Six Years of Living with the Lab

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Six Years of Living with the Lab:
A Survey of Student Experience

Abstract

This paper is a report on *evidence-based practice* in a first year engineering program for Mechanical Engineering Students. We adapted a year-long curriculum called *Living with the Lab* (LWTL) that uses a project-based, hands-on instruction to introduce students to engineering fundamentals, programming, sensors, controls and engineering design. While adhering to the spirit and much of the content of the original curriculum, we added material, created new hands-on projects, introduced a flipped instructional model for the first course in the sequence, and experimented with an alternative final project model. We briefly describe our key innovations to the LWTL curriculum.

Introduction of this curriculum has coincided with a sharp rise in enrollment in our Mechanical Engineering program. Retention at the end of the three-term sequence is approximately 60%. After six years of implementation the curriculum continues to evolve. We report on a survey of student opinion that spans all cohorts of students passing through the program. Overall there is strong student satisfaction with the curriculum, especially the hands-on approach. Students describe the courses as both "fun" and "challenging". Survey responses show female students are more positive than males about the hands-on pedagogy despite having less prior hands-on experience. Both male and female respondents think the pedagogical approach is appropriate for the course material and beneficial to their learning.

Introduction

In Winter 2010, the Mechanical and Materials Engineering Department at Portland State University offered a trial version of the Living with the Lab (LWTL) Curriculum, which was developed at Louisiana Tech University[1,2,3]. Following that initial offering to 12 students, a cohort of 60 students began the full 3-term LWTL course sequence in Fall 2010. Enrollment continued to increase, and to meet demand we now offer multiple sections of each course and a trailer sequence starting in Winter term. The exciting and challenging courses have contributed to a high level of interest in the ME major.

Class meetings in the LWTL curriculum are highly interactive, with limited lecturing and a large fraction of class time involving hands-on activity. Instructors need to be flexible and accessible to students in order to help trouble-shoot computer programs, electrical circuits, fabrication

techniques, and mechanical component and system design. While simultaneously encouraging the ambitious students who may have prior relevant experience, instructors also need to be patient and to coach those students who are not as well-prepared and who feel overwhelmed by the pace of instruction and the difficulty of the projects.

Adoption of LWTL as our Freshman Engineering (FE) curriculum has had positive side effects on other parts of our BSME program. Students have asked for more hands-on experiences in other classes; some have incorporated Arduino microcontrollers into their senior capstone projects; and a group of sophomore through senior-year alumni of the FE curriculum has formed the Mechanical Engineering Lab Team (MELT), a club to train other students on the use of the laser cutters, 3D printers and conventional machine tools that are introduced in the LWTL curriculum.

This paper is one part of an on-going assessment of the outcomes of our FE program. Here we report on a survey of student opinions of the LWTL curriculum as adapted to our BSME program. We begin with an brief overview of the LWTL curriculum and highlights of our innovations to the curriculum. We then present summary data on enrollment and retention. The bulk of the paper is a report and analysis of a survey of students who have taken at least one of the FE courses.

Method and research questions

Instructors in the program and other faculty in our department have heard very positive feedback from students as well as complaints about the difficulty of the courses. Rather than rely on anecdotes, we wanted to survey the entire population of students who had taken these courses. The high level question addressed in this paper is, “Does this freshman engineering curriculum work for our students?” More specifically, we sought answers to these questions:

- Are students motivated by, or are they discouraged by, the fast pace and challenging projects?
- Do students find the emphasis on hands-on learning conducive to learning?
- Do students gain confidence in their engineering and problem-solving abilities by taking these classes?
- Do students become clear about whether engineering (and Mechanical Engineering in particular) is a desirable career?

Before we discuss the survey, we describe the curriculum and the history of enrollment in the freshman engineering course sequence.

Curriculum

Living with the Lab (LWTL) is a project-based, hands-on curriculum for first year engineering students. The overall approach is consistent with recommendations for improving engineering education[4,5,6]. The only mathematical prerequisite is college-level algebra. No prior experience

with computer programming is required. At Louisiana Tech, all freshman engineering students are required to take the LWTL curriculum. At Portland State, only Mechanical Engineering students are required to take the LWTL curriculum, though the courses are accepted by the Electrical and Computer Engineering department as satisfying first year, introduction to engineering, course requirements.

In the rest of this report we will mostly use LWTL to refer to the curriculum, and use FE (Freshman Engineering) to refer to logistics or the first year experience in general. Most of our students refer to the LWTL curriculum as "Freshman Engineering".

Our BSME program has a $2 + 2$ model. The first two years are referred to as Lower Division and the last two years are referred to as Upper Division. Lower Division classes cover fundamentals of Engineering, Math, Physics, Chemistry and Liberal Arts. As they near completion of their Lower Division requirements, students apply to the BSME program, which has competitive admission.

We are a large urban University, and a significant fraction of our students take some Lower Division courses at community colleges and other institutions. A student-friendly co-enrollment policy between local community colleges and our University makes a mixed selection of Lower Division classes feasible. Most all of the local community colleges have adapted their FE curriculum to incorporate at least some aspects of LWTL. The positive reputation of our FE curriculum has caused some transfer students to complete their Lower Division Math, Physics, Chemistry and Liberal Arts electives at community colleges, and FE at Portland State University.

Our University uses the term model where the 9-month academic year is divided into three 10-week terms: Fall, Winter and Spring. Our FE curriculum consists of three classes in consecutive terms, ME 120, *Introduction to Engineering*, ME 121 *Introduction to Sensors and Controls*, and ME 122 *Introduction to Design*. These courses are all required for the BSME program, and they must be taken in order. Details of the curriculum for each class are available on the following public web sites.

ME 120: `http://web.cecs.pdx.edu/~me120`

ME 121: `http://web.cecs.pdx.edu/~me121`

ME 122: `http://web.cecs.pdx.edu/~me122`

Over the six years that we have taught LWTL, we have adapted the curriculum to improve the student experience. The key innovations are listed below.

- *No mobile robot.* We substituted the Sparkfun Inventors kit (`www.sparkfun.com`) for the BOE-Bot (`www.parallax.com`) mobile robotics platform.
- *Use of Arduino microcontroller.* After a two-term trial implementation of the LWTL curriculum, we switched microcontrollers from the BASIC-Stamp, which is standard on the BOE-Bot, to the Arduino platform.
- *Checklists for project management.* To help prevent teams from slipping behind on project work, we created a series of checklists that are used to grade weekly homework

Table 1: History of enrollment and retention for the FE course sequence since it was first implemented. ME 122 was not taught during the experimental offering in AY 2009-10. R_{1-2} is the retention from the first class to the second class. R_{1-3} is the retention from the first class to the third class. ? indicates data for terms after this report was written.

	Enrollment			Retention	
AY	ME 120	ME 121	ME 122	R_{12} (%)	R_{13} (%)
2009-10	12	8	N.A.	67	N.A.
2010-11	60	43	29	72	48
2011-12	93	65	58	70	62
2012-13	102	80	60	78	59
2013-14	148	128	101	86	68
2014-15	168	116	87	69	52
2015-16	143	108	?	75	?

assignments that involve fabrication, assembly and testing.

- *Flipped instruction.* One of the instructors (N.N.) developed screencast lectures for the entire first course, ME 120. Students are required to watch the screencasts and take a short quiz before coming to class. As a result, students are now better prepared for class and there is more class time for project work.
- *Experimental use of a large system design project.* This past year one instructor (E.T.) organized a section of ME 122 around a single large design goal. Student opinion of this model was mixed. We may attempt this style of project in the future if we can identify a suitable topic.

The innovations to LWTL have arisen from our desire to assess and adapt the curriculum in ways that better serve students and keep the curriculum fresh. Though we do not have formal assessment data on the impact of this particular changes, observations by instructors indicate that the innovations have improved student learning outcomes.

Enrollment and retention

Table 1 lists the enrollment and retention statistics for the FE courses since we began offering LWTL as our FE curriculum. Prior to using LWTL, our FE curriculum consisted of a lecture-only introduction to engineering course and a graphics class using Auto-CAD and Solidworks. The first two courses in the LWTL sequence were offered in a trial implementation in the 2009-2010 academic year. After the trial offering in AY 2009-10, enrollment grew steadily until it peaked in AY 2014-15. Data for ME 121 and ME 122 in AY 2015-16 are incomplete because that year is underway.

Note that our students are admitted to the BSME program as juniors, not as freshmen. All PSU students having the prerequisites are free to take Lower Division (freshman and sophomore level)

engineering courses. Therefore, enrollment in the FE courses is an indication of initial interest in the BSME program, but not a guarantee of admission to the Upper Division BSME program. The rise in enrollment after AY 2010-11 resulted in increased admissions, with a two year lag, to the Upper Division BSME program. Informal conversations with students and faculty from other departments show that the new FE curriculum has created increased visibility of and interest in the BSME program at PSU.

The data in Table 1 represents two trends: the phasing in of the new curriculum and a significant overall increase in students interested in the BSME. As the new curriculum was phased in from AY 2009-10 to AY 2010-11, students could meet their FE engineering requirements either by taking the new curriculum or by taking existing courses that satisfied earlier Upper Division admission requirements. AY 2011-12 was the fully phased-in implementation of the FE curriculum, and we were pleased to see the large increase in ME 120 enrollment from 60 to 93 students. In AY 2013-14 we were stunned (and pleasantly surprised) by the increase in enrollment to 148 students. We cannot explain the 15% drop in enrollment from AY 2014-15 to AY 2015-16 other than a fluctuation in student interest. We think that a steady state enrollment in ME 120 of roughly 150 students is sustainable.

Retention from the first to second course, R_{12}, and from the first to the third course, R_{13}, are listed in the last two columns of Table 1. The retention rates are somewhat noisy. The averages of R_{12} and R_{13} over the last four years are 77% and 60%, respectively. Some students do not continue the FE course sequence because they are not academically successful. Others, though academically successful, learn that they are not truly interested in Mechanical Engineering.

The enrollment growth indicates strong interest in the BSME program. The consistent retention rates indicate acceptable success of students in the program. This data does not tell us about the student experience in these classes. For that information, we turn to our survey of students who have completed one or more of the FE courses.

Assessment methodology

A survey using Qualtrics web-based software was developed to gain understanding of how students experience the FE course sequence. The survey has a total of 38 items: 4 on participation history, 6 on academic status and demographics, 4 free text responses; 2 miscellaneous items, and 20 core items on student opinions of the course and its relationship to the BSME program. The Appendix lists the full text of the prompts for all 38 items.

The survey was approved by the Portland State University Institutional Review Board (HSRRC Proposal No. 153648). Official campus email addresses were used to create a pool of 622 potential survey participants from the rosters of the FE courses offered during the past 6 years. The Qualtrics survey software was configured to not record any personally identifying information in the survey results. Survey participation is completely voluntary and no material incentive (e.g., cash, gift certificate, or prize drawing) was offered for participation.

The survey was opened for three months at the beginning of 2016. During that time 416 students (67% of the 622) in the pool opened the email invitation. By the time it was closed, 133 students

Table 2: Gender of students completing the survey. The third column is the fraction of each gender that responded to the survey, relative to all students of that gender who were invited to take the survey.

Gender	# of responses by gender	# of responses as % of pool
Male	102	18.2
Female	24	28.2
Do not say	7	70.0

Table 3: Academic terms of FE taken by students responding to the survey. A cohort is made up of students who started at least one course in the sequence. Either by attrition, or because some respondents are currently taking FE courses, not all respondents finished all three courses.

Cohort	# of surveys completed by the cohort	Total students in cohort	% of cohort completing survey
W2010-Sp2010	1	9	11.1
F2010-Sp2011	8	56	14.3
F2011-Sp2012	10	77	13.0
F2012-Sp2013	17	94	18.1
F2013-Sp2014	32	117	27.4
W2014-Su2014	2	31	6.5
F2014-Sp2015	17	124	13.7
W2015-Su2015	18	44	40.9
F2015-Sp2016	26	111	23.4

finished the survey for an overall completion rate of 21% relative to the number of invitations to participate (622), and 32% relative to the number of students who opened the email (416). The median time to complete the survey was 14 minutes. The survey responses were analyzed with the `R` software system[7], and the `assocstats`, `likert`, `psych` and `wordcloud` packages[8,9,10,11] for `R`.

Demographic characteristics of respondents

Table 2 shows the self-reported distribution of gender, both as absolute numbers and as a proportion of each gender in the pool of 622 students who were invited to take the survey. The third column in Table 1 shows that the response rate for females (28.2%) is greater than that for males (18.2%). In the analysis presented in the remainder of this report, no correction has been made for the over-representation of females in the response sample.

Table 3 shows that the response rate is roughly equal across all cohorts since Fall 2010, which was the start of regular offerings of the curriculum. Although the proportions of responses does

Table 4: Majors of survey respondents grouped by college and by ME/non-ME categories.

By College	# of Students	% of respondents	By Major	# of Students	% of respondents
Engineering	123	92.5	ME	117	88
Other	10	7.5	non-ME	16	12

not match the proportions of students in each cohort, a Wilcoxon signed rank test indicates that the distribution of response rate by annual cohort in the sample is not significantly different from the distribution of students by annual cohort in the pool of all students ($p = 0.91$ for H_0: proportions of the sample and pool are the same). We therefore assume that the sample is representative of the historical distribution of students taking the FE classes.

Survey respondents were asked to identify their current major. Recall that with our $2 + 2$ curriculum, students are not admitted to the BSME major until their Junior year. In Table 4, for simplicity of presentation, we group the majors by college and by whether or not the respondents indicated that they are BSME majors. Most (92.5%) of the respondents have declared majors in the College of Engineering, and most (88%) of the respondents are, or are intending to be, BSME majors. Students selecting majors outside of engineering or other than ME have most likely decided to switch majors since taking one or more of the FE courses.

What three words best describe your experience in FE?

Survey participants were asked to list the three words that describe their experience in the FE courses. Figure 1 is word cloud of the responses. The font size of each word in the cloud indicates the frequency of that word occurring in the three-word responses. The two most common words are “challenging” and “fun”. Analyzing the associations between words shows that challenging and fun were rarely used by the same respondent. The next most frequently occurring words are (in order of decreasing frequency) “interesting”, “hands-on”, “frustrating”, “engaging”, “exciting”, “stressful”, “informative”, “rewarding”, “useful” and “difficult”. It is encouraging that despite the appearance of “challenging”, “frustrating”, “stressful” an “difficult”, the remaining top-ten terms (6 out of 10) indicate a positive student experience in the FE curriculum.

Core set of Likert scale responses

The core of the opinion survey consists of 20 Likert scale items that were presented to students in three panels: 5 items to elicit the overall opinion of the freshman engineering experience; 8 items focusing on student opinion of hands-on experiences; 7 items to relate Freshman engineering to the rest of the BSME curriculum. The three-best-words survey item (discussed above) and two open-ended response items at the end of the survey we used to collect opinions that were not constrained by the Likert scale items in the bulk of the survey.

Figure 1: Word cloud of responses to the prompt, "What three words would you use to describe your experience in Freshman Engineering?". Plot created with the `wordcloud` package[11].

Survey participants chose responses from a five-point Likert scale with levels *Strongly Disagree*, *Disagree*, *Neither*, *Agree*, *Strongly Agree*. For all items the response choices are consistently ordered from *Strongly Disagree* to *Strongly Agree*. Negatively coded prompts were used in 7 of the 20 core survey items in order to avoid potential bias in responses caused by students mindlessly choosing from the same end of the scale. A negatively-coded prompt would lead to a *Strongly Disagree* response from students who had a positive experience in the course. An example of a normal or positively-coded prompt is

> *As a result of taking courses in the ME freshman engineering sequence, I became more confident in my ability to solve engineering problems.*

An example of a negatively coded prompt is

> *Relative to lecture and other modes of teaching in the class sequence, there was too much hands-on work during class time.*

The complete list of text prompts for all items is given in the Appendix.

For the 20 items in the core of the survey, the Cronbach α is 0.88 with a 95% confidence interval of $[0.83, 0.93]$. The value of α and standard errors were computed with Revelle's `psych` package[10] and used a correction for negatively coded items. Since $\alpha > 0.7$ we are confident in the internal consistency of the survey responses[12,13,14].

Scores for core items

Figure 2 is a horizontal bar plot of responses to the 20 core items on the survey. Response levels are color coded with the width of each colored bar in proportion to the number of responses at that level. The survey items are ordered by the ratio of most-positive (sum of *Agree* and *Strongly Agree* counts) to most-negative (sum of *Disagree* and *Strongly Disagree* counts) with the largest ratio at the top of the plot. The vertical line in the middle of the plot anchors the center of the

proportion for the *Neither* responses to each item. The far left side of the bar plot gives an abbreviated version of the prompt.

The general impression from Figure 2 is that the survey respondents have very strong opinions either in agreement or disagreement to most of the survey prompts. Fifteen of the 20 items have *Agree*/*Disagree* ratios (or *Disagree*/*Agree* ratios) greater than 5-to-1. Seven items have ratios greater than 10-to-1. The specific numerical values for large ratios of agreement to disagreement are dependent on sampling small numbers in the denominator of the ratio. Therefore, it is important to identify the items with large agree/disagree ratios, but not to ascribe too much precision to the numerical value of the ratio when the ratio is large.

The items with the most positive responses (agree $\gg$ disagree) are related to student interest in ME, the value of hands-on work, the usefulness of the skills learned, and how the course increased student confidence. For example, by almost 20-to-1, respondents agreed that the hands-on work in the FE courses increased their interest in Mechanical Engineering. By 9.5-to-1 respondents agreed that the FE courses increased their confidence in their ability to solve engineering problems. By 5.6-to-1 respondents agreed that *as a result of taking ME FE courses* they became certain that ME is a good career choice.

Items with the most negative responses have negatively-corded prompts. For example, by a 14.6-to-1 ratio respondents *disagreed* with the prompt "I have not retained anything that I learned in the ME FE sequence". By almost 9.5-to-1, respondents disagreed with the prompt "The freshman engineering sequence should use a traditional lecture format". By a 5.6-to-1 ratio, students disagreed with "Relative to lecture and other modes of teaching, there was too much hands-on work during class time".

Given the goals of the LWTL curriculum, the core survey responses are encouraging. Despite the students' description of the courses as challenging, students also have overwhelmingly positive attitude towards the hands-on and practical nature of the course. They also report that the course has improved their confidence that Mechanical Engineering is a good career choice. Though student opinions of a course are not the same as student learning, getting student buy-in for pedagogical reform is important to sustaining that reform[15]. Positive student response to pedagogy is also a component of success at implementing broader curriculum reform because it provides evidence to faculty that adopting new pedagogy may be favorably received by students[16].

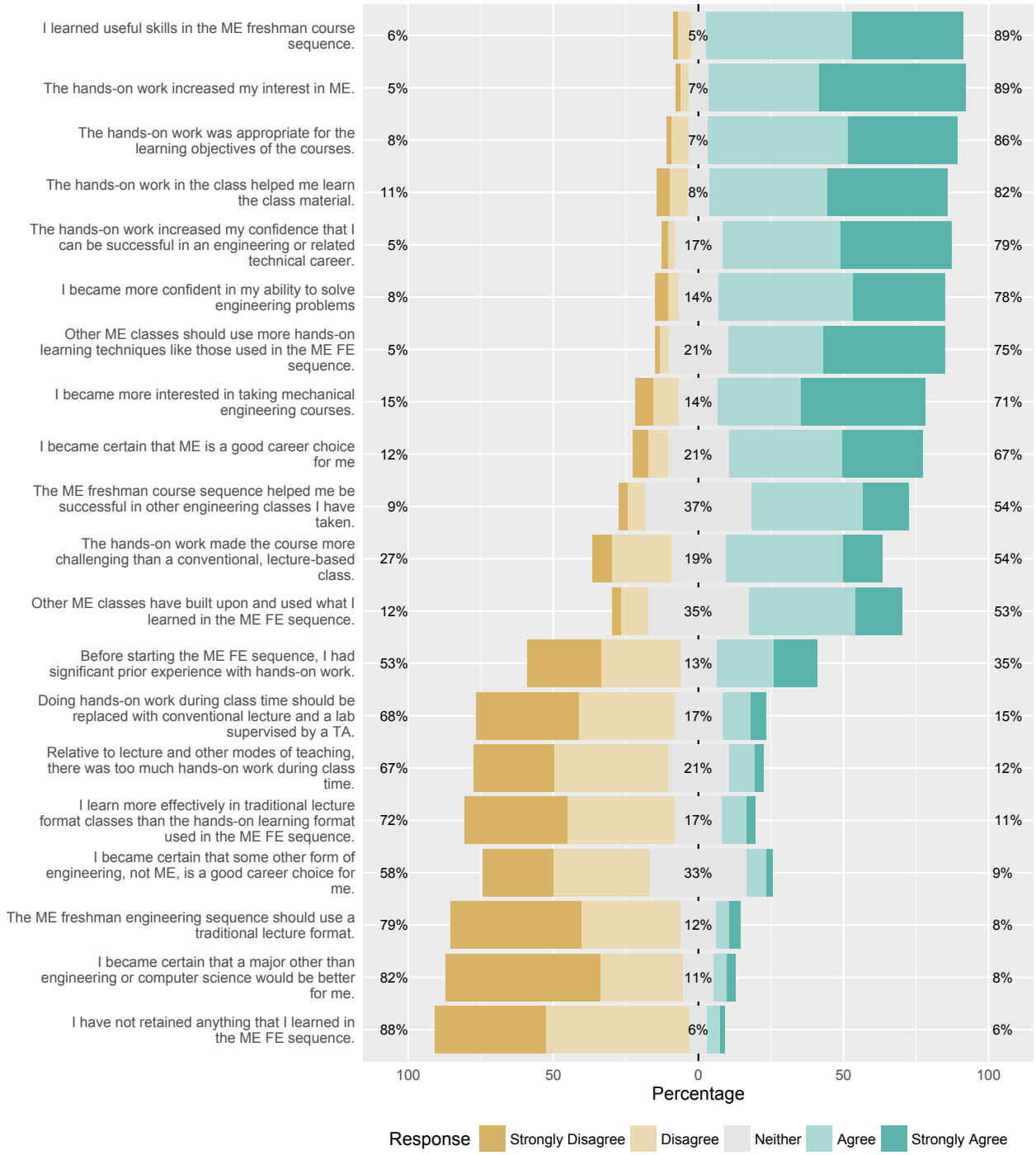

Figure 2: Composite bar plot of responses to core items in the survey. Plot created with the 'likert' package[9].

Table 5: Gender differences in the responses to the prompt: 'Before starting the ME freshman course sequence, I had significant prior experience with this type of hands-on work'.

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree	Total
Male	21	27	15	22	17	102
Female	11	7	2	3	1	24
Do not say	2	2	0	1	2	7
Total	34	36	17	26	20	133

Prior experience

The core survey item with the most neutral overall response has the prompt,

> *Before starting the ME freshman course sequence, I had significant prior experience with this type of hands-on work.*

Refer to Table 11 in the Appendix for the preamble where "this type of hands-on work" was identified to students as "building circuits, fabricating mechanical components, assembling components into a working system, running experiments, and debugging hardware".

Table 5 lists the distribution of responses to the prior experience prompt by gender. The totals in the bottom row show that a majority of the respondents (70 to 46) did *not* have significant prior experience with the type of hands-on work used in our FE courses. Examining the rows for male and female respondents shows that a greater proportion of females (75%) than males (47%) reported no prior hands-on experience.

If the "Do not say" category of gender is excluded, a Wilcoxon rank sum test applied to the hypothesis H_0: "there is no gender difference in the degree of self-reported prior experience" gives $p = 0.005$ meaning that the observed difference in distribution of responses is unlikely to have occurred by chance. Alternative tests performed with the `assocstats` function in the `vcd` package[8] yield a Likelihood ratio χ^2 with $p = 0.073$ and Pearson χ^2 with $p = 0.076$. The tests with `assocstats` are appropriate for the categorical data of the Likert scale. These more conservative null hypothesis tests still indicate an important, though marginally statistically significant, difference in prior hands-on experience for females compared to males.

The gender difference in prior hands-on experience is especially interesting when responses to other survey items about hands-on learning are considered. The only other survey item (besides the previously discussed item on prior experience) in the set of 8 hands-on items where males were different than females, was in response to the prompt

> Relative to lecture and other modes of teaching, there was too much hands-on work during class time.

Overall, respondents disagreed with the statement by 5.6 to 1. Males disagreed by a ratio of 4.5 to 1, whereas no females agreed with the statement (a disagreement ratio of ∞ to 1). In simple

Table 6: Responses to the prompt, 'If the Freshman Engineering sequence was an elective, would you recommend that a friend take it?' Table on the left has data for all survey respondents. Table on the right has data for only ME majors.

All respondents

	NA	Yes	No	Total
Male	2	78	22	102
Female	1	20	3	24
Do not say	0	5	2	7
Total	3	103	27	133

ME majors only

	Yes	No	Total
Male	72	19	91
Female	18	2	20
Total	90	21	111

terms: although females reported less prior hands-on experience than males, none of the females thought that there was too-much hands-on work in the class.

Would you recommend Freshman Engineering to a friend?

At the end of the survey, students were asked,

> *If the Freshman Engineering sequence was an elective, would you recommend that a friend take it?*

Table 6 lists the responses to this prompt organized by two groups of survey respondents. The left table summarizes the response data for all survey participants. The right table summarizes the response data only for ME majors. For all survey respondents, there is a strong, $103/27 = 3.8$, ratio of positive to negative recommendations to a hypothetical friend. The overall ratio for ME majors is slightly stronger, $90/21 = 4.3$.

For males, the odds of recommending FE as an elective is slightly higher for ME majors (3.8:1) than for all survey respondents (3.5:1). There is a larger difference in recommendation (for smaller sample size) for female ME majors (9:1) compared to female non-majors (6.7:1). However, the difference in ratios of yes/no recommendations for males and females is not statistically significant ($p = 0.9$, Fisher's exact test).

Discussion

After six years of implementing a challenging and resource-intensive curriculum for first-year engineering students, we surveyed students to learn how they experienced the program. The response rate of 21% of the total pool of FE alumni cautions against drawing firm conclusions for the pool as a whole. We cannot rule out a non-response bias that could occur if alumni who did not respond have significantly different opinions than those who did respond. However, the survey responses are consistent with years of observation and other forms of feedback from students.

The students who responded to the survey have overwhelmingly positive opinions about the FE course sequence. Despite the strong overall positive response in the survey results presented here, a small number survey respondents gave very negative responses to the core Likert scale items and in comments in the free-response items.

We now turn to the larger questions raised in the *Methods and Research Questions* section. Are students motivated by, or are they discouraged by, the fast pace and challenging projects? Do students find the emphasis on hands-on learning conducive to learning? Do students gain confidence in their engineering and problem-solving abilities by taking these classes? Do students become clear about whether engineering, and Mechanical Engineering in particular, is a desirable career? The survey responses give strong answers of "yes" to each of these questions. The top three survey responses ranked by highest Agree/Disagree ratios are related to the hands-on experiences integrated into the courses.

- The hands-on work increased my interest in Mechanical Engineering. Agree:Disagree =19.7:1
- The hands-on work increased my confidence that I can be successful in an engineering or related technical career. Agree:Disagree =17.5:1
- Other ME classes should use more hands-on learning techniques like those used in the ME FE sequence. Agree:Disagree =16.3:1.

Therefore, the hands-on project work has a strong positive impact on the student engagement and learning, which is consistent with the research literature. (See, e.g. Prince[17], and Freeman et. al[18]). Responses related to whether students are encouraged or discouraged from continuing in engineering are also strongly positive.

- As a result of taking courses in the ME freshman engineering sequence, I became more confident in my ability to solve engineering problems. Agree:Disagree =9.5:1
- As a result of taking courses in the ME freshman engineering sequence, I became certain that ME is a good career choice for me. Agree:Disagree =5.6:1
- As a result of taking courses in the ME freshman engineering sequence, I became more interested in taking mechanical engineering courses. Agree:Disagree =4.8:1

Although there is strong student support for the FE course sequence, the program is not without its external and internal challenges. The largest external challenge is the integration of transfer students who do not have the same FE curriculum. We have worked with community college partners who have responded positively by embracing parts of our FE courses. Local community colleges have resource constraints and mixed enrollments that make a wholesale switch to a LWTL-based curriculum difficult. For transfer students we offer a bridge course to in-coming Juniors who lack the foundational experience of our FE curriculum. The bridge course is required for some students as a condition of admission to the Upper Division BSME program.

The internal challenges are related to the effort required to offer the FE curriculum and the lack of universal agreement by faculty that the effort is worth the outcome. Some faculty consider the FE curriculum to be "too expensive" and therefore advocate a return a single large lecture format in order to divert instructional resources to upper division electives and graduate level classes. That

assertion by faculty was motivation for including a survey item asking students whether they would prefer a lecture-based freshman engineering course – they do not, by a 9.5:1 ratio.

Another internal challenge is the lack of continuity in the curriculum after the FE experience. After freshman year, the next substantial project-based learning experience is the senior capstone, which begins two and a half years after students complete their FE curriculum. Faculty in favor of reverting the FE class to a lecture-based experience are also resistant to including hands-on exercises and design experiences in sophomore and junior level courses. The survey results presented in this report argue for a continuation of the FE curriculum as well as expansion of hands-on and project-based learning in the Junior and Senior years. How to do that given resource constraints and faculty resistance to change is an ongoing engineering design problem.

Future directions

The survey provides a retrospective view on student experiences. New questions are inspired by the survey data.

- What are the longitudinal gains or changes experienced by students who complete the FE curriculum?
- Are transfer students who do not complete the FE curriculum less motivated, or at some disadvantage relative to students who complete the FE curriculum?
- Does the reported gain in student confidence from the FE experience persist?
- How does the rest of the BSME curriculum affect student confidence and persistence?
- What causes students who took FE to *not* pursue a BSME?
- Do the positive responses in the survey mask other trends that could be uncovered by alternative research techniques such as focus groups or interviews?

We have abundant anecdotal evidence that students carry their FE experience forward into their other classes. The most clear examples of this affect show up in the senior capstone courses where FE alumni tend to implement bolder and more sophisticated design solutions.

Some of the outstanding questions can be addressed as we analyze the free-text responses collected as part of the survey. Some of these questions will require additional inquiry outside of the FE course experience. For example, we are analyzing student transcript data in an attempt to reveal longitudinal patterns. There will always be opportunity for additional research toward continuous improvement of the BSME curriculum.

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Appendix: Full text of survey prompts

The following tables list the abbreviated versions and the full text prompts for all survey items. The item prompts are presented in groups so that the text fits better on the pages. The grouping also reveals patterns in prompts. Although presented in groups, the prompts are given in the order presented to the survey takers. Note that Tables 10, 11, and 12 contain preamble text in the table captions. The preambles were presented as an introduction to the respective group of Likert scale items.

The tables of prompts have the same column headings. The first column is "Q #", which is the item label assigned by the Qualtrics software. Those item labels are also tags for identifying and selecting items in the `R` code used for statistical analysis, but otherwise the item label is not significant. The second column labeled "Rev." is a 1 or 0 depending on whether the prompt text was positively worded ($\mathrm{Rev.} = 0$) or negatively worded ($\mathrm{Rev.} = 1$). The second-to-last column is the short text version of the prompt used in plot and table labels in this report. The last column is the full text of the prompt as presented by the Qualtrics software.

Table 7: Shorthand and full text of item prompts used to elicit information about participation in the FE curriculum.

Q #	Rev.	Short text	Full text
Q2.2	0	Which terms did you take FE?	Which academic year (or terms) did you enroll in the ME Freshman Engineering Sequence?
Q2.3	0	How many FE courses did you take?	How many courses in the three-course sequence did you complete? Please select only one value.
Q2.4	0	How many instructors did you have?	If you took more than one course in the sequence, how many different instructors did you have?
Q2.5	0	Were differences in instructors important?	If you had more than one instructor, how important were any differences between the instructors?

Table 8: Shorthand and full text of item prompts used to elicit demographics information of survey respondents.

Q #	Rev.	Short text	Full text
Q2.6	0	What is your current academic major?	What is your current academic major?
Q2.7	0	Since taking the FE sequence, have you graduated with a BA/BS?	After taking the Freshman Engineering sequence, have you graduated with a BA/BS?
Q2.8	0	What was the academic major for your degree?	If you answered ”yes” to the preceding question, what was the academic major for your degree?
Q2.9	0	What is your gender?	What is your gender?

Table 9: Shorthand and full text of item prompts for students to list three words that describe their experience in the freshman engineering sequence.

Q #	Rev.	Short text	Full text
Q2.10_1_TEXT	0	First of 3 words to describe FE courses	What three words describe your experiences in the ME FE Courses?
Q2.10_2_TEXT	0	Second of 3 words to describe FE courses	What three words describe your experiences in the ME FE Courses?
Q2.10_3_TEXT	0	Third of 3 words to describe FE courses	What three words describe your experiences in the ME FE Courses?

Table 10: Shorthand and full text prompts for the core items dealing with overall student opinion of the freshman engineering curriculum. **Preamble to prompts:** Based on your experience in the ME freshman engineering course sequence, please indicate your degree of agreement with each of the phrases in the left-most column. The phrases complete the sentence, 'As a result of taking courses in the ME freshman engineering sequence. . . '

Q #	Rev.	Short text	Full text
Q3.1_1	0	I became more interested in taking mechanical engineering courses.	As a result of taking courses in the ME freshman engineering sequence, I became more interested in taking mechanical engineering courses.
Q3.1_2	0	I became more confident in my ability to solve engineering problems	As a result of taking courses in the ME freshman engineering sequence, I became more confident in my ability to solve engineering problems
Q3.1_3	0	I became certain that ME is a good career choice for me	As a result of taking courses in the ME freshman engineering sequence, I became certain that mechanical engineering is a good career choice for me.
Q3.1_4	1	I became certain that some other form of engineering, not ME, is a good career choice for me.	As a result of taking courses in the ME freshman engineering sequence, I became certain that some other form of engineering, not mechanical engineering, is a good career choice for me.
Q3.1_5	1	I became certain that a major other than engineering or computer science would be better for me.	As a result of taking courses in the ME freshman engineering sequence, I became certain that a non-engineering or non-computer science major would be a better choice for me.

Table 11: Shorthand and full text prompts for the core items dealing with the use of hands-on activities in the FE curriculum. **Preamble to prompts:** The ME freshman engineering course sequence involves a lot of hands-on work: building circuits, fabricating mechanical components, assembling components into a working system, running experiments, and debugging hardware. Based on your experience with hands-on work in the ME freshman engineering course sequence, please indicate your degree of agreement with each of the statements in the left-most column.

Q #	Rev.	Short text	Full text
Q4.1_1	0	Before starting the ME FE sequence, I had significant prior experience with hands-on work.	Before starting the ME freshman course sequence, I had significant prior experience with this type of hands-on work.
Q4.1_2	0	The hands-on work was appropriate for the learning objectives of the courses.	The hands-on work in the course sequence was appropriate for the learning objectives of the courses.
Q4.1_3	0	The hands-on work in the class helped me learn the class material.	The hands-on work in the class helped me learn the class material.
Q4.1_4	1	Relative to lecture and other modes of teaching, there was too much hands-on work during class time.	Relative to lecture and other modes of teaching in the class sequence, there was too much hands-on work during class time.
Q4.1_5	1	Doing hands-on work during class time should be replaced with conventional lecture and a lab supervised by a TA.	Doing hands-on work during class time should be replaced with a conventional lecture and separate lab time supervised by a Teaching Assistant.
Q4.1_6	0	The hands-on work made the course more challenging than a conventional, lecture-based class.	The hands-on work made the course more challenging than a conventional, lecture-based class.
Q4.1_7	0	The hands-on work increased my interest in ME.	The hands-on work increased my interest in mechanical engineering.
Q4.1_8	0	The hands-on work increased my confidence that I can be successful in an engineering or related technical career.	The hands-on work increased my confidence that I can be successful in an engineering or related technical career.

Table 12: Shorthand and full text prompts for the core items dealing with the relationship of the FE curriculum to the BSME program. **Preamble to prompts:** We are interested whether, and to what degree, the ME freshman engineering sequence had a lasting impact on your learning. We are also interested in your opinion of whether we should apply the style of teaching used in the freshman engineering sequence to other courses in the BSME curriculum. Based on your experience in the ME freshman engineering course sequence, please indicate your degree of agreement with each of the statements in the left-most column.

Q #	Rev.	Short text	Full text
Q5.1_1	0	The ME freshman course sequence helped me be successful in other engineering classes I have taken.	The ME freshman course sequence helped me be successful in other engineering classes I have taken.
Q5.1_2	0	I learned useful skills in the ME freshman course sequence.	I learned useful skills in the ME freshman course sequence.
Q5.1_3	1	I have not retained anything that I learned in the ME FE sequence.	I have not retained anything that I learned in the ME freshman engineering sequence.
Q5.1_4	0	Other ME classes have built upon and used what I learned in the ME FE sequence.	Other ME classes have built upon and used what I learned in the ME freshman engineering sequence.
Q5.1_5	1	I learn more effectively in traditional lecture format classes than the hands-on learning format used in the ME FE sequence.	I learn more effectively in traditional lecture format classes than the hands-on learning format used in the ME freshman engineering sequence.
Q5.1_6	1	The ME freshman engineering sequence should use a traditional lecture format.	The ME freshman engineering sequence should use a traditional lecture format.
Q5.1_7	0	Other ME classes should use more hands-on learning techniques like those used in the ME FE sequence.	Other ME classes should use more hands-on learning techniques like those used in the ME freshman engineering sequence.

Table 13: Shorthand and full text prompts for the closing group of items on the survey.

Q #	Rev.	Short text	Full text
Q6.1	0	Prior to this survey, when was the last time you thought about your FE experience?	Prior to receiving the email invitation to this survey, approximately when was the last time you thought about your freshman engineering experience?
Q6.2	0	What else should the MME faculty know about your experiences in this course sequence?	What else should the MME faculty know about your experiences in this course sequence? (Free text response.)
Q6.3	0	What else should MME faculty know about other courses in the BSME curriculum?	What else should MME faculty know about other courses in the BSME curriculum? (Free text response.)
Q6.4	0	If the FE sequence was an elective, would you recommend that a friend take it?	If the Freshman Engineering sequence was an elective, would you recommend that a friend take it?
Q6.5	0	Why or why not would you recommend the ME FE sequence	Following up on the previous question, why or why not would you recommend the ME Freshman Engineering classes to a friend?