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Prioritizing learning objectives for chemical engineering laboratory courses

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Prioritizing learning outcomes for chemical engineering laboratory courses

Abstract

Chemical engineering laboratory courses allow students to work hands-on with equipment they may see in industrial positions. These courses often account for learning outcomes related to experimentation, teamwork, and communication skills, among others. To work towards alignment of laboratory courses with industrial needs, it is necessary to understand 1) the learning outcomes currently addressed in laboratory courses and 2) how key stakeholders perceive the importance of specific laboratory learning outcomes. Therefore, three surveys were designed based on thirteen proposed learning outcomes for engineering laboratory courses that were identified in the literature [1]. The surveys were developed and distributed to faculty members, students, and industrial engineers to gain understanding of the outcomes important to the various stakeholders [2]. The results will provide guidance on how to prioritize lab learning outcomes and allow for the redesign of laboratory courses that better align with the skills and attributes desired by stakeholders.

This paper describes results from the survey of 73 chemical engineering faculty members. Faculty were asked to identify key learning outcomes for a unit operations course through a series of three questions: 1) an open-ended response question, 2) identifying the importance of previously identified learning outcomes through a Likert-Scale response and 3) ranking their top five learning outcomes. Open ended responses were coded based on the learning outcomes previously identified in the literature [1]. The survey was distributed via snowball sampling, with initial distribution at the American Institute of Chemical Engineers' annual meeting in 2022 and via social media. Faculty response data was analyzed to identify trends across the three different response types. Across the survey responses, there was agreement on the high level of importance of four learning outcomes: design experiment, compare to theory, analyze data, and communication. While the learning outcome of ethics was rated as significantly important for a laboratory course, many faculty did not include this in their ranking of the top five learning outcomes or their open-ended response of important learning outcomes for a laboratory course. Moving forward, results will be combined with findings from the student and industry surveys to suggest which outcomes should be prioritized within a chemical engineering laboratory course setting.

Introduction

Due to COVID restrictions, undergraduate laboratories have been forced to examine what it means to be an educational laboratory. Changing the mode of instruction in the labs and/or lowering densities within in-person lab spaces made many instructors challenge long-held assumptions about the purpose of these courses. This reexamination of the core purpose and key learning outcomes of the lab course has been especially true in chemical engineering laboratories as much of the in-lab equipment does not transition to remote or at-home experiments due to the larger scale.

At the same time, industry and academics have been exploring the future vision of chemical engineering (ChE) as a field. A 2015 survey explored the academia-industry alignment for ChE and found that "the chemical-engineering laboratory course typically contributes to outcomes desired by industry like safety, troubleshooting, teamwork, written and oral communications, and critical thinking" [3]. More recently, the National Academies released a report entitled "New Directions for Chemical Engineering" [4]. Within the report, National Academy members described some challenges and improvements needed within the chemical engineering curriculum, focusing on the importance of experiential learning through hands-on learning:

> "…The remainder of this section describes some of the challenges that represent important considerations in the near-term evolution of the undergraduate curriculum, as identified by members of this committee and shared by invited external speakers in discussions and presentations. **Three challenges are discussed: the need for experiential learning and greater connectivity among the concepts/tools of the discipline and their application in practice through (1) more effective connections among the individual core courses ("the silos"); (2) experiential learning through virtual or physical laboratory experiences earlier in the undergraduate course of studies; and** (3) a more effective and seamless embedding of statistics and of mathematical and computational thinking into the core**.**"

This report highlighted the importance of laboratory experiences; however, there was little specificity regarding which learning outcomes are important in a chemical engineering laboratory.

Even ABET, the major accrediting board for engineering programs in the US, provides little guidance for laboratories. ABET-required student outcomes [5] are general to all ChE undergraduate programs, and programs use laboratories to assess many of the ABET student outcomes. ABET student outcomes are listed below; in bold are outcomes that are often addressed within a chemical engineering laboratory course:

> "The program must have documented student outcomes that support the program educational objectives. Attainment of these outcomes prepares graduates to enter the professional practice of engineering. Student outcomes are outcomes (1) through (7), plus any additional outcomes that may be articulated by the program.

1. **an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics**
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, **safety**, and welfare, as well as global, cultural, social, environmental, and economic factors
3. **an ability to communicate effectively with a range of audiences**
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. **an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives**
6. **an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions**
7. **an ability to acquire and apply new knowledge as needed, using appropriate learning strategies."**

In the 2018 paper "How we teach: Unit Operations Laboratory" [6], 70 chemical engineering degree programs were surveyed. Part of their survey results (Table 1) show Writing/Communication and Safety as the primary ABET student outcomes assessed in the ChE labs.

Table 1: ABET Outcomes assessed through ChE laboratory courses [6]

ABET outcome	% of Responses
Writing/Communication	96.6%
Safety	70.7%
Ethics	41.1%
Evaluation of information sources	34.5%
Knowledge of environmental/political/social impacts	13.8%
Regulatory understanding / compliance	12.1%
Other	10.3%

Additional data within the survey analyzed responses from laboratory instructors on which laboratory course outcomes were represented in their laboratories and if they were assessed (Table 2).

Table 2: Laboratory course outcomes; unit of analysis is one course [6]

Outcome	Represented?	Directly assessed?
Practice data analysis	100%	93.4%
Practice effective teamwork	98.4%	80.3%
Demonstrate laboratory ethics	98.4%	93.4%
Exercise creativity within an engineering context	88.5%	62.3%
Become familiar with appropriate instrumentation	78.7%	62.3%
Design an experiment	78.7%	62.3%
Identify strengths and weaknesses of theoretical models as descriptors of real-world outcomes	77.1%	57.4%
Practice professional communication	67.2%	24.6%
Practice engineering design	54.1%	39.3%
Learn from failure	45.9%	16.4%
Develop specific psychomotor skills	45.9%	16.4%
Identify health, safety, and environmental issues	45.9%	11.5%
Other	29.5%	6.6%
Develop sensory awareness of chemical processes	14.8%	3.3%

The laboratory course outcomes identified in Table 2 were based on a list of learning outcomes for general engineering labs from Feisel and Rosa [1]. While responses from faculty of this survey show ***what*** is covered in the labs for specific programs, there is little justification for ***why*** these outcomes should be addressed in a lab course. Additionally, it does not identify which outcomes faculty feel are the ***most important***.

The results from Vigeant et al. show that 9 out of 13 of the laboratory outcomes are represented in greater than 50% of lab respondents; however, only 7 out of 13 outcomes are directly assessed. These results show an important choice that faculty must make when it comes to structuring their course: while all outcomes can be achieved, not all can be feasibly assessed. Though there seems to be no defined number of course outcomes that faculty should assess within a course, University of North Carolina - Charlotte's Center for Teaching and Learning targets 3-6 course outcomes [7], which corresponds to Teaching@Tuft's guideline of "no more than six"[8]. Therefore, the bigger question is "Which learning outcomes can ***best*** be covered in the ChE labs?"

In order to answer this question, the authors of this paper developed a survey tool [2] to survey stakeholders (faculty, industry personnel, and current students) to determine which outcomes should be prioritized in ChE laboratory courses. This paper will describe the ChE faculty survey results. Faculty members understand what is currently taught and can be change agents for improvements within their departments and curricula [12] [13]. The results will provide an understanding of faculty perceptions of the key learning outcomes of ChE laboratory courses. Student and industry results will be analyzed at a future date, allowing for the development of a shared vision for key learning outcomes in ChE laboratories.

Methods

Survey Development and Distribution

Initial development of the survey questions and content for each of the three stakeholder groups was previously described and the survey can be found in Appendix A [2]. Respondents were asked about their demographics (gender identity, race/ethnicity) before asking them to self-identify into a stakeholder group (undergraduate student in chemical engineering or related field, faculty member in chemical engineering or related field, non-academic/industry, or other). 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 demographics questions that allowed the authors to situate the survey responses in context of the respondents' experiences. The faculty branch asked for their institution name, job title, bachelor's degree field of study, year of completion of bachelor's degree, and experience teaching lab courses or working outside academia.

Following the demographics questions, the survey provided a definition of learning outcomes in ChE laboratory courses and then asked the respondents to answer survey items related to three research questions:

1. What are the most important learning outcomes for a laboratory-intensive chemical engineering course? [Open-ended Response]
2. Which of the 13 engineering laboratory learning outcomes identified by Feisel and Rosa are perceived as most important? [Likert scale for level of importance and Top 5 of importance ranking]

The survey attempted to elicit an "unbiased" answer to question #1 by asking respondents to list the three most important learning outcomes without providing any suggestion or commonly used outcomes as examples. The remaining research questions referred to the outcomes shown in Table 3.

Respondents were asked to rate the overall importance of each of the 13 outcomes on a Likert scale, and also 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.

The survey design was approved by the Institutional Review Board (IRB) at The 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 is 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 coded by two of the authors using the 13 learning outcomes identified in Table 3.

The applied codes were then compared and disagreements were resolved. Learning outcomes that did not match the 13 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 response, 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 (1 = 5, 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. For both the Likert-scale and ranking data, a Chi-squared test was used to determine statistically significant differences between the responses for those who had previously taught lab and those who had not. Further, differences across the Likert-scale rankings for the importance of learning outcomes were determined through an Independent-Samples Kruskal-Wallis test with Bonferroni correction [14].

Table 3: Thirteen important learning outcomes for engineering laboratories, as described by Feisel and Rosa [1]. The "short name" indicates an abbreviated name of the outcome for use in presentation of the data.

#	Short name	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.

Results

Participants

Responses were received from 73 faculty members from over 35 different institutions in the United States and at least one university internationally. The faculty were a range of teaching faculty (35%), research faculty (1%), laboratory staff (1%), assistant professors (15%), associate professors (15%) and full professors (33%). About 22% of respondents earned their bachelor's degree before 1990, 18% between 1990 and 1999, 36% between 2000 and 2009 and the remaining 24% after 2010. Finally, 80% of respondents had previously taught a unit operations course and 83% had job experience outside of academia (44% full-time position and 44% co-op or internship).

Open response to most important learning outcomes

Sixty-five 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 13 learning outcomes listed in Table 3. The number of mentions of each learning outcome can be found in Figure 1.

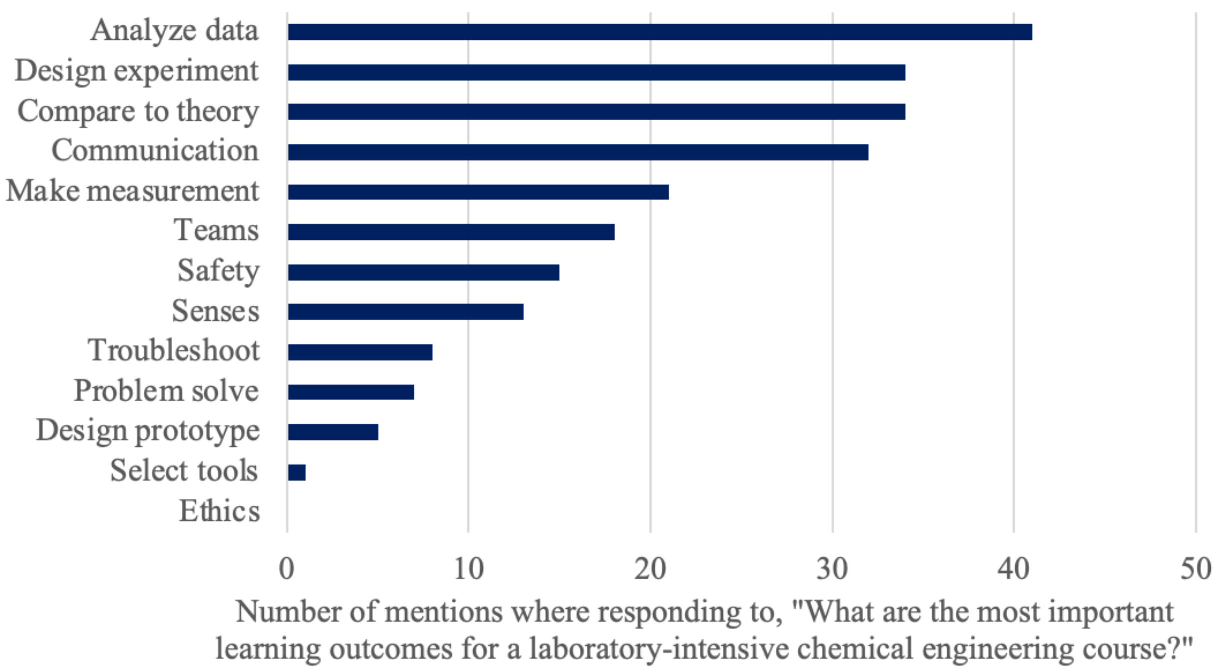

Figure 1: Histogram showing the number of times each of 13 outcomes was coded from responses to an open-ended question asking for the three most important outcomes.

Responses in Figure 1 are ordered from most mentioned (top) to least mentioned (bottom). The top four learning outcomes (each with over 30 mentions, as compared to just over 20 for the next most common) were analyze data, design experiment, compare to theory, and communication.

Five outcomes had fewer than ten mentions: troubleshoot, problem solve, design prototype, select tools, and ethics.

In addition to the 13 learning outcomes identified in Table 3, further learning outcomes that were identified were: 1) gaining experience operating "real systems," 2) using experimental data to apply to process scale up, 3) creating predictive models of experimental systems, 4) critical thinking and 5) using resources and literature to support findings from an experimental study. Each of these learning outcomes were identified less than four times across the open-ended responses.

Evaluation of the importance of the thirteen different learning outcomes

Faculty respondents were asked to rate on a Likert-scale the relative importance of each of the 13 common learning outcomes in a laboratory-intensive ChE course (Figure 2).

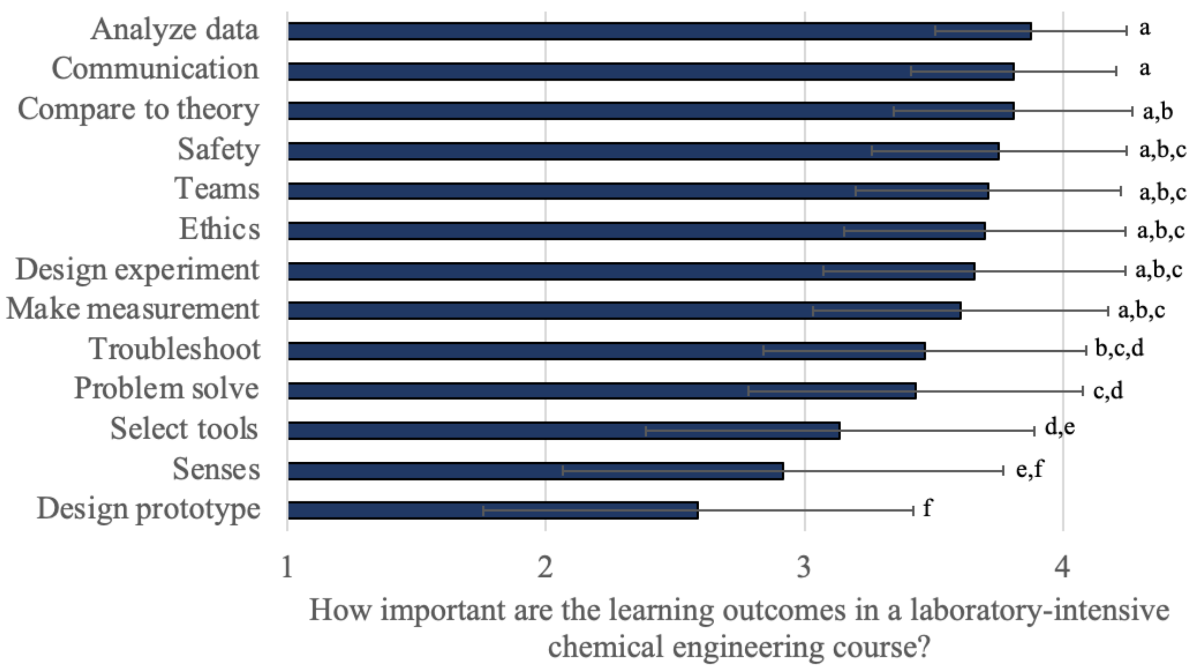

Figure 2: Mean value of a Likert-scale assessment of the relative importance of 13 common learning outcomes (1 = not at all important, 2 = slightly important, 3 = moderately important, 4 = very important). Error bars represent one standard deviation. Letters indicate outcomes that are statistically the same ($p \geq 0.05$) as determined by the Independent-Samples Kruskal-Wallis test with Bonferroni correction.

The learning outcomes are ordered from highest Likert-Scale rating (top) to lowest Likert-Scale rating (bottom). Eleven out of thirteen outcomes were given an average rating of "moderately important (3)" or higher. The only two outcomes with a lower average rating (using human senses to gather information, design and/or prototype) still had an average rating above "slightly important (2)". The top eight learning outcomes (analyze data, communication, compare to theory, safety, teams, ethics, design of experiment and make measurements) were all statistically similar ($p \geq 0.05$). Troubleshooting and problem solving were only statistically different from either two or three of the top-ranked learning outcomes. The three lowest-ranked outcomes (select tools, senses, and design prototype) were statistically different ($p \leq 0.05$) from at least the top eight highest-ranked learning outcomes.

The outcomes with the highest and lowest ratings aligned well with the coded open-ended responses. At the highly rated end, analyze data, communication, and compare to theory were in the top four of both questions. At the low end, four outcomes were shared amongst the bottom five of each question: troubleshoot, problem solve, design prototype, and select tools.

A Chi-squared test was used to determine the difference between rating of learning outcomes between faculty who had previously taught laboratory courses (n = 59) and those who had not (n = 14). Those faculty who had previously taught laboratory courses were more likely to indicate that communication was a more important learning outcome than those who had not (p = 0.012). On the other hand, faculty who had previously taught laboratory courses felt that designing a prototype was less important than those who had never taught laboratory courses (p = 0.026).

Ranking of the top five learning outcomes
Respondents were then asked to rank the top five most important learning outcomes from the list of 13 in Table 3. The distribution of these rankings is shown in Figure 3.

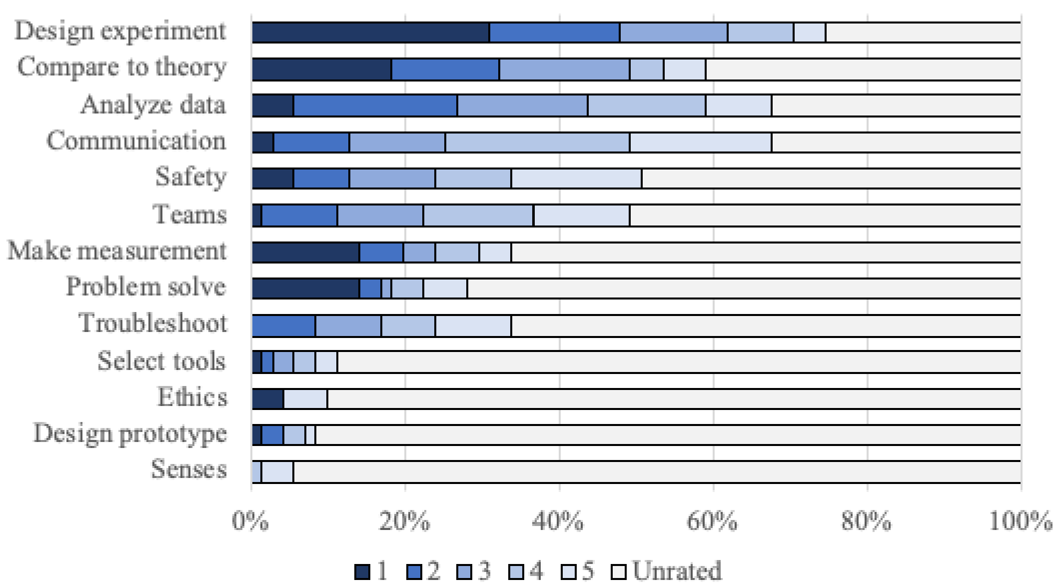

Figure 3: Distribution of rankings of 13 common learning outcomes in which respondents were asked to select the top five most important outcomes for a ChE laboratory-intensive course. Outcomes are presented in order from highest to lowest mean ranking.

The outcomes in Figure 3 are listed in order from highest (top) to lowest (bottom) mean ranking. The four outcomes with the highest mean ranking (design experiment, compare to theory, analyze data, communication) are identical to the four outcomes mentioned most often in an open-ended context (Figure 1), although the rank order of the outcomes within the top four is different. Of these, designing an experiment had the highest percentage of number one rankings at over 30%. The next high percentage of number one rankings was comparison to theory, at 18% of respondents. Three of these outcomes (analyze data, communication, compare to theory) were also the highest-rated in terms of their importance (Figure 2).

The least-important outcomes also aligned closely with other survey items: troubleshoot, select tools, and design prototype were in the bottom five for all three questions (open-ended coding, relative importance, top five ranking). The outcome of ethics rated much higher in terms of its relative importance compared to the overall ranking, Further, senses was mentioned often in the open-ended question, was not considered as important and was almost never put in the top five most important outcomes. In fact, 94% of respondents did not rank senses in the top five learning outcomes for a unit operations laboratory.

Two other outcomes, make measurement and problem solve, received a large number of number one rankings (14% each), but received only a moderate ranking on average. Theses outcomes were tied for the third highest percentage of number one rankings. Interestingly, these two outcomes were largely considered to be either very important (ranked very highly) or not important at all (no ranking).

The only significant difference in rankings between faculty who had taught laboratory courses versus those who had not was for the selection of appropriate tools for data collection. Faculty who had not previously taught laboratory courses ranked the selection of appropriate tools as more important than those who had not ($p = 0.044$).

Missing learning outcomes

A final open-ended survey question asked respondents to list any outcomes important for a ChE laboratory-intensive course that were not listed earlier in the survey. Eight respondents listed one or more outcomes, most of which align reasonably well with the outcomes in Table 3. For example, “Learn how chemical engineering intersects with the world, how it can be used to do good and do harm” might reasonably be grouped in with ethics. Similarly, “Experience the operation of chemical engineering equipment (e.g. physically operating a distillation column)” could be considered a form of senses.

Two responses were somewhat unique. The first, “Introduce students to equipment and control systems used in industry and associated terminology”, describes a more knowledge-based learning outcome rather than a skill-based outcome. The second, “Acquire and apply new knowledge, as needed, by planning, monitoring, and assessing one's individual learning preferences" focuses on metacognition.

Discussion

The survey results revealed consensus on the top four outcomes (design experiment, compare to theory, analyze data, communication) both when asking for ranked assessment of importance as well as in the open-ended responses. However, when asked to rate the relative importance of the outcomes without ranking, there was significant overlap in the evaluation of learning outcomes as important, and ratings for the top eight learning outcomes were statistically similar. ChE laboratory courses are often tasked with assessing many outcomes given the experiential nature of these courses compared to the lecture-based core courses. Because best practices suggest limiting course outcomes to six or under [7], [8] it is unrealistic to think that faculty can adequately assess all thirteen learning outcomes for engineering laboratories described in Table 3. This report based on responses from faculty supports the notion that not all lab learning outcomes are equally important and points towards candidates for a focused set of outcomes that should be more thoroughly assessed. Departments should be mindful when determining which learning outcomes are best-suited for the ChE laboratory courses, with consideration of which outcomes translate to ABET criteria as well as which outcomes can be taught and assessed in other courses. While this paper focuses on understanding how faculty perceive the importance of learning outcomes in a ChE laboratory course, it is important to consider input from additional stakeholders when making decisions on course learning outcomes. Future surveys of student and industrial partners will give further insight on what stakeholders outside the university deem as important, and help departments make assessment decisions.

While there was consensus on the top outcomes in terms of importance, there were also some interesting cases where the outcomes did not align between the three measurements (open-ended responses, unranked assessment of importance level, and ranked assessment of importance). The most notable case was ethics. Ethics was not mentioned at all in the open responses, was rated 6th in the level of importance, and rated 11th when respondents were asked to rank the top 5 most important outcomes. This is a problem that may persist across the overall curriculum; there is broad agreement that ethics is extremely important, but it is not prioritized in comparison to other learning outcomes. Faculty must consider whether the laboratory courses are the most appropriate place in the curriculum for instruction on ethics, and, if so, what would the instruction and assessment consist of, as it can be challenging to address this topic beyond a superficial level.

Another outcome that showed misalignment across the measurements was senses, which was mentioned 8th in the open responses, 12th in the level of importance, and 13th when respondents were asked to rank the top 5 most important outcomes. Senses are inherent to the ChE laboratories, as they are often among the only courses in the curriculum that are "hands on." It's possible that while students are likely learning to use their senses when operating the equipment in the laboratory setting, many faculty likely aren't including this topic in the instruction and assessment that they incorporate into their course. Assessment of student's ability to use their senses to gather information about the equipment and experiments being conducted could be challenging.

Given the misalignments on importance of topics such as ethics and senses, it is hypothesized that outcomes like these that are difficult to assess have been ranked lower by the respondents. The lack of resources available for instruction and assessment of these topics contributes to the challenges in addressing these outcomes. Safety, teamwork, and communication have become more of a focus in the ChE laboratories in recent years, and thus the resources to teach and assess them have emerged. A similar effort to develop projects and materials that focus on topics that are harder to assess may be required if they will be prioritized as important learning outcomes for the ChE laboratory courses.

Only 8 of the 73 faculty respondents provided an answer to the last survey question, addressing ChE lab course objectives not covered in the list provided. Only two of the answers were unique, addressing outcomes not covered in the list. This indicates that from the faculty perspective, Table 3 comprehensively covers important learning outcomes that are covered in our current curricula. However, the limited faculty response also highlights the importance of future surveys with students and industry partners to probe if there are blind spots. The two unique responses both focused on metacognition and skill development required by students outside of the classroom, or in the traditional ABET phrasing, "lifelong learning"; this is an important outcome that should not be limited to laboratory teaching.

Another interesting observation was that there were differences between faculty who have taught ChE laboratory courses and those who have not. For example, faculty who had previously taught laboratory courses were more likely to rate communication as an important learning outcome than those who had not taught these courses, while they were more likely to say designing a prototype was less important than those who had never taught these courses. This discrepancy suggests that there may be misalignment in what is being taught in the laboratory course compared to the perception of the course content by other faculty. However, it is also possible that these discrepancies are due to unconscious bias from those who teach the laboratory courses who feel that what they currently focus on in the course instruction is most important. Thus, faculty who do not teach laboratory courses may have insights into potential gaps in the curriculum or perceptions of what could be implemented that could serve as catalysts to drive changes in the lab curriculum. These findings provide more support for the importance of gathering additional input from stakeholders outside of academia to identify what outcomes are most valuable for our students' success in industry.

Conclusion

In this work, faculty perceptions on the most important learning outcomes in ChE laboratory courses were evaluated. Additionally, identification of possible gaps in learning outcomes were targeted. There was notable hierarchy in the perceived importance of the thirteen outcomes included in the survey, with broad support for the importance of four of the outcomes (design experiment, compare to theory, analyze data, communication). This work can provide an important starting point for determining which outcomes are most relevant for the chemical engineering laboratories as opposed to those that can be taught and assessed in other courses, with consideration of how the outcomes translate to ABET criteria. However, it will be critical to consider input from other stakeholders. Accordingly, our future work will focus on other constituents to determine what is taught best in the lab course (student survey) and what is perceived as most valuable outside of academia (industry/non-academic personnel survey). Through this work, data collected across the various stakeholders will be compared to develop a comprehensive set of recommendations for a more focused set of learning outcomes to prioritize in the chemical engineering laboratory courses.

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Appendix - 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 institution do you work at?

____

What is your job title?

- o Adjunct (part-time faculty)
- o Assistant Professor
- o Associate Professor
- o Professor (Full)
- o Teaching faculty (professional track faculty)
- o Other (please specify) ____

What was your major field of study for your bachelor's degree?

- o Chemical Engineering or closely related field (e.g., Biochemical Engineering)
- o Other (please specify): ____

When did you earn your bachelor's degree?

- o 2010 or later
- o 2000-2009
- o 1990-1999
- o 1980-1989
- o Before 1980

Have you taught a chemical engineering laboratory-intensive course (e.g., the Unit Operations Laboratory)?

- o No
- o Yes

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

- ☐ Yes - Full-time position
- ☐ Yes - Co-op/internship
- ☐ Yes - Other (please specify):

____

☐ No

Definition of Chemical Engineering Laboratory Courses

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.

Definition of learning outcomes

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?

____

____

____

____

____

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:

____

____

____