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A Project-Based Cornerstone Course in Civil Engineering: Student Perceptions and Identity Development

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ABSTRACT

Our study used a natural experiment to compare a project-based cornerstone course with the traditionally-taught introductory course in civil engineering. During the study, two sections of the course were organized around an overarching project, the design of an event center, and the remaining sections used guest lectures, a textbook, and traditional laboratory activities to familiarize students with civil engineering. Students in the project-based course gained more on measures of creativity and design self-efficacy on a survey of engineering identity than traditionally-taught students. Pre/post comparisons of the project-based students confirmed gains in design self-efficacy, but indicated a decrease in mathematical self-efficacy. In interviews students indicated that they recognized and appreciated that the project-based course enabled them to do real engineering, speaking to the development of engineering identity. They expressed concerns, however, that they might not be learning de-contextualized science and mathematics, a possible explanation for the decrease in mathematics efficacy.

Key words: Project based instruction, self-efficacy, civil engineering

INTRODUCTION

As of 2013, women are still outnumbered by men in civil engineering by over 5 to 1, and the situation does not appear to be nearing gender parity. In 2012, only 19.2% of undergraduate degrees in engineering were awarded to women (National Center for Science and Engineering Statistics, 2013). At our institution, the six-year graduation rate for all students in engineering was only 56%, below the national average. In civil engineering (CE) the retention rate, particularly for women, was a major concern. In many cases students leaving the program were not required to do so for academic reasons, i.e., not because of insufficient capability or preparation. Rather, they were making a decision that another major or program was a better fit for them (Tobias, 1990; Seymour & Hewitt, 1997). They did not feel that they belonged in CE; they were not developing a professional identity as civil engineers. In alignment with other researchers, we posit that the development of engineering identity is a critical element contributing to persistence in engineering (Knight et al., 2013).

For the work we describe here, we have adopted a domain identification framework, in which students' perceptions of coursework influence their development of engineering identity and motivation, resulting in choices and effort that in turn lead to academic outcomes, such as persistence and achievement (Jones, Osborne, Paretti, & Matusovich, 2014). A strong correlation has been shown between engineering identity and retention in engineering (Tonso, 2014), particularly for women engineers (Meyers, Ohland, Pawley, Silliman & Smith, 2012; Jones, Ruff & Paretti, 2013).

In CE, the transition from freshman to sophomore year was identified as a critical point where students were lost to the program. An ongoing study of students' identification with engineering has found that it typically dips from freshman to sophomore year, although recovering in junior and senior years for students who are retained (Patrick, Borrego & Prybutok, submitted). In a survey of factors related to engineering identity, Meyers et al. (2012) found that "the difference between first-year students and all other students [i.e., those retained past the first year] was profound" (p.123), indicating the importance of identity development in the first year. Pierrakos, Beam, Constantz, Johri, and Anderson (2009) concur that "the first year is critical in educating students on the breadth of the engineering profession and what it means to be an engineer" (p.M4F-6). Faculty members hypothesized that more robust opportunities to develop identity as civil engineers in the first year might enhance retention to the sophomore year.

Orientation and student-group activities provide opportunities for students to develop an affiliation with the field and meet other engineers, but the majority of student time and energy during the first year is typically devoted to coursework, and what many students experience in courses is quite different from the work of engineering. In classes, they are developing identities as students rather than as engineers (David & Marshall, 2017). Thus, typical courses will not necessarily serve to enhance identity. In contrast, authentic engineering experiences, such as service learning courses, have been shown to attract students, women in particular, to engineering (Matusovich, Oakes & Zoltowski, 2013; Pierrakos et al., 2009). In a limited qualitative study with four students, Pierrakos et al. (2009) found that students who persisted beyond the freshman year were more likely to have had experiences that exposed them to the different kinds of things that engineers do and what it means to do engineering.

First-year design experiences, in particular, serve to enculturate students and allow them to experience engineering work. Such experiences have been shown to enhance retention in engineering. Knight, Carlson, and Sullivan (2007) report results of a large-scale longitudinal study of the retention effects of an interdisciplinary, first-year engineering projects (FYEP) course. In that course students undertake a complete design-build-test cycle to develop and deliver a prototype to potential customers.

Students who completed the FYEP course were retained at significantly higher levels than those who did not, regardless of gender or ethnicity. The expected differential benefit for students from underrepresented groups was not observed, however. Although the FYEP course enhanced retention for all student demographics measured, it did not work to close gaps. In a later study, however, Knight et al. (2013) found that engineering identity declined for students taking the FYEP course, leaving open the question of the mechanism by which it enhanced retention. The authors point out that professional identity development was not an explicit goal of the course. Indeed, given the interdisciplinary nature of the course, and non-discipline-specific nature of the projects involved, one can imagine that students might not have recognized its relationship to their intended work as engineers, pointing toward a need for first-year design experiences targeting a specific engineering discipline.

In seeking to design a first-year experience specific to CE, faculty members at our institution targeted the introductory course as an opportunity to enhance retention by allowing students to experience curriculum more representative of what they will do as engineers. This is the only course offered by the department specifically for students in their first year, the majority of first-year coursework being pre-requisite courses, such as calculus and physics. Two of the authors undertook a major redesign of the introductory course, replacing the traditional lecture and prescriptive laboratory introduction to the sub-disciplines of CE with project-based instruction (PBI) situated in a collaborative design project in an authentic context- the design of a new campus event center.

Undertaking a full engineering design specific to CE would be difficult for first-year students, who have very limited engineering training. Faculty must balance the scaffolding necessary for novice students to succeed against the goal of allowing students to undertake an authentic, open problem (Rynearson, 2015). Therefore, the course was organized around a design project, rather than a full design to specifications for a customer, striking a balance between accessibility and allowing students to experience the elements of the design process and the philosophy of design. It must be emphasized that the term design used in the context of this study does not refer to the design of an entire project and its components to produce construction drawings and specifications, or a prototype, e.g., Knight et al. (2007) or Bringardner, Georgi, and Bill (2016).

Instead, in the context of this study, the term design comprises narrowly focused, heavily scaffolded, 'benchmark lessons' (Petrosino, 2004), in which the students try to figure out the specifications of particular components to meet certain requirements, all toward the overarching goal of designing a new event center. Students were introduced to the complexities that were discounted in these exercises and were also appraised on the higher-level courses and background that they would need to accomplish similar tasks as practicing engineers. In this way, students were provided with an exposure to the design process, but also motivated for learning in further coursework. As one student put it:

> [W]hen you're doing this project, you come up with a question, and you like ask someone, but it's… "you'll learn that in this class" or "you'll learn that in that course." It's like, "Oh, so my question will be answered later." But you're getting pretty much the feel for everything now.

Such scaffolded projects are expected to provide "better understanding of project design process, teamwork, application of basic engineering knowledge, communication skills and critical thinking required for academic success" (Purasinghe, Shamma & Lum, 2013 p.4). There is, however, limited research on the effect of such a scaffolded design project experience in developing engineering identity and promoting persistence in CE, particularly with a comparison group.

In CE, we find one report of a project-based cornerstone course (Purasinghe et al., 2013). That course parallels the one studied here in many ways. Students were tasked with completing a 'preliminary design' for a water conveyance system, also situated in a realistic local context. Surveys of students and practitioners involved in the course indicated that the first-year design project helped students to understand the civil engineering profession and motivated them to continue their studies. That study was not focused on the development of engineering identity and did not provide a comparison with a matched group who were taught with a more traditional lecture/lab approach. Further, there was no disaggregation of data to determine the effect of the course design on students from underrepresented groups, such as women.

PBI more generally has been posited as a means to promote broader student identification with engineering (Prince & Felder, 2006). The American Society for Engineering Education (2012) lists offering a socially relevant curriculum and integrating projects into classes among reported best practices for student retention. This may be particularly applicable to women students. Feder (2017) argues that the "hands-on, interdisciplinary, socially conscious approach common to project-based learning seems to make engineering and other traditionally male-dominated fields more appealing to women" (p.28). This aligns with reports that one of the reasons women do not choose or persist in engineering majors is that they fail to see the social relevance of the field, particularly in introductory coursework dedicated to abstract science and mathematics (Seymour, 1995; Tsui, 2010). Feder (2017) cites evidence for a correlation between the introduction of project-based learning and closing of the gender gap in engineering at schools as diverse as Harvey Mudd College and the University of Texas at El Paso. Despite these hints at a possible role for project-based instruction in moving toward gender parity in engineering, rigorous, experimental studies of the effect of PBI, particularly disaggregated by gender, are difficult to do and rare. Reports of the success of this model are typically limited in generalizability by the lack of random (or even quasi-random) assignment to treatment and control groups.

Thus, the effect of a scaffolded first-year project-based course, on identity in particular, had not been reported. Two unique circumstances provided an opportunity at our institution to investigate this effect. First, we were able to take advantage of a natural experiment made possible by multiple sections of the introductory CE course offered every year (with separate instructors and meeting times), permitting essentially random assignment of students to either the project-based design treatment, or the standard lecture and lab version of the introductory course. Second, a number of our colleagues were engaged in a cross-sectional study of engineering identity, during which they gathered survey data using a previously developed, well studied instrument (Prybutok, Patrick, Borrego, Seepersad & Kirisits, 2016). This enabled us to access data on identity development for students in the innovative course, as well as comparison students in the traditional course. We were able to investigate effects of a first-year, project-based course broadly, and on identity development specifically. Given the concern with the participation of women in civil engineering, we sought to investigate any differential gender impacts of the intervention.

The research questions for the study include:

Research question 1: Does a project-based design course in CE help to develop engineering identity in students compared to a traditional lecture/lab introduction? Are there gender differences in the effect?

Research question 2: How do students' perceptions of a project-based cornerstone course in CE differ from their perceptions of traditional courses?

The second research question was designed to look for other, broader, effects of the PBI course, but also with the intention of possibly shedding light on the mechanisms by which the course might affect the development of students' identity as civil engineers.

IMPLEMENTATION CONTEXT

The Department of Civil, Architectural, and Environmental Engineering at our institution is housed within the school of engineering. The department has 50 faculty members and more than

900 students enrolled in its BS, MS, and PhD programs. Civil Engineering Systems is the introductory course all CE majors take within their first year in the bachelor's degree program here. This course covers topics including an overview of civil engineering, an introduction to its sub-disciplines (construction, environmental, geotechnical, structural, transportation, water resources), as well as surveying, technical communication, ethics, and sustainability. It was selected as an appropriate venue in which to introduce PBI as it involved all the sub-disciplines within CE, and addressed the desire to give students a better appreciation of the 'design' aspect of engineering early on and provide context and motivation for challenging future coursework.

The traditional version of the course was designed to provide an overview of civil engineering (5 lectures), the history of the field (1 lecture), sub-disciplines (structural, environmental, transportation, water resources, geothermal) of civil engineering (1 lecture each), surveying (6 lectures), ethics (5 lectures), and sustainability (1 lecture). Lectures on the sub-disciplines were provided by guest lecturers from the various sub-fields. Lectures were complemented by once-weekly lab sessions covering the use of Excel (1 lab), beam bending (1 lab), Weir flow (1 lab), measuring dissolved oxygen (1 lab), surveying (4 labs), engineering ethics (1 lab), and writing cover letters and resumes (1 lab).

DESCRIPTION OF THE INNOVATION

For the implementation of PBI described here, the course was reorganized around an overarching civil engineering project: the design of a new event center to replace the existing event center on campus (currently slated for demolition to make way for construction of teaching facilities). Students were introduced to a candidate site for the relocation and challenged to produce a design concept for a new center. To enable comparisons and judgments about possible replication, we describe the project, its deliverables, and the process developed to assess them, in detail here. Kolmos and de Graaff (2014) delineate seven elements of PBI (which they group with problem-based learning as PBL) and provide descriptors characterizing innovative, student-centered approaches aligned with this curriculum philosophy. The course design for this innovation follows these design guidelines.

Students completed five major design activities, purposefully highlighting various sub-disciplines within civil engineering, as scaffolding for a final design submission. Table 1 describes the task and deliverable for each activity. The deliverables for each of the five major activities were developed to focus on simple yet important elements that could be analyzed and/or partially designed by first-year students with no prior background in engineering. For example, students were required

Table 1. Task and deliverables for each of the five major design activities and final report in the PBI course.

Activity	Constraints	Deliverables
Activity 1: Site Selection	• Geographical location of proposed site • Building height cannot exceed 520 ft above MSL (Capitol view corridor)	• Capacity of event center • Parking plan (e.g. parking capacity and plan for overflow) • Line sketch of plot of land (event center, parking, and other planned facilities located) • Comparison of two potential site layouts
Activity 2: Water – Flood Plain and Runoff	• Geographical location of proposed site • Location of manmade structures on property • Approximate proportions of ground cover • $Q = ciA$ (water runoff) • $Q = \frac{1.49\pi^2}{128n} d^{8/3} \sqrt{S}$ (pipe flow) • Table of runoff coefficients (c) • Table of pipe material coefficients (n)	• Identification of 100-year flood plain on site and conformation of its impacts (or lack thereof) on site layout (from A1) • Calculation of runoff for a 100-year flood event • Sketch of drainage system(s) for site layout (including diameter and slopes of pipes) • Differences between two site plans from A1
Activity 3: Structure	• Developer wants “modern look” (avoid curves and arch features) • Developer is committed to innovation in construction and sustainability • Failure modes • Know qualitatively how forces are transferred	• 2D/Elevation sketch for front, side, and back of building • 3D model of building & internal frame • Novel features of building explicitly mentioned (be there eco-friendly, sustainable, or innovative) • Explanation of how load is transferred from non-structural element to structural elements to foundation • 2D sketch of one frame with qualitative sketch of loads on the frame
Activity 4: Transportation	• Beginning and ending of events are special traffic events that require a separate traffic control plan. • Construction of building will also disrupt current corridors around building. • Know how to determine lane groups and calculate green, yellow, and all-red time. • Know how to calculate uniform and incremental delay for each lane group, average delay for each approach, and average intersection delay	• Challenges of providing access to event center safely and efficiently • List of constraints in transportation plan • Stakeholders to be considered and community issues related to plan • Sketch of changes to city infrastructure (e.g. new signalized intersections, new roads, transit stops, etc.) • Calculations describing how plan is appropriate for event center at full capacity • Calculation of predicted delay at each signal (with commentary on results)
Activity 5: Geotechnical	• Size of column (A3) • $\tau = c + \sigma * tan\Phi$ (shear strength of soil) • $\tau = \gamma$d • Density and depth of layers • Column carries 25 kips • Footing must be 2 feet below ground and no more than 8x8 feet in size	• Size of footing (area needed to distribute load of column to soil beneath it) • Design of footing
Final Report	• All design constraints addressed • Format suitable for presentation to a client	• Executive Summary • Synthesis report on all 5 activities • Response to ethical challenge: plan to address bat population

to identify the 100-year flood plain on the new site and possible impacts thereof as an introduction to water resources engineering. They then produced a sketch of a drainage system for two potential site layouts, and evaluated the differences. In the process, they encountered fundamental laws governing runoff and pipe flow motivated by a 'need to know'.

Fundamentals such as systems thinking, ethics, engineering communications and sustainable development were introduced and connections were made to later coursework at each stage. Although it is typically considered a challenge to incorporate ethics into a course structure in an authentic and meaningful way (Wittig, 2013; Finelli et al., 2012), the design of the event center posed actual ethical considerations for the student teams, as any large-scale construction project likely would. Students considered five sources of ethical standards: utilitarian approach, rights approach, fairness or justice approach, common good approach, and virtue (Markkula Center for Applied Ethics, n.d.). Teams pursued different approaches to the problem of ethically treating a population of Mexican free-tailed bats living near the proposed site while honoring obligations to their firms and clients. The final project report consisted of a synthesis of these five reports, plus an executive summary and a response to the ethics challenge of a sensitive bat population near the prospective site. Students were given the opportunity to revise their previous reports and reformat the complete report to make it suitable for presentation to a client. Thus, the project-based version of the course addressed all the objectives of the standard version with the exception of surveying, which was a major emphasis in the traditional course.

Assessment of student learning is a critical element of project-based instruction (Krajcik & Blumenfeld, 2006). Student work products were reviewed and results are reported here to elucidate the range of possible outcomes in the project-based class. A team of educational researchers worked with the instructors to develop and pilot a rubric that could be used to score group artifacts (designs and problem solutions) in a consistent way. The rubric has four evaluation criteria—design elements, documentation and presentation, technical feasibility and use of engineering tools, and collaboration and contribution—and twelve quality definitions. Additionally, a scoring strategy was provided. The final version of the rubric is included in the online supplemental materials.

Although scoring rubrics do not completely eliminate variations between raters, empirical evidence indicates that a well-designed rubric can reduce the occurrences of these discrepancies (Moskal & Leydens, 2000). A consistency estimate (Stemler, 2004) was used to establish reliability of the rubric prior to the grading of the final cornerstone project. Fifteen independent raters utilized the rubric to provide feedback on several of the activities submitted by the students. Groups of 3-4 raters looked at a given set of submissions for each activity for the first three activities. The percent of agreement across groups of independent raters, activities, and evaluation criteria was used to evaluate rubric inter-rater reliability. Percent agreement across all evaluation criteria for each group of independent raters was calculated by summing the number of raters in agreement in each group, without segmenting for activity or evaluation criteria, and dividing by the maximum number of possible agreements. Averaging across all groups yielded a total percentage of raters in agreement across all groups, activities, and evaluation criteria of 82.5%, well above the minimum 70% recommended in the literature (Jonsson & Svingby, 2007).

Teaching assistants and the two course instructors then assigned scores to all student work products, using the same rubric. Student teams were given the opportunity to revise all work products based on self-evaluation with the rubric and instructor feedback. The initial submissions were given considerably less weight in the final grade than the revised submissions in the final report. The group grades for the project had a range of 63%–95%, with a mean of 89%. Examples of student work products can be found in the online supplemental materials.

The innovation was piloted to 32 students in the introductory CE class taught by two faculty members (one assistant professor and one associate professor), aided by three teaching assistants. Students were divided into eight groups, which acted as consulting firms with names they choose themselves. All assignments were in the form of reports to clients. The students were 41% female and 59% male; approximately 36% were Hispanic, 25% White, 18% Asian, 3% African-American and 18% self-classified as 'other.' The class met for two 1-hour lectures and one 3-hour session dedicated to work time for the project (the designated 'laboratory' time) per week, over the course of a 15-week semester.

RESEARCH DESIGN

To answer the first research question, the authors took advantage of the natural experiment made possible by the multiple offerings of the course during the period of the study, as well as the concurrent cross-sectional study of engineering identity (Patrick, Borrego & Prybutok, submitted). During the first semester, all students were taught by the same instructor (with additional guest lecturers) in one lecture section with multiple lab sections, using traditional instruction. Couse materials were collected and lecture sections were observed. An assessment of engineering identity was administered to all students (N = 69) at the beginning of the semester. Additional detail about the survey and its development can be found in Prybutok et al. (2016). In the same semester, this survey was also administered to traditionally-taught CE students at other stages in their degree program, as part of the large-scale cross-sectional study.

In the second semester, approximately 1/3 of the students in the introductory course (enrolled in two sections) were taught using PBI, while the rest were taught in the traditional lecture and lab format (enrolled in four sections). The two PBI sections were co-taught by two instructors, who took responsibility for different segments of the curriculum. No announcement was made of the difference between the sections, and course instructor names are often not identified at the time of registration, so students self-selected into the project-based vs. the traditional sections on an essentially random basis, typically based on scheduling constraints imposed by other classes.

The same assessment of engineering identity administered to traditionally-taught students in the previous semester was administered to all students in the project-based sections both at the start of the semester and the end of the course (N = 28). Of course, the fact that the project-based and traditional instruction was delivered to different students in different semesters is a limitation of our study. To ensure that the two groups were comparable, we compared student characteristics of the two groups. As these were first-year students, for whom GPA would not yet be a valid indicator, SAT/ACT scores, required for admission, were compared and not found to be significantly different between the two groups. No significant demographic differences were identified.

Based on prior exploratory factor analysis of previous responses to the instrument (see Prybutok et al. (2016) for additional detail), seven identity subscales, three comprising multiple items from the survey and three consisting of individual items, were used as outcome variables: mathematics efficacy, interest in engineering, communication, creativity, mentor influence, design self-efficacy (DSE), and design group efficacy (DGE). A multivariate analysis of variance (MANOVA) was conducted using Stata (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP). Input variables included gender, instruction type (project-based vs. traditional) and time (pre/post instruction).

To answer the second research question and possibly gain insight into the mechanisms for effects identified with the survey data, we interviewed a subset of students from the project-based class mid semester (N = 21) and at the end of the semester (N = 19, including 18 previously interviewed and one student who was not interviewed mid-semester). Students were interviewed in their project teams about their perceptions of the course using a semi-structured protocol. Course instructors were also interviewed about their impressions of the course, and these interviews and other course artifacts (syllabus, observer reports, rubrics) were used to situate the student results.

Student interviews were recorded, transcribed, and analyzed for emergent themes, along with the other artifacts. Following a grounded process (Corbin & Strauss, 1990), two independent reviewers coded the interview transcripts and other course artifacts for themes arising naturally in the data. Codes identified in open coding were compared and merged into axial themes. All disagreements in the coding were negotiated to reach the final version reported here.

All participating students gave informed consent under an approved Institutional Review Board protocol.

RESULTS

Surveys

In the PBI section, 28 matched pre/post engineering identity surveys were collected out of 32 students enrolled. Of those, 27 students completed every item on the survey. Students who were surveyed at the beginning of the traditional introductory CE course and the beginning of a sophomore CE course the previous semester served as pre/post comparison groups experiencing traditional instruction.

The analysis of the pre-survey results (MANOVA) yielded no significant differences on any of the seven outcome variables between the group experiencing PBI and results from the traditionally taught group at the beginning of the previous semester. ($F(7,87)=1.19$, $p=.3197$). Further, there were no significant gender differences in either of the two groups (either before or after the semester).

In contrast, there were significant differences between the PBI group and the traditionally taught group on the post-survey, after the introductory course ($F(7,66)=2.31$, $p=0.0359$). Table 2 gives median Likert-scale values, on a scale from 1-5, for the each of the output variables for the two groups.

After the MANOVA showed statistically significant differences, a multivariate regression was performed to identify the variables likely to be responsible. Post-hoc t-tests showed significant differences between the two-groups, favoring PBI students, in terms of creativity ($t = 3.0471$, $dF = 74$, $p = 0.0032$) and design self-efficacy ($t = 2.2282$, $dF = 74$, $p = 0.0289$).

A repeated measures test was also done to compare the PBI students' responses on the pre-survey with responses from the same students on post-survey (immediately before and after instruction) to investigate the effect of instruction on individual students. This MANOVA showed significant

Table 2. Comparison of the composite variables for students experiencing PBI and traditional instruction after the introductory course.

	Project Based Instruction (PBI)					Traditional Instruction					
Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Sig**
Math Efficacy	29	3.97	0.63	3	5	47	4.11	0.71	3	5	n.s.
Engineering Interest	29	3.54	0.53	2.4	4	47	3.53	0.52	2.2	4	n.s.
Communication Skill	29	3.63	0.62	2.8	5	47	3.47	0.68	2	5	n.s.
Creativity	29	4.11	0.62	3	5	47	3.63	0.70	1.7	5	**
Mentor Influence	29	1.90	1.08	1	4	47	1.68	0.81	1	3	n.s.
Design Self-Efficacy	29	3.86	0.88	2	5	47	3.43	0.80	1	5	**
Design Group Efficacy	29	3.90	0.77	2	5	47	4.09	0.65	2	5	n.s.

Table 3. Pre/post comparison of mean outcome variables on a scale from 1-5 for students experiencing PBI.

	Pre					Post					
Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Sig**
Math Efficacy	27	4.43	0.62	3	5	27	4.00	0.62	3	5	**
Engineering Interest	27	3.67	0.51	2.2	4	27	3.54	0.53	2.4	4	n.s.
Communication Skill	27	3.60	0.71	2	5	27	3.65	0.61	2.8	5	n.s.
Creativity	27	4.10	0.67	2.7	5	27	4.12	0.63	3	5	n.s.
Mentor Influence	27	1.93	1.11	1	4	27	1.93	1.11	1	4	n.s.
Design Self-Efficacy	27	3.30	0.91	2	5	27	3.93	0.87	2	5	**
Design Group Efficacy	27	4.04	0.76	3	5	27	3.89	0.80	2	5	n.s.

pre/post differences ($F(7,44)=2.72$, $p=0.0195$). Again, there were no gender interaction effects. Table 3 shows the median values for each of the composite Likert-scale variables both before and after project-based instruction.

Post-hoc t-tests confirmed the significant increase in design self-efficacy scores from before to after instruction implied in the comparison of the PBI and non-PBI groups ($t = -2.5902$, $dF = 52$, $p = 0.0124$). On the other hand, there was a statistically significant *decrease* in mathematical efficacy (students' belief in their ability to do mathematics) over the course of the semester ($t = 2.5328$, $dF = 52$, $p = 0.0144$). To investigate whether a similar drop might have occurred in the traditionally-taught students' reported mathematical efficacy, a MANOVA was run comparing responses from traditionally taught students at the beginning of their freshman year (prior to the introductory course) and at the beginning of their sophomore year, after the introductory course (unmatched cross sectional sample). This test yielded no significant differences ($F(7,106)=1.28$, $p=0.2672$), implying that the drop in mathematical efficacy might be unique to the PBI students. The fact that the same traditionally-taught students were not tested before and after instruction is, however, a limitation in comparing the PBI and non-PBI groups.

Interviews

Two reviewers coded transcripts of all interviews, and negotiated disagreements to reach a consensus. Codes were then grouped together into major themes, which are reported in Table 4. The majority of the codes were positive toward PBI, but in some cases, contrasting codes arose in

Table 4. Major codes arising in reference to project-based and traditional instruction.

Code	Applied to	Exemplar
Unexpected	PBI	I was surprised because I knew people who had taken this course before, and definitely seemed a lot more, I guess, hand held, the way they did it before… So, when it actually came to like a project-based class, I was pretty excited about it… Not what I expected, but excited about it.
Boring	Traditional	I had heard that it was a lot of work, and they told me it was very boring, too. And I feel like an intro class, you should, like the purpose of you taking it is seeing, like, am I going to like civil engineering in the future? …I feel like if it was like how the other class is taught, I'd be very bored throughout it all, and I wouldn't really, it would disappoint me for the future. It would make me think, like, my life as a civil engineer was going to be very boring
Real engineering experience	PBI	[W]hen you hear about… things that civil engineers have accomplished or these are the kinds of jobs you can hold as a civil engineer, it's a lot harder to picture yourself doing it than if you're actually given a task where they tell you, "You *are* a civil engineering firm. Make us a building."
Need for career information	PBI	I wish there was, like, a little more, like, I guess teaching on the, like, subcategories of civil engineering, like, and all of the, like, specifics [inaudible] because I feel like I don't know as much as I could. We weren't tested over that stuff.
Hands on	PBI	Yeah, I didn't think it was going to be as hands on as it is. And I really like that compared to my other classes where it's a lot of, "lecture, lecture, lecture, test."
Collaboration/ Time management	PBI	I learned that you can't do it alone. That's really important. For me, like, working in a team is really an issue I have. So, I have to stop and ask everybody, like, what they think or am I missing something, are we missing something, and how can we work together to solve it.
Learning by application	PBI	[in] normal lectures, you just learn about it, then hopefully you'll remember it for the test. Here it's kind of like, learn about it, now go apply it almost immediately, so you can remember easy… how like all these things that we're learning take effect into what you're going to do.
But am I learning?	PBI	Uh, the engagement is there. Awesome questions…So all of those points are there. It's just like, I don't know if the, like, actual material is there necessarily. Because you still leave empty handed, you know. The class, like, you still feel like it was nice to go--like it's fun, it's engaging…but it's not necessarily like, "this is what I learned today," like leave with something in your hand, you know.
Basic science/ math	PBI	Well I had taken … statics, which touches on, you know, beams and stuff…But uh, [PBI class] definitely built on what I was doing ….It was comforting because it was a lot simpler, like compared to what I had to do for the [physics] class. It made me happy because, [I thought] "why is this so hard?" when I was taking that class, but then I looked at this, I'm like, "This is the easiest thing."
Open ended/ Student driven	PBI	I feel like the most valuable thing with like having a class like this, is like, having to figure out everything on your own. 'Cause like, they don't give you much guidance or instruction or, like, examples. You just have to kind of like figure it out… I've never had a class like that.
Desire for clarification	PBI	The calculations were pretty simple, but then, like, at some points, I feel like there were things that we just needed to know, that we didn't know. Like, for instance, well, like, when we're doing the calculation, we don't even know what our answer should be, like, to see if we've done it right.

regard to the very features that students found valuable. For example, students appreciated that they were learning civil engineering in an authentic context:

> So, it really helped me see what the real life problems are, and it got me thinking like a civil engineer would, which to me was really important. Because even though you're taking a math class or physics class, you never really know what you're gonna do, you're just doing problems. That's definitely not going to be the job you have.

However, they also worried that they were missing out on something, in some cases, facts to be memorized or harder, abstract mathematics and science that they felt they should be learning even though they did not see a connection to their future work. Some students were uncertain exactly what was missing, but felt that there must be something they were not learning in the absence of lectures, textbooks, and tests. These concerns were coded as, "But am I learning?" All of the groups interviewed expressed concern about this at some point:

> Everything they talk about is super interesting, and…engaging…, but I don't know how much I'm like really learning… 'cause like I don't have something to study…I feel like, maybe I would learn more with a set lesson like, I don't know.

DISCUSSION

Research question 1

Does a project-based design course in CE help to develop engineering identity in students compared to a traditional lecture/lab introduction? Are there gender differences in the effect?

Results from the surveys indicate that the project-based course appeared to promote the development of some aspects of engineering identity as compared with the traditional lecture and lab introduction. Comparison of the survey responses at the beginning of the project-based and traditional courses found no statistically significant differences in the two groups on any of the previously identified identity construct clusters of items, indicating that the two groups held comparable conceptions of themselves as engineers prior to instruction.

Design self-efficacy

The pre/post comparison, on the other hand, showed significantly higher gains in responses to the group of items representing the engineering design self-efficacy construct for PBI students than for students in the traditional version of the course. These results were corroborated by qualitative evidence from the interviews, particularly the large number of statements from interviews that coded as 'real engineering experience'. This is not surprising, as the students in the traditional class did not undergo any type of design activity, whereas the entire PBI class was organized around the event center design project. As one student eloquently put it, "when you hear about, like, these are things that civil engineers have accomplished or these are the kinds of jobs you can hold as a civil engineer, it's a lot harder to picture yourself doing it than if you're actually given a task where they tell you, 'You *are* a civil engineering firm. Make us a building'."

Meyers et al. (2012) found that students considered 'making competent design decisions' to be a key factor in self-identifying as an engineer. PBI students in this study did not complete a full or even prototype design to specifications for a customer, yet the constrained design project does seem to have increased their design self-efficacy- their perceived competence at making design decisions. This is despite the fact that they reported discomfort at being unsure "if we've done it right." Despite initially finding it 'daunting', over the course of the semester they expressed increasing comfort with the uncertainty inherent in design:

> It's kind of daunting and intimidating. [Another student] Yeah, that's like how we always start. We're like, "what do we do?" [laughter] The first time we meet, it's always like, we have no idea what we're doing. But it just kind of, like, happens. It just kind of happens.

It is interesting, however, that it was their self-efficacy, rather than 'group' efficacy (confidence in their group's ability to find a solution), that showed a significant increase in the survey results, despite the fact that the project work was accomplished entirely in teams. Social interaction is considered to be a salient feature of project-based instruction (Krajcik & Blumenfeld, 2006) and the value of 'collaboration' was identified as one of major themes in interviews. Mills and Treagust (2003) identify developing the ability to work in teams as a major affordance of project-based learning. Likewise, Knight et al. (2007) reported that students undergoing a first-year design intervention, "liked how it built teamwork among random people you really didn't know and you learned to work with them," (p.7) and the students surveyed in Meyers et al. (2012) identified "working with others to share ideas" (p.119) as a factor necessary to being considered an engineer.

Still, our survey data did not show an increase in design group-efficacy as might have been expected from the existing literature and in consonance with interview results. Some researchers do report concerns that students may resent the challenges of cooperative learning, particularly if the development of group skills is not an explicit part of the curriculum (Smith, Sheppard, Johnson & Johnson, 2005). Further study of this issue is needed to elucidate the difference between results on design self-efficacy and group-efficacy.

Creativity

Project-based learning has been shown to be associated with the development of creativity in engineering, although care must be taken that the time schedule does not serve as a barrier to group creativity (Frank, Lavy & Elata, 2003; Zhou, Kolmos & Nielsen, 2012). In our case, students appeared to be learning time management skills at the same time as they developed the creativity component of their identity as engineers. As noted above 'time management' was a code arising from interview data. Students noted that they had learned "time management… general thought-process skills." At the same time, compared with students receiving traditional instruction, survey results after the introductory project-based course were also significantly higher on the cluster of responses that comprised the 'creativity' variable. Although it did not occur in the majority of interviews, and thus did not rise to the level of a major code, 'creativity' was also a theme that arose in the interview data ("I mean, engineers create.", "I actually really do enjoy the fact that it's so free, because as an engineer, I feel that's what is gonna happen when we're out there… my dad is an engineer, and I see what he does, and it's very much like their thought process; that's why engineers put so much work into creativity"). The creative aspect of engineering became very salient for the students as they generated a concept for the event center, albeit with some constraints, essentially from their own imagination.

Math self-efficacy

In contrast to the results for design efficacy, students who experienced PBI reported a significant drop in math self-efficacy, confidence in ability to do mathematics, from the pre-course survey to the post-survey. This drop seems to reflect the concerns expressed by students in the interviews that there might be (hard) mathematics and physics that they were not learning by creating designs rather than reading books, listening to lectures, and taking tests. The mathematics and science that they found so 'hard' in other classes became much more intelligible when they encountered it in terms of an application they understood, thus invoking the affordances of situated cognition (Brown, Collins & Duiguid, 1989). Once they knew "what it meant and how we were going to use it in the project", students characterized the math as "a bit less…than I expected" and "not too difficult."

It is possible that the decontextualized mathematics they were encountering in calculus and physics classes led them to doubt their abilities, while the mathematics they successfully encountered in the project-based course was perceived as too 'basic' to convince them they were good at math. Even though students recognized that typical academic learning did not constitute an experience of real engineering ("You're just doing problems… That's definitely not going to be the job you have"), and did not relish the addition of un-engaging work, they worried that perhaps they were missing something and wouldn't mind "a few more formulas."

Impact on women students

In regard to gender, it should be noted that there was not a statistically significant difference in engineering identity going into either version of the course- and none was found at the end of either course. In terms of developing identity, each version of the course was equally effective for male and female students.

That said, the project-based version was more effective in developing engineering identity for *both* female and male students; there was, however, no enhanced benefit for women that might have served to address gender gaps in engineering as anticipated in the literature (Feder, 2017). These results parallel those of Knight et al. (2007), who found no statistically significant differential gender impact of participation in an interdisciplinary freshman design project experience, leading to the conclusion that such an approach benefits all students, regardless of gender.

Summary: Developing Engineering Identity

In summary, the project based course appeared to enhance some aspects of engineering identity development, although not all, for the PBI students. Interview data shed light on possible mechanisms for this difference. Successfully undertaking an actual civil engineering challenge gave students confidence that they could figure out "what we want to do with it *and how to do it*" without having to be told. This was true despite the fact that the design project was highly scaffolded- and possibly because of it. That students frequently referenced civil engineering, specifically, hints at a possible explanation for the differences in our results and those of studies, e.g., Knight et al. (2013), that looked for the effect of a 'generic' design experience not tailored to the students' major. Although clearly engaging enough to promote persistence (Knight et al., 2007; Jones et al. 2014), the accelerated design-build-test-deliver cycle required for a complete design-to-customer experience characteristic of some freshman design experiences may not be uniformly recognized as mirroring students' future work as engineers. Such design activities may promote persistence through other mechanisms.

In contrast, being "good at mathematics" is also often associated with engineers (National Academy of Engineering, 2008), but apparently an aspect of engineering identity that the project-based experience worked against in comparison with the traditional course. The interviews also shed light on this result. As the PBI course was carefully scaffolded to minimize the need for prerequisite mathematics, students viewed the math used to successfully complete the engineering tasks as "basic", and feared that there was (harder) mathematics that they should be learning but were not. In this sense, students in the PBI course were clearly differentiating their sense of themselves as students (learners) from their sense of themselves as engineers (doers). The fact that this perceived shortcoming in learning mathematics was made salient to students by the PBI course might have challenged their sense of math self-efficacy.

Research question 2

How do students' perceptions of a project-based cornerstone course in CE differ from their perceptions of traditional courses?

Not only did the project-based version of the course result in significant differences in participants' development of engineering identity, there were marked differences in students' perceptions of the PBI course and the traditional course as reported in the interviews.

Doing engineering vs. learning engineering

Students clearly perceived the PBI course to reflect the actual work of engineers much more than the traditional course ('real engineering experience' vs. 'lecture/textbook/test') and found it to be much more engaging and enjoyable. They went so far as to express sympathy for their colleagues taking the standard version of the course ("They were crying to me"; "it would disappoint me for the future"). On the other hand, they still worried that they were somehow not *learning* engineering, manifested primarily as (abstract) mathematics and science ('But am I learning?'). They expected to be receiving some body of information (facts, algorithms, procedures) from lectures or textbooks that they would memorize and apply in hard homework and test problems. Likewise, they did not consider being evaluated on a work product to be a fair assessment of learning as compared with a traditional test ("because I feel like I don't know as much as I could. We weren't tested over that stuff.")

In fairness to the students, it is important to recognize that there may be some merit to their concerns, given the way that knowledge is often measured in school settings. Despite overall positive reports of the effects of PBI, particularly on long-term ability to apply knowledge and solve authentic problems, there are some indications that students taught through project-based or problem-project hybrid instruction may have a "less complete mastery of engineering fundamentals" (Prince & Felder, 2006, p.131) and not perform as well on standardized tests measuring short-term acquisition of basic science knowledge (Strobel & van Barneveld, 2009). This dichotomy between the nature of knowledge in academic settings and in engineering work has been reported previously (David & Marshall, 2017) and may reflect a deep-seated epistemological stance about what it means to know something in schools vs. in engineering practice.

Open-ended/student centered vs. the need for clarification

'Open-ended' and 'student control' were major codes arising in interviews as descriptors of the PBI class ("You just have to kind of like figure it out… I've never had a class like that") as opposed to the "over guided" traditional course ("I was surprised because I knew people who had taken this course before, and it definitely seemed a lot more, I guess, hand held, the way they did it before…slightly over guided").

Most students did not value "just *look[ing] at* a piece of paper that has a list of things that you have to do and you do it" but rather appreciated "figure[ing] out what we want to do with it *and* *how to do it."* These findings mirror those of Knight et al. (2007), who likewise reported that students engaged in an interdisciplinary first-year design experience liked "that the class was student-oriented, and the professor and TAs did not tell us what to do, but helped us towards our goal" (p.7) and valued being able "to control your own project, to figure things out, open-endedness allows us to experience real engineering" (p.8).

At the same time, there was a widespread desire for more direction (clarification) and some indication of "things that we just needed to know, like... what our answer should be... to see if we've done it right." For some students, this resulted in considerable frustration:

> We were pretty frustrated with not having enough, …I don't know what was lacking, but I feel like having so much freedom… we felt like our group went and did a lot more research than was apparently necessary… We would see other groups that were just, like, picking numbers randomly out of the air and running with it, and we were, like, spending half an hour looking up the laws involved…

In the case of the group above, these concerns were eventually resolved. In end-of-semester interviews, they reported reaching a collective decision that they would take responsibility for their work (noted in Meyers et al. (2012) as a factor frequently associated with engineering identification) regardless of the course requirements:

> We discussed it, like um, how we how the group felt about it…because we thought, "well maybe …should we continue… going really deep into it and, um, really considering every aspect"… And I think we came to an agreement that, it sort of did matter, so, you know, we'll just keep doing things the way we're doing. And I think once we realized that as a group, it became a lot less tense between everybody, and, we just learned to appreciate what we were doing in the class.

Prince and Felder (2006) warn of similar resistance to PBL seen in previous studies, and advise instructors making the shift to student-directed learning that they might need to provide substantial scaffolding in terms of instructional guidance, at least until students are more comfortable with taking responsibility for their own learning. One of our students articulated it this way in her description of how the course might be improved: "be like, 'Alright, off you guys go. Make your own decisions for a little while.' And then gather everyone back. So it's like, you know, guiding the sheep, making sure everybody is actually doing what they're supposed to, but only enough to where you can still make your own decisions and have fun with it. That would be nice. So maybe a little bit more of tapered intervention." Addressing these concerns will be a long-term undertaking, requiring "a long, serious process of [systemic] change" (Kolmos & de Graaff, 2014, p.155).

CONCLUSIONS AND LIMITATIONS

Despite student concerns about learning in a traditional academic sense, we concur with Knight et al. (2007) that the benefits of project-based design experiences in the first year reported here, in terms of developing design efficacy, creativity, and providing real engineering experience, merit making project-based first-year courses more broadly available. This study adds to the body of work on engineering identity by showing that a highly-scaffolded, constrained, first-year design project in a civil engineering context can promote the development of some aspects of engineering identity, design self-efficacy and creativity in particular. In contrast to Prince and Felder (2006), who argue that such projects, which they characterize as 'task projects', are expected to provide "minimal motivation" (p.130), our students found the course "interesting" and "engaging", despite concerns about whether they were learning what they should be. It remains to be seen whether such projects result in greater retention, as projects involving a complete design-build-test cycle in which a prototype is created, possibly for a customer, have been shown to do (Knight et al., 2013).

Our results also indicate that the critical element of authenticity in the project may result from the context in which the project is situated, one in which the task is something that students might actually expect to do in their engineering careers, as opposed to the existence of an actual customer. This element of authenticity would be difficult to orchestrate in interdisciplinary courses, which is of concern given the trend toward 'generic' first-year courses for engineering students from all disciplines (perhaps even before they declare or are accepted into a major within engineering), a possibility under consideration at our own institution. Interdisciplinary courses are likely to focus on electro-mechanical design challenges due to their tractable nature within the time limitations of a standard course, and may not serve to promote identity in some disciplines.

To date, the innovation has only been applied in the semester reported in this study, and in one subsequent semester, both times with the same two co-instructors, and with a fairly small number of students. The identity survey was not administered in second implementation, as the larger study of engineering identity was no longer gathering data, but other measures, including student work products and student evaluations of course and instructor effectiveness were essentially the same between the two implementations.

The fact that the project-based and traditional courses were taught by different instructors also poses a limitation. Given the importance associated with faculty interactions in promoting persistence

(American Society for Engineering Education, 2012), it could be that the effects on engineering identity seen here are due, at least in part, to the influence of the instructors rather than the curriculum. We feel that this limitation is mitigated somewhat by the fact that multiple instructors were responsible for both courses. Students in the PBI course interacted with 'consultants' for some aspects of the design project. The guest instructors for the traditional course were selected based on their ability to connect with students and present their respective subfields of civil engineering in an engaging light. Thus, the influence of any single professor is unlikely to have been the determining factor.

Finally, the differences found here between the students experiencing project-based instruction and traditionally-taught students, although statistically significant in some cases, may not be large enough to have practical significance. In addition, the comparison group used in our assessment of the course was a cross-sectional sample, rather than a true pre/post comparison, and students in the traditional class were not interviewed for a comparison of the qualitative results. Further study with additional students in a variety of settings is required to confirm these results. It is our intention in publishing these initial findings to promote possible replication of our study at additional sites.

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