze data
- ☐ Design and/or prototype

- ▢ Troubleshoot issues
- ▢ Independent real-world problem-solving
- ▢ Select appropriate tools and resources
- ▢ Handle safety issues
- ▢ Oral and written communication
- ▢ Work in teams
- ▢ Behave ethically
- ▢ Use human senses to gather information

Which learning outcome(s) do you feel your overall chemical engineering curriculum should do a better job of covering? Select up to 3.

- ▢ Make measurements
- ▢ Compare theory to reality
- ▢ Design an experiment and interpret the results
- ▢ Analyze data
- ▢ Design and/or prototype
- ▢ Troubleshoot issues
- ▢ Independent real-world problem-solving
- ▢ Select appropriate tools and resources
- ▢ Handle safety issues
- ▢ Oral and written communication
- ▢ Work in teams
- ▢ Behave ethically
- ▢ Use human senses to gather information

Is there anything else related to teaching chemical engineering lab courses that you would like to comment on?

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