

Measuring the Effects of Pre-College Engineering, Year 3

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Abstract

With the increased national focus on STEM education, many states now including engineering as part of their education standards for both students and teachers, and the popularity of co-curricular and extracurricular engineering activities, young people have unprecedented ability to explore engineering prior to matriculation in a university engineering program. This study uses a mixed-methods exploratory approach to examine how exposure to pre-college engineering programs affects the experiences of university engineering students. Conducting and analyzing phenomenographic interviews with cohorts of first year engineering students yielded five qualitatively different ways undergraduate engineering students experience the transition from pre-college to university engineering: Foreclosure, Frustration, Tedium, Connection, and Engaging Others.

Utilizing the results of these interviews, we developed a quantitative instrument to explore the relationship between pre-college engineering participation and students' transitions into first-year engineering programs at a larger scale. Results of the administration of a pilot version showed high overall reliability for the instrument as a whole, as well as high reliability for sets of items associated with the different ways of experiencing the transition from pre-college to university engineering.

The results of this research will help engineering administrators, instructors and designers of undergraduate and pre-college curricula adapt to students' changing needs and abilities as a result of their increased experience with engineering prior to university.

Background

With the recent national focus on improving and increasing access to STEM education, many K-12 students now have the opportunity to study and experience engineering in many different contexts prior to matriculation in a university engineering program. With the growing inclusion of engineering content in many states education standards^{1,2} and the inclusion of significant engineering learning outcomes in the Next Generation Science Standards³, engineering is increasingly becoming a formal part of the K-12 curriculum. In addition to the incorporation of engineering in mathematics and science classes, standalone pre-college engineering classes such as those developed by Project Lead The Way (PLTW), the International Technology and Engineering Education Association (ITEEA) and others have also seen tremendous growth that has resulted in more opportunities for students to study engineering and do design projects at the middle and high school^{4,5}. These initiatives reach even the youngest students, with curricula and professional development programs like Engineering is Elementary (EiE) working to increase the presence of engineering in the elementary classroom⁶. As a result of these initiatives, students are much more likely to encounter engineering as part of their pre-college studies.

In addition to formal learning within the classroom, numerous opportunities exist for students to learn about engineering in informal learning environments. These include extracurricular programs such as robotics competitions or after school engineering clubs, engineering-focused

summer camps, and university sponsored pre-college engineering outreach programs designed to engage students and encourage them to pursue further study in engineering^{7,8}. Other ways students can be exposed to engineering prior to university include internships at engineering companies and school or community-based maker spaces.

Despite the growth of formal and informal pre-college engineering learning opportunities, relatively little is known about undergraduate engineering students' overall participation in these experiences or how they affect their pursuit of an engineering degree. Research on individual programs such as Project Lead The Way⁴ and FIRST Robotics⁹ suggests that students who participate in these programs tend to pursue engineering degrees at higher rates than students who have not participated in pre-college engineering programs, although establishing causal relationships has proven challenging with this work. Participation can positively affect students' transitions from secondary education to undergraduate engineering programs by helping students develop a stronger identity as an engineer and increasing their comfort working as a member of a team to solve open-ended design problems¹⁰. They also have the potential to negatively affect students' transitions to university engineering programs by creating unrealistic expectations about the content of university engineering courses and the level of mathematic and scientific ability necessary to be successful in most engineering programs¹⁰.

This project seeks to address these issues through a mixed-methods research approach. Phenomenographic interviews with first-year engineering students resulted in the development of a theoretical framework identifying five distinct ways students experience the transition from pre-college to university engineering programs. These results were used to develop a quantitative research instrument that has been successfully piloted at two institutions, and will be distributed to first-year engineering students at multiple institutions in the spring of 2016 to better understand how pre-college engineering programs and activities influence the experiences of students in first-year engineering programs.

Summary of Work Completed Over the Past Year

Major work completed over the past year included an analysis of the relationship between pre-college engineering participation and students' grades in their First-Year Engineering courses, a large scale survey of First-Year Engineering Students pre-college engineering experiences and differences in participation between different engineering majors, and the development of a quantitative instrument to assess students' experiences of the transition from pre-college to first-year engineering programs. Brief summaries of each of these findings (several of which have been published in earlier conference proceedings) are presented in the following sections.

Effects of Participation in Pre-College Engineering Activities on First-Year Engineering Achievement

In 2013, a cohort of 229 first-year engineering students at Purdue University completed a survey on their pre-college experiences, along with consent to access their academic records to explore the relationship between pre-college participation and their university grades. Table 1 shows the relationships between the context of pre-college engineering participation and students' grades in their first two engineering and mathematics classes at Purdue University. T-tests on these data

showed no significant differences between students who had participated in various types of pre-college engineering activities and students who had not.

Table 1: Differences in mean first-year course grades by context of pre-college engineering participation
Course Mean Grades and Sample Sizes

Context		%	ENGR 1	ENGR 2	Math 1	Math 2
Elementary School	Y	4.4	3.50 (10)	3.00 (10)	3.00 (9)	2.30 (10)
	N	95.6	3.67 (219)	3.11 (200)	2.78 (199)	2.57 (198)
Middle School	Y	18.3	3.62 (42)	3.15 (40)	2.92 (37)	2.50 (41)
	N	81.7	3.67 (187)	3.09 (170)	2.76 (171)	2.57 (167)
High School	Y	66.8	3.65 (153)	3.14 (142)	2.84 (141)	2.57 (139)
	N	33.2	3.67 (76)	3.03 (68)	2.66 (67)	2.55 (69)
Extracurricular	Y	32.3	3.57 (74)	3.04 (69)	2.79 (69)	2.47 (69)
	N	67.7	3.70 (155)	3.13 (141)	2.78 (139)	2.60 (139)
Summer Camp	Y	17.5	3.55 (40)	3.23 (35)	2.59 (38)	2.60 (36)
	N	82.5	3.68 (189)	3.08 (175)	2.83 (170)	2.55 (172)
University Program	Y	14.8	3.65 (34)	3.07 (28)	2.63 (29)	2.53 (29)
	N	85.2	3.66 (195)	3.11 (182)	2.81 (179)	2.57 (179)
Other	Y	16.6	3.58 (38)	3.14 (35)	2.63 (31)	2.74 (36)
	N	83.4	3.68 (191)	3.10 (175)	2.81 (177)	2.52 (172)

Mean (Sample Size); No differences significant

Similarly, Table 2 shows differences in mean first-year engineering and mathematics courses broken down by the number of engineering activities students participated in prior to attending university. Again, the differences between students who had participated in pre-college engineering and those who had not were small, and no differences were significant based on T-tests comparing the means.

Table 2: Differences in mean first-year course grades by amount of pre-college engineering participation
Course Mean Grades and Sample Sizes

Participation		ENGR 1	ENGR 2	Math 1	Math 2
1 or more activities	Y	3.65 (178)	3.10 (163)	2.79 (160)	2.55 (164)
	N	3.69 (51)	3.11 (47)	2.76 (48)	2.60 (44)
2 or more activities	Y	3.60 (118)	3.16 (108)	2.82 (106)	2.57 (108)
	N	3.72 (111)	3.05 (102)	2.75 (102)	2.55 (100)
3 or more activities	Y	3.61 (70)	3.22 (65)	2.70 (63)	2.50 (66)
	N	3.68 (159)	3.06 (145)	2.82 (145)	2.59 (142)
4 or more activities	Y	3.59 (39)	3.25 (36)	2.63 (34)	2.38 (38)
	N	3.67 (190)	3.07 (174)	2.82 (174)	2.60 (170)

Mean (Sample Size); No differences significant

Although these initial analyses do not demonstrate significant differences between students who have participated in pre-college engineering experiences and those who had not, we are continuing to track these students as they enter into the disciplinary engineering programs and will be exploring the relationship between pre-college engineering participation and students' persistence in earning their chosen engineering degrees.

Variation in Pre-College Participation between Engineering Majors

A second study conducted this year for this project involved a brief survey of all First-Year Engineering students at Purdue University that asked for their first choice of engineering major and their exposure to pre-college engineering across nine different contexts. The contexts were elementary school class, middle school engineering class, engineering within a middle school mathematics or science class, high school engineering class, engineering within a high school mathematics or science class, extracurricular activity, university-sponsored pre-college engineering activity, and other. For each of the contexts, students chose one of the following levels of participation: no exposure, minimal exposure, one project or class, two projects or classes, three projects or classes, and four or more projects or classes.

A total of 1576 students completed the survey, and of these respondents 1227 or approximately 78% indicated at least one context where they had more than minimal exposure to engineering prior to attending university. Comparing the mean levels of participation for each major to the population mean showed wide variation between the majors. Civil, nuclear, and electrical and computer engineering had the highest rates of pre-college engineering participation, while environmental, chemical, and those intending to leave engineering after the first year had the lowest rates of pre-college engineering participation. These data suggest that either pre-college engineering experiences may influence students' choice of major, or that students tend to self select into pre-college engineering activities based on their interests which are in turn related to their choice of engineering major.

Development of Quantitative Instrument

In the first phase of this project, completed last year, phenomenographic interviews with first-year engineering students explored how their experiences with engineering prior to university influenced their transitions to first-year engineering. Analysis of these data resulted in the development of a theoretical framework identifying five distinct ways of experiencing the transition from pre-college to first-year engineering shown in Figure 1.

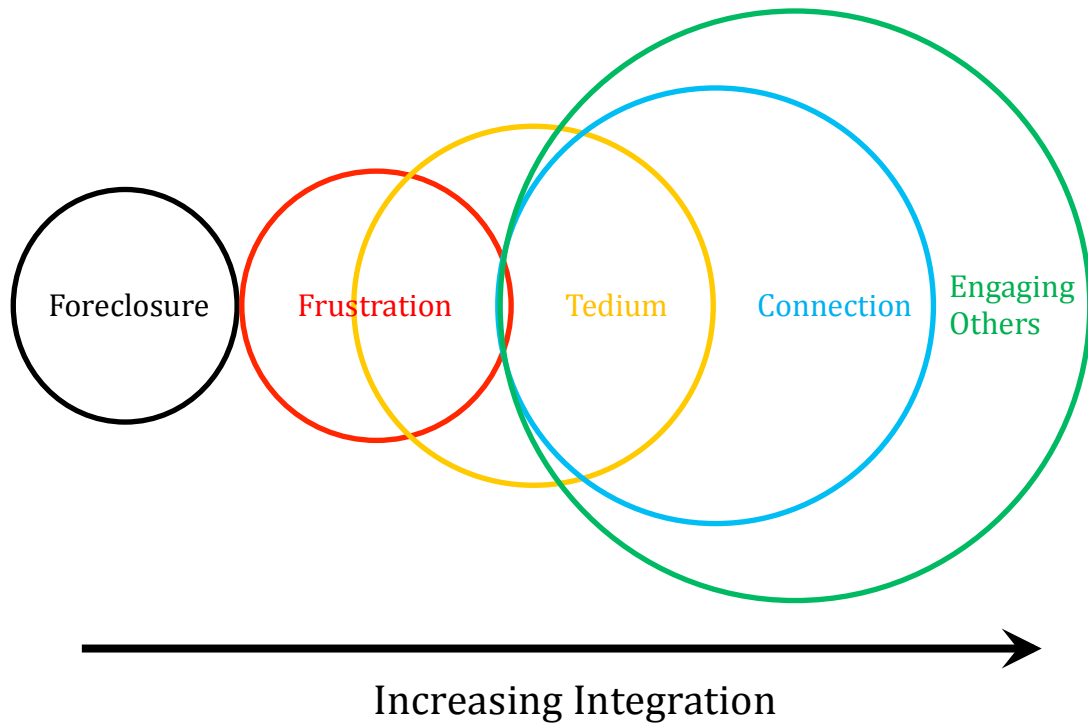


Figure 1: Phenomenographic outcome space of ways of experiencing the transition from pre-college to first-year engineering.

Over the past year, these qualitative results were utilized to develop a survey instrument to allow for the collection of quantitative data from a larger sample of students. This involved creating Likert-style survey items based on the qualitative data, using the statements provided by the students whose experiences informed the qualitative results to create items for the instrument. The instrument was validated by expert review, where multiple individuals with knowledge of pre-college and/or first-year engineering programs provided feedback on the initial instrument. A pilot version of the instrument was administered using the Qualtrics online survey tool to students at both Boise State University (N=152) and Purdue University (N=127). The survey items and associated mean and standard deviation for each item at each of the two institutions grouped by construct is shown in Table 3.

Table 3: Initial instrument items, means, and standard deviations.

	Boise State		Purdue	
	Mean	SD	Mean	SD
Foreclosure				
1. I chose engineering as a major because I didn't know what else to do	2.09	1.03	2.20	1.11
2. I feel trapped in engineering	2.27	1.04	2.08	0.91
3. I'd rather be studying something besides engineering	2.14	1.02	2.26	1.03
4. I majored in engineering because I was expected to	2.38	1.20	2.48	1.05
5. I've never considered majoring in anything other than engineering	2.65	1.30	2.70	1.28
6. I am mostly studying engineering because of the influence of other people	2.70	1.00	2.70	1.04

Frustration

1.	I am struggling academically in my university engineering program	2.49	1.02	2.31	0.92
2.	If I didn't participate in pre-college engineering programs, I probably wouldn't be in engineering right now	2.87	1.16	2.28	0.98
3.	University engineering courses are less welcoming than my pre-college engineering experiences	2.78	0.89	2.71	0.93
4.	The pre-college engineering activities I participated in were more like real engineering than what I am doing now in university engineering	2.80	1.02	2.87	1.18
5.	My experiences with engineering prior to university taught me what to expect in a university engineering curriculum	2.86	1.00	2.89	1.01
6.	I am frustrated by the lack of hands-on projects and activities in my engineering courses	2.80	0.95	3.11	0.99
7.	I felt a stronger sense of connection to my teammates or classmates in my pre-college engineering experiences than in my college engineering classes	3.13	1.05	2.94	1.06
8.	My pre-college engineering projects were more exciting than the projects I have done so far at the university	2.93	1.05	3.23	1.16
9.	I have sought out other opportunities to do engineering at the university or in the community outside of my engineering courses	3.11	0.99	3.09	1.01
10.	Participation in pre-college engineering programs has helped me to overcome frustration that I have experienced in my university engineering program	3.13	0.97	3.10	0.93
11.	I think that my university engineering classes are weed-out classes	3.00	1.04	3.26	1.14
12.	Based on my pre-college engineering experiences, I thought engineering in college would be more hands-on	3.02	0.99	3.41	1.02
13.	The engineering I am doing at the university is more like the work of a practicing engineer than what I did before college	3.30	0.87	3.35	0.90
14.	I feel a strong sense of connection to my teammates or classmates in my university engineering courses	3.28	0.92	3.39	0.96
15.	I am motivated to be successful in engineering because of my experiences with engineering prior to university	3.43	0.91	3.48	0.96
16.	My experiences with engineering prior to university prepared me to understand the role and importance of science to engineering	3.43	0.96	3.53	0.93
17.	I would rather be doing things with my hands than learning theory	3.66	1.02	3.51	1.11
18.	University engineering is fun	3.74	0.95	3.43	0.98
19.	My experiences with engineering prior to university prepared me to understand the role and importance of mathematics to engineering	3.60	0.95	3.63	0.93
20.	Pre-college engineering was fun	3.65	0.96	3.61	0.98
21.	I feel like I belong in engineering	3.95	0.87	3.97	0.83
22.	I will graduate with a degree in engineering	4.17	0.93	4.37	0.76

Tedium

1.	I don't have to work as hard in university engineering classes as I did in my pre-college engineering programs and classes	2.42	0.96	2.46	1.10
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2.	My university engineering courses are less academically challenging than my pre-college engineering classes and activities	2.62	0.97	2.34	0.97
3.	My pre-college engineering programs and classes had higher expectations than my university engineering classes	2.73	0.92	2.54	1.06
4.	I am less motivated to do my university engineering projects than I was when I was working on my pre-college engineering projects	2.56	0.96	2.73	1.07
5.	I am bored relearning things that I already learned in my pre-college engineering experiences	2.73	1.08	2.82	1.12
6.	I learned most of what is being taught in my university engineering classes in my pre-college engineering classes and programs	2.81	1.07	2.79	1.06
7.	I could probably have skipped one or more of my introductory or freshman-level engineering courses because of my pre-college engineering experiences	2.76	1.14	3.16	1.25
8.	Most of my team's designs are based mostly on my ideas	3.07	0.80	2.94	0.81
9.	I tend to do most of the work on my team's engineering design projects	3.16	0.91	3.02	1.02
10.	I had more control over my pre-college engineering projects than I do over my university engineering projects	2.95	0.94	3.25	1.10
11.	My transition from pre-college to university engineering has been easy	3.16	0.99	3.34	0.99
12.	I am more comfortable than my peers solving open-ended problems that can have more than one right answer	3.35	0.86	3.38	0.81

Connection

1.	University engineering looks a lot like pre-college engineering	2.80	0.89	2.57	0.99
2.	Engineering design in my university courses is similar to the engineering design that I did in my pre-college engineering classes and activities	2.91	0.90	2.87	0.97
3.	My pre-college engineering classes and activities prepared me for the challenges of studying engineering at the university	3.11	1.00	3.20	1.04
4.	I am better prepared for university engineering because I participated in engineering program and activities prior to university	3.22	1.04	3.19	1.11
5.	I am confident in my ability to do engineering design in my university engineering courses because I did engineering design prior to university	3.18	0.99	3.28	1.08
6.	My pre-college engineering experiences helped me learn how to overcome the challenges I have faced in university engineering	3.30	0.91	3.22	1.01
7.	My pre-college engineering experiences gave me a bigger picture of what engineers do	3.26	1.06	3.27	1.03
8.	Learning similar content in my pre-college engineering classes and activities has helped me to be more successful in my university engineering courses	3.32	0.88	3.29	0.98
9.	My pre-college engineering experiences gave me a bigger picture of what engineering is	3.38	1.02	3.27	0.99
10.	I can solve open-ended problems with more than one right answer because I solved these kinds of problems in my pre-college engineering activities	3.37	0.95	3.39	1.02

11.	Working on an engineering team before coming to the university has helped me to work on a team as part of my university engineering classes	3.31	0.91	3.46	0.98
12.	My transition from pre-college to university engineering has been fairly smooth	3.29	0.97	3.65	0.84
13.	Taking risks is an important part of the engineering design process	3.72	0.89	3.88	0.78
14.	Failure is a normal part of the engineering design process	4.11	0.77	4.06	0.82

Engaging Others

1.	My teammates tend to look towards me for leadership	3.39	0.81	3.33	0.87
2.	My engineering team tends to work better than others that I see in this class	3.30	0.85	3.60	1.02
3.	My teammates look to me for advice and guidance when we are doing engineering design	3.52	0.81	3.52	0.76
4.	I am good at encouraging my teammates to contribute their ideas to the engineering design process	3.66	0.74	3.80	0.79
5.	Compromise is an important part of the engineering design process	3.71	0.81	3.88	0.86
6.	I am patient with other peoples' ideas, even if they're different than how I would approach a problem	3.83	0.82	3.77	0.84
7.	I incorporate ideas and feedback from my teammates when we are working on an engineering design problem	3.82	0.87	3.86	0.72
8.	I like helping other people on my team to be successful	4.06	0.75	3.94	0.69
9.	I am comfortable working with people who are different than me	4.04	0.89	4.01	0.83
10.	It's useful to have multiple perspectives/lots of peoples' ideas when doing engineering design	4.12	0.93	4.18	0.71
11.	It's important to listen to your teammates when doing engineering design	4.30	0.84	4.23	0.72

Discussion

The results shown in Table 3 suggest most of the items in the instrument are functioning fairly well. Most items have a standard deviation of approximately one on a five point scale, indicating that for most items there is sufficient variability to establish that respondents are experiencing variation across most aspects of their transitions from pre-college to university engineering. Examining these data also shows that most students do not experience the transition to university engineering as Foreclosure, with lower means across all of the items in this construct. This suggests that most of the respondents do not feel trapped in engineering or pressure to be studying engineering from external forces. Likewise, the overall higher means for Engaging Others suggest that most of the respondents recognize the value of others' contributions to the engineering design process and value working as part of a team.

When examining these results, it is interesting to note that despite significant differences both institutionally and in the first-year engineering curriculum between Purdue University and Boise State University, the means and standard deviations for most of the items are fairly similar. Purdue University is highly ranked nationally across its undergraduate engineering degree offerings, and as a result has a highly competitive admissions process and attracts top students from across the United States and around the world. Boise State University is a well-regarded

regional institution, but is nationally ranked significantly lower than Purdue University with a much less competitive admissions process. The first-year engineering curricula also vary considerably between the institutions. Purdue University has a two-semester first-year engineering sequence focused primarily on design and programming with a strong focus on developing students' ability to work on a team, while Boise State University has a single first-year engineering course with a strong focus on developing students' mathematics capabilities. Even though the institutional and student characteristics and the curricula are quite different between the two institutions, the similarities in the responses to the instrument suggest that students' experience their transitions from pre-college to university engineering in similar ways which in turn suggests that the theoretical framework developed earlier in the study can help understand students' experiences across a variety of institutions.

Future Work

As of writing, data collected from the pilot administration of the survey are being analyzed to assess the reliability of the instrument and make changes prior to distributing the survey to a larger sample of students across multiple institutions in the spring of 2016. This will include assessing the overall reliability of the instrument, the reliability of the five subscales representing the five ways of experiencing the transition from pre-college to university engineering, and identifying and removing items that reduce the reliability of this instrument. The final instrument will then be distributed to new populations of students at Boise State University and Purdue University, along with distribution to four other institutions that will contribute additional demographic, institutional, and curricular diversity. The resulting data will be used to understand students' transitions to university engineering programs, identify and explore variation in students' pre-college engineering experiences and how these experiences influence their transition to first-year engineering, and provide valuable information to both the participating institutions and the larger first-year and pre-college engineering communities to facilitate better alignment between their programs and curricula.

Publications to Date

- Salzman, N., & Ohland, M. W. (2015). Effects of Pre-College Engineering Participation on First-Year Engineering Outcomes. Presented at the 2015 IEEE Frontiers in Education Conference, El Paso.
- Salzman, N., & Ohland, M. W. (2015). Differences in Pre-College Engineering Participation Between Engineering Majors. Presented at the 7th First Year Engineering Experience (FYEE) Conference. Roanoke, VA.
- Salzman, N., Ohland, M. W., & Cardella, M. E. (2015). Measuring the Effects of Precollege Engineering Education, Year 2. Presented at the American Society for Engineering Education Annual Conference, Seattle, WA.
- Salzman, N. (2014). *A Phenomenographic Study Of Students' Experiences With Transition From Pre-College Engineering Programs To First-Year Engineering* (Doctoral dissertation). Purdue University, West Lafayette, IN.
- Salzman, N., Ohland, M. W., & Cardella, M. E. (2014). Measuring the Effects of Precollege Engineering Education. Presented at the American Society for Engineering Education Annual Conference, Indianapolis, IN.

- Salzman, N., Ohland, M. W., & Cardella, M. E. (2014). Work In Progress-A Qualitative Study of the Effects of Participation in Pre-College Engineering Programs on First-Year Engineering Students. Presented at the 2014 IEEE Frontiers in Education Conference, Madrid.
- Salzman, N., Ricco, G. D., & Ohland, M. W. (2014). Pre-College Engineering Participation Among First-Year Engineering Students. Presented at the American Society for Engineering Education Annual Conference, Indianapolis, IN.
- Salzman, N., & Ohland, M. W. (2013). Precollege Engineering Participation among First-Year Engineering Students. Presented at the 5th First Year Engineering Experience (FYEE) Conference. Pittsburg, PA.

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