Asset-based Design Projects in a Freshman-level Course

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Asset-based design projects in a freshman level course

Abstract

This Complete Research paper describes how we identified diverse student assets and redesigned a first year course to develop professional engineering identity. Despite many efforts to diversify engineering, first-generation college attendees, non-traditional students, and students from groups typically underrepresented in engineering are still less likely to persist. We see introductory-level engineering courses as having the potential to play a critical role at universities like ours that serve a large percentage of such students. With this purpose in mind, we redesigned an introductory chemical engineering course at a research university that is minority-serving. Participants included students enrolled in two sections of the original course (n=117) and one section of the redesigned course (n=53). Data include pre/post surveys of student beliefs about design and interviews. We coded student responses and interviews to understand how they perceived the original and redesigned course. We conducted a repeated measures ANOVA to examine the effect of redesigning the course on student understanding of design as an iterative process. Students in the original course reported a neutral/unsure stance when asked if design is a linear process, and by the end of the course tended to agree that it is a linear process. In contrast, students in the redesigned course tended to begin the course reporting that design is a linear process, but shifted to a more neutral stance by the end of the course. Students in the redesigned course reported significantly more positive and also more specific reflections about the design challenges in the redesigned course. They more commonly described active roles, positioning themselves as doing engineering. We argue the design challenges provided an opportunity for students to begin developing professional engineering identities without sacrificing their existing identities.

Introduction and research purpose

This Complete Research paper describes how we identified student assets and developed community-, industry-, research-, and entrepreneurship-based design challenges that built on identified assets. We sought to support diverse students to begin developing professional engineering identity in a first year 1-credit course.

Despite many efforts to diversify engineering, first-generation college attendees, non-traditional students, and students from groups typically underrepresented in engineering are still less likely to persist. Such students are less likely to have family members who can serve as a source of information about engineering practice. Given that professional engineering identity is formed in relation to the messages students receive about engineering practices, we see introductory-level engineering courses as having the potential to play a critical role at universities like ours that serve a large percentage of such students.

Literature review

Our work to redesign the freshman course was guided by past research demonstrating the success of design projects, especially for retention of diverse students. Because service-learning design projects are particularly impactful, we sought to integrate aspects of community-engaged learning, while balancing this with feasibility and scalability. Finally, we were guided by research on identity development and its relationship to learning, both in engineering and in other fields.

Past research has revealed freshman/first-year design challenges to be an effective addition to undergraduate programs. Design projects, especially when implemented in the freshman year or in multiple courses, lead to higher overall retention of students in engineering [1-14]. Design projects lead to higher overall retention of students in engineering [1-13]. Though sample sizes were small, The University of Colorado at Boulder has shown their design-based First Year Engineering Projects course (FYEP) increased Latino/Latina student retention from 50 to 77% and African American student retention from 44 to 60% [15]. The same program increased retention of women from 53 to 67% [1].

While increasingly commonplace, many such design challenges are relatively artificial or have a single correct answer, despite evidence that authentic design problems that have meaning beyond the classroom are most effective [16]. Authentic design problems are ill-structured, meaning they have multiple satisficing solutions, and domain specific, meaning they require specific disciplinary content knowledge to be resolved [17]. This latter characteristic makes it particularly challenging to incorporate authentic design challenges into first year coursework. As a result, some have sought shorter-term conceptual design projects [18, 19].

Many universities have found success by integrating service-learning and community engaged learning projects into coursework, even at in the first year [20]. However, this approach also presents challenges. Such projects are common in low-enrollment courses at liberal arts institutions and increasingly in K12 settings [21-24], and occasionally in low enrollment first-year programs [8]. However, they are seldom used in large enrollment courses common at public universities [25]. Such projects require a great deal of oversight and effort from faculty involved, and engaging a large number of students meaningfully can be challenging. Yet the benefits of service and community-engaged learning are clear, with positive impacts on academic and social learning, as well as citizenship [26]. We sought to incorporate aspects of community-engaged learning into a large-enrollment first year engineering course by adding authentic, community-inspired and industry-inspired design challenges.

We also wanted to create early opportunities for students to try on professional engineering identities. Research has articulated double-sided connections between identity and learning: what you learn affects how you identify yourself and how others identify you, and further, how you are identified affects what you have the opportunity to learn [27-29]. For instance, earlier admission to engineering majors signals to students that they belong in engineering, and this seems to support retention [30-36]. Identity development stems from an accumulation of experiences. Course-based experiences may be more important for students who don't have other sources (e.g., friends, family members who work as engineers) of information about engineering practices, because such experiences can provide opportunities for students to try on these identities. If most of their course-based experiences are passive, or highly constrained problem sets, they won't have this opportunity. In contrast, opportunities to make design decisions can support professional engineering identity [37].

Identity development is socially negotiated [27-29], meaning students benefit from working with others on authentic and meaningful tasks and from being part of a social community of engineers

[38]. It also means that engineering identity is contextualized by students' perceptions of engineering careers and their potential contributions as engineers [39].

To guide our investigation of the changes we made as we redesigned our first-year course, we posed the following research questions:

- To what extent did students' understanding of design as an iterative rather than linear process improve, and did this change following the redesign?
- What do differences in how students perceived the original and the redesigned courses suggest about their developing engineering identities?

Methods

Setting and participants

We redesigned an introductory 1-credit chemical engineering course at a research university that is minority-serving. Participants included students enrolled in two sections of the original course (n=117, taught in Fall 2015 and Spring 2016) and one section of the redesigned course (n=53, taught in Fall 2016).

Course and instructional materials

The purpose of this course is to help students learn about the process of becoming a chemical or biological engineer, the scope of careers open to chemical or biological engineering graduates, and to introduce students to engineering design practices, laboratory safety, and professional ethics.

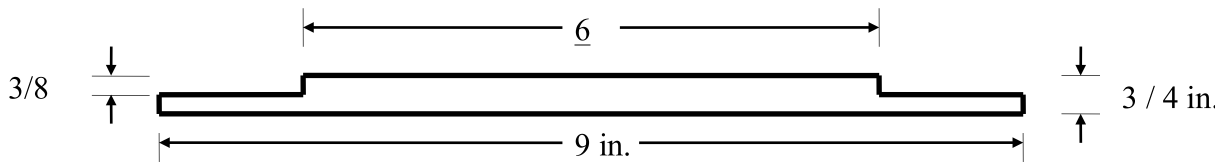
Original course. The original course included guest speaker presentations, one laboratory session paired with a redesign assignment, and a culminating design challenge. Presentations typically included a research-active faculty member presenting his or her research, though there were also visits from student organizations and advisors.

In the laboratory, students filled out a worksheet that guided them through steps on making coffee using a standard coffee maker, but at relatively high altitude. This negatively affects coffee flavor because water boils at a lower temperature. Students were then asked to propose redesigns of a coffee maker to overcome this issue. While we liked this activity because it connected to many aspects of the work chemical engineers do, we felt the students seldom saw this connection, and they rushed through the lab without really understanding it.

The culminating design challenge involved working as a team to design an edible car, with the following design requirements:

- No more than <u>8 inches</u> in length and no more than <u>3 kg</u> in total weight.
- Capable of traveling down a ramp and then along the floor as <u>far as possible</u> from the starting point (extra points if distance is greater than <u>1.5M</u>).
- The vehicle must have been stored at <u>room temperature for 24 hours</u> before its demonstration.

- The vehicle must be capable of carrying a passenger (and maintaining him/her in an upright position throughout the travel) whose dimensions will be no larger than 1.5 cm radius and 8 cm in height.
- The top of the ramp will be about 5 feet above the floor and situated at an angle of around 41 degrees.
- The cross section of the ramp will be:



While students enjoyed the edible car design challenge, and they learned a little about design process, the challenge was poorly aligned with chemical and biological engineering content.

Redesigned course. The redesigned course still included guest speaker presentations. However, in this version, several of the guests visited as "design challenge originators." In addition, one guest speaker presented on hydrogen fuel cell cars; we designed a short task for students to investigate the pros and cons of hydrogen fuel cell cars. They then choose a side (pro or con) and produced a 1-page document that argued for or against further funding for hydrogen fuel cells.

We created three main design challenges. Each challenge began with a video that set the context in an engaging manner and posed a design challenge task. We created the design challenges to be community-, industry-, research- and entrepreneurially-inspired. The Antimicrobial Design Challenge is research-based and entrepreneurial. The Bioshipping Package Design Challenge is industry- and community-based. The Acid Mine Drainage Design Challenge is community- and research-based.

The Antimicrobial Design Challenge was inspired by the research of one of our faculty who normally does not teach undergraduates [40]. This design challenge tasks student teams with proposing and pitching entrepreneurial applications of a new antimicrobial oligomer developed by Dr. Whitten. In the design brief, students are given information about the oligomer, and instructed:

> Your product must be an application of the oligomer, such as a surface coating applied to an object already being manufactured (though you can propose changes to the design or manufacture). Your proposed product must be specific, not a general class of objects or a setting. You must show that it is a feasible to use the oligomer in your product, that there is a market for the product and that it would prove useful to consumers. You may not propose a product such as a wipe or spray, as these are already in production.

Students were scaffolded to investigate different types of antibiotic and antimicrobial materials, and then guided to generate ideas about possible applications they could propose. They first worked individually, and then brought their ideas together as a team. Once they chose an application, they were guided to conduct market analysis. They researched competitors and estimated costs and market reach. They presented a 3-minute pitch, with the following guidelines:

- Dress: Dress professionally.
- The problem: Concisely explain the problem and needs addressed by your design.
- Use-case: A good pitch helps the potential investor envision how the product will be used, not just what it looks like. Sharing a (very) short story about how it will change customers' lives for the better will help seal the deal. The story should communicate what makes your product better than existing products.
- Creativity: An idea viewed as novel will be received better than an ordinary one. Your pitch should highlight what makes your product stand out.
- Market potential: Your pitch should concisely convey the market potential of your product.

The Bioshipping Package Design Challenge was inspired by two local industries and the challenge of providing rural communities with high quality medical services. This design challenge tasks student teams with improving upon existing solutions used by an industry partner, TriCore Reference Laboratories for keeping medical samples within set temperature ranges. Students are given background on bioshipping in the launch video and design brief, including information about the challenges of serving rural New Mexico communities and the volume of samples processed each day by TriCore. The design challenge brief also introduces design requirements as follows:

> The internal space of the box need only be as large as 9” x 6 ½” x 5 ½” in order to contain the sample vial and instant cold pack. The rest of the internal space may be taken up by materials as part of your design. “New MexicoLabs” would like the entire box to remain within FedEx's One Rate shipping dimensions of 11 ¼” x 8 ¾” x 7 ¾”.
>
> Insulation must be incorporated into the design of the shipping container in order to maintain the low temperatures required by the biogenic samples. The total cost of insulating material should not exceed $2 per box. For the range of samples to be sent using this service, it has been determined that the temperature should reach no higher than 50°F and drop no lower than 38°F within a 24-hour period. This range of temperatures must be maintained assuming that the package will spend a majority of its time in the back of a delivery truck where the ambient temperature can reach as high as 100°F.

To support students to understand approaches to solving this problem, they also completed a lab on thermodynamics. They submitted a short technical report on their design process, the materials they chose, its advantages and disadvantages, and how well their design met the design requirements. Afterwards, a guest speaker from another local industry that solved this same problem from a very novel approach spoke to the students about his experiences, failures, and ultimate success in marketing his solution. This sequence was deliberate, allowing students to generate their own solutions before learning about his.

The Acid Mine Drainage Design Challenge was inspired by the Gold King Mine spill on the Animas river, which affected many communities our students come from. This design challenge tasks student teams with proposing a comprehensive response plan, including community engagement strategies and choosing a treatment system that could filter water for an entire community in the event of pollution from abandoned mines. The launch video and design brief included information on the more than 15,000 abandoned mines in New Mexico that threaten safe access to water, how acid mine drainage occurs, a brief history on why mining was beneficial to the state, and how mining disasters have had and continue to have myriad negative consequences for people and the environment.

Students were guided to conduct research on the problem and existing solutions, as well as researching ways to engage with communities that might be mistrustful of outsiders. We felt this would provide them an opportunity to reflect on engineering ethics. They gave 5-minute pitches of their solutions, following similar guidelines for the previous pitch.

Data collection and analysis

Students completed pre/post surveys of beliefs about design, drawn from previously published instruments [38, 41-43]. Most survey questions were 5-point Likert scale (1= strongly disagree; 5= strongly agree), with a few negatively worded items that we recoded for analysis. We also collected demographics information on the survey, and included a few open-ended items focused on understanding students' perceptions of design and of the course activities.

We calculated descriptive statistics and conducted select repeated measures ANOVA to compare gains related to the original and redesigned course to avoid an inflated type I error.

We also collected student work in the design challenges and interviewed a subset of students, primarily focusing on their prior experiences and interests and how they were making sense of the course experiences. We developed coding schemes to analyze student work, comments and utterances, using a grounded, inductive approach [44-46]. We refined the coding scheme, testing it with our educational research lab members who are experienced in qualitative data analysis. We sought low-inference codes to enhance reliability and discussed any differences in coding, per recent recommendations [47].

Results and discussion

To answer research question 1, we conducted repeated measures ANOVA to examine the effect of the course experiences on the pre-course and post-course survey responses in the original course and in the redesigned course. Specifically, we sought to compare changes in student understanding of design as an iterative process. Students' scores in the redesigned course increased (Pre M = 2.54, SD = 1.189; Post M = 2.74, SD = 1.17, n=35), whereas students' scores in the original course decreased (Pre M = 2.72, SD = 1.13; Post M = 2.10, SD = 1.1134, n=63). This difference was significant, $F(1, 96) = 5.72$, $p > .05$. Practically, this means that on average, students in the original course reported a neutral/unsure stance when asked if design is a linear process, and by the end of the course tended to agree that it is a linear process. In contrast, students in the redesigned course tended to begin the course reporting that design is a linear process, but shifted to a more neutral stance by the end of the course.

To answer research question 2, which focused on how students perceived the course, we coded student responses to an end of course survey using a grounded coding approach. We also analyzed responses to interview questions.

We found that students in the original course were somewhat likelier to mention the lectures, both as a positive and a negative, than were students in the redesigned course (Figure 1). Students in the original course linked the lectures to learning about careers in chemical engineering. For instance, one student explained, “I enjoyed learning from guest speakers and faculty. They help paint the picture of what chemical engineers do in such a diversified field.” Students in the redesigned class also did this, but they additionally gave examples linked to the design challenges, and positioned themselves as active participants. For instance, a student explained, “I got to participate in coming up with solutions to every day problems, which allowed me to think outside of the box, like an engineer.” We see this active positioning, which was not found in the original course, as a marker of students’ developing professional identities.

Students in the redesigned course were likelier to mention teamwork and working on design challenges, again in both positive and negative ways. Concerns about team members not participating were amplified in the redesigned course because more of the assignments—and therefore more of their grade—were team-based. Many students also recognized the need for engineers to develop team skills and appreciated “opportunities to build team skills” and saw value for their learning and work because they “were able to come up with different ideas.”

Students in the redesigned course were significantly more likely to mention the design challenges in a positive manner, $t\ (137) = -4.78$, $p < .00001$, though they also mentioned them in negative ways. While students in the original course appreciated the design challenges, they largely seemed to value them because they were enjoyable, “I liked building the car.” In the redesigned course, students specifically mentioned liking the design challenges because of their authenticity and because they learned how to design, “I loved doing the real life situation design challenges. It makes me excited to be an engineer.” Another explained, “We learned how to design a final product from the ground up. We identified problems from the proposal, researched ideas on how to fix them, and finally, come up with a solution for problem.” Again, in contrast to comments about the original course, students in the redesigned course mentioned active engineering roles, suggesting they are beginning to take on professional engineering identities.

Their critiques of design challenges differed by course. Some students in the original class saw the activities as “not helpful at all and a waste of time” and others wished for more interesting, realistic problems, “I think there is probably a more interesting problem that teams could solve besides reverse engineering a coffee maker and make an edible car. Even if the problem was hypothetical, there are more real world problems that should be considered.” In contrast, critiques from the redesigned course focused on the limitations of time and difficulties working on an authentic problem, complaining that the challenges were “vague and hard to complete in the time given.”

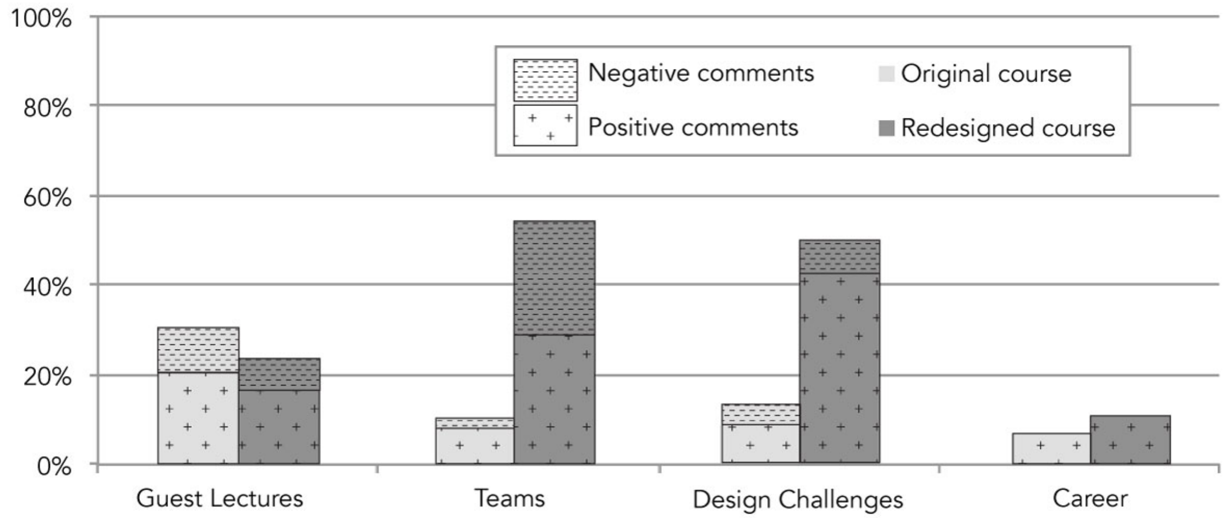


Figure 1. Percent of students in the original and redesigned course mentioning aspects of the course that went well or could be improved.

Interviews mirrored our findings above. We found that students interpreted the design challenges in divergent ways: some expressed hope that engineering would include activities like the design challenges, whereas others expressed concern about the ambiguity and ill-structured nature of the design challenges. We see this as a strength of our approach. In our previous work, we found that students enrolled in a more traditional program with only a capstone design course struggled when they realized that engineering was more than problem sets, and some students regretted pursuing the degree as a result [48-50]. We would rather students make this discovery in the first year of college.

Significance and implications

Based on our analysis, we infer that the redesigned course provided more students with a sense of what engineers actually do, and gave them an early opportunity to experience extended teamwork. The redesigned course helped them understand design as an iterative process.

We argue the design challenges provided an opportunity for students to begin developing professional engineering identities. By providing them with this understanding, students are better positioned to make informed judgments about whether a career in engineering is a good fit for them.

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References

1. Knight, D.W., L.E. Carlson, and J. Sullivan, *Improving engineering student retention through hands-on, team based, first-year design projects*, in *Proceedings of the International Conference on Research in Engineering Education*. 2007, ASEE: Honolulu, HI
2. Carlson, L.E. and J.F. Sullivan, *Exploiting Design to Inspire Interest in Engineering Across the K-16 Engineering Curriculum.* International Journal of Engineering Education, 2004. **20**(3): p. 372-378.
3. Fortenberry, N.L., et al., *Engineering education research aids instruction.* Science, 2007. **317**(5842): p. 1175-1176.
4. Pierson, H.M. and D.H. Suchora, *First Year Engineering Curriculum at Youngstown State University*, in *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*. 2004, ASEE: Salt Lake City, UT. p. 1-11.
5. Demel, J.T., et al., *Bringing about marked increases in freshman engineering retention*, in *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*. 2002, American Society for Engineering Education: Montreal, Canada. p. 2002-2043.
6. McWilliams, L.H., S.E. Silliman, and C. Pieronek, *Modifications to a Freshman Engineering Course Based on Student Feedback*, in *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*. 2004, ASEE: Salt Lake City, UT. p. 1-13.
7. Courter, S.S., S.B. Millar, and L. Lyons, *From the students' point of view: Experiences in a freshman engineering design course.* Journal of engineering education, 1998. **87**(3): p. 283-288.
8. Piket-May, M. and J. Avery, *Service learning first year design retention results*, in *Proceedings of the 31st annual Frontiers in Education Conference*. 2001, IEEE: RENO, NV. p. 19-22.
9. Hoit, M. and M. Ohland, *The Impact of a Discipline ‐ Based Introduction to Engineering Course on Improving Retention.* Journal of engineering education, 1998. **87**(1): p. 79-85.
10. Richardson, J. and J. Dantzler, *Effect of a freshman engineering program on retention and academic performance*, in *Proceedings of the 32nd annual Frontiers in Education conference*. 2002, IEEE: Boston, MA. p. 16-22.
11. Felder, R.M., G.N. Felder, and E.J. Dietz, *A Longitudinal Study of Engineering Student Performance and Retention: Comparisons with Traditionally-Taught Students.* Journal of Engineering Education, 1998. **87**(4): p. 469-480.
12. Parsons, J.R., et al., *The engage program: Implementing and assessing a new first year experience at the University of Tennessee.* Journal of Engineering Education, 2002. **91**(4): p. 441-446.
13. Al ‐ Holou, N., et al., *First-Year Integrated Curricula: Design Alternatives and Examples*.* Journal of Engineering Education, 1999. **88**(4): p. 435-448.
14. Torres, W.J., A. Saterbak, and M.E. Beier, *Long-Term Impact of an Elective, First-Year Engineering Design Course*, in *ASEE Annual Conference & Exposition: Jazzed about Engineering Education*. 2016: New Orleans.
15. Carlson, E., H. Lee, and K. Schroll, *Identifying attributes of high quality special education teachers.* Teacher Education and Special Education: The Journal of the Teacher Education Division of the Council for Exceptional Children, 2004. **27**(4): p. 350.

16. Goncher, A. and A. Johri, *Contextual Constraining of Student Design Practices.* Journal of Engineering Education, 2015. **104**(3): p. 252-278.
17. Jonassen, D.H., *Toward a Design Theory of Problem Solving.* Educational Technology Research and Development, 2000. **48**(4): p. 63-85.
18. Brophy, S.P., *Developing Flexibly Adaptive Skills through Progressive Design Challenges*, in *ASEE Annual Conference & Exposition: Jazzed about Engineering Education*. 2016: New Orleans.
19. Bates, J.S. *A First-Year Course Based on Conceptual Design*. in *AsEE Annual Conference & Exposition*. 2014.
20. Jung, H.Y., Z. Zhou, and L. Ni, *Growing Together with the Community through Service Learning*, in *ASEE*. 2016: New Orleans.
21. Billig, S.H., *Support for K-12 service-learning practice: A brief review of the research.* Educational Horizons, 2002. **80**: p. 184-189.
22. Bradford, M., *Motivating students through project-based service learning.* Technological Horizons in Education, 2005. **32**(6): p. 29.
23. Kline, A., E. Tsang, and B.M. Aller. *Service-Learning Engineering Design Activities at Western Michigan University to Support K-12 STEM Education*. in *ASEE Annual Conference & Exposition: The Changing Landscape of Engineering and Technology Education in a Global World*. 2005. Portland, OR.
24. Pinnell, M., et al. *Can service-learning in K-12 math and science classes affect a student's perception of engineering and their career interests*. in *2008 38th Annual Frontiers in Education Conference*. 2008. IEEE.
25. Furco, A., *Advancing Service-Learning at Research Universities.* New Directions for Higher Education, 2001. **2001**(114): p. 67-78.
26. Conway, J.M., E.L. Amel, and D.P. Gerwien, *Teaching and learning in the social context: A meta-analysis of service learning's effects on academic, personal, social, and citizenship outcomes.* Teaching of Psychology, 2009. **36**(4): p. 233-245.
27. Holland, D., et al., *Identity and agency in cultural worlds*. 1998, Cambridge, MA: Harvard Univ Press.
28. Wortham, S., *From good student to outcast: The emergence of a classroom identity.* Ethos, 2004. **32**(2): p. 164-187.
29. Wortham, S., *Learning identity*. 2006, New York: Cambridge University Press. 305.
30. Atman, C.J., et al., *Findings from the academic pathways study of engineering undergraduates 2003-2008 -- Overview and panel discussion*, in *Proceedings of American Society for Engineering Education*. 2009: Austin, TX.
31. Atman, C.J., et al., *Moving from pipeline thinking to understanding pathways: Findings from the academic pathways study of engineering undergraduates*, in *Proceedings of American Society for Engineering Education*. 2008: Pittsburgh, PA. p. 1-17.
32. Garrison, L., R. Stevens, and A. Jocuns, *Gender, institutional structure and learning in an engineering college*, in *Cre8ing a learning world: Proceedings of ICLS 2008*. 2008, ISLS: Utrecht, Netherlands. p. 265-272.
33. Jocuns, A., et al., *Students' changing images of engineering and engineers*, in *Proceedings of American Society for Engineering Education*. 2008, ASEE: Pittsburgh, PA. p. 1-28.
34. O'Connor, K., et al., *Sponsorship: Engineering's tacit gatekeeper*, in *Proceedings of ASEE Annual Conference & Exposition*. 2007, ASEE: Honolulu, HI. p. 1-14.

35. Stevens, R., K. O'Connor, and L. Garrison, *Engineering student identities in the navigation of the undergraduate curriculum*, in *Proceedings of American Society for Engineering Education Annual Conference*. 2005, ASEE: Portland, OR. p. 1-8.
36. Stevens, R., et al., *Becoming an engineer: Toward a three dimensional view of engineering learning.* Journal of Engineering Education, 2008. **97**(3): p. 355-368.
37. Meyers, K.L., et al., *Factors relating to engineering identity.* Global Journal of Engineering Education, 2012. **14**(1).
38. Pierrakos, O., et al. *On the development of a professional identity: engineering persisters vs engineering switchers*. in *Proceedings of the 39th Frontiers in Education Conference*. 2009. San Antonio, TX: IEEE.
39. Eliot, M. and J. Turns, *Constructing Professional Portfolios: Sense‐Making and Professional Identity Development for Engineering Undergraduates.* Journal of Engineering Education, 2011. **100**(4): p. 630-654.
40. Hill, E.H., et al., *Cationic oligo-p-phenylene ethynylenes form complexes with surfactants for long-term light-activated biocidal applications.* Photochemical & Photobiological Sciences, 2014. **13**(2): p. 247-253.
41. Sheppard, S., et al., *Exploring the Engineering Student Experience: Findings from the Academic Pathways of People Learning Engineering Survey (APPLES). TR-10-01.* Center for the Advancement of Engineering Education (NJ1), 2010.
42. Nocito-Gobel, J., et al., *Are Attitudes Toward Engineering Influenced by a Project-Based Introductory Course*, in *Proceedings of ASEE Annual Conference and Exposition: The Changing Landscape of Engineering and Technology Education in a Global World*. 2005, ASEE: Portland, OR. p. 693-706.
43. Mosborg, S., et al., *Conceptions of the Engineering Design Process: An Expert Study of Advanced Practicing Professionals*, in *Proceedings of ASEE Annual Conference & Exposition*. 2005, ASEE: Portland, OR. p. 1-27.
44. Creswell, J.W., *Qualitative inquiry and research design: Choosing among five approaches*. 2013: Sage.
45. Creswell, J.W. and D.L. Miller, *Determining validity in qualitative inquiry.* Theory into practice, 2000. **39**(3): p. 124-130.
46. Denzin, N.K. and Y.S. Lincoln, *Strategies of qualitative inquiry*. Vol. 2. 2008: Sage.
47. Hammer, D. and L.K. Berland, *Confusing Claims for Data: A Critique of Common Practices for Presenting Qualitative Research on Learning.* Journal of the Learning Sciences, 2014. **32**(1): p. 37-46.
48. Svihla, V., *How differences in interaction affect learning and development of design expertise in the context of biomedical engineering design*, in *Science Education, .* 2009, The University of Texas: Austin.
49. Svihla, V., *Contingent Identification in a Biomedical Engineering Classroom*, in *Learning in the Disciplines*, K. Gomez, L. Lyons, and J. Radinsky, Editors. 2010, International Society of the Learning Sciences: Chicago, IL. p. 913-920.
50. Danielak, B. and V. Svihla, *Why early courses matter for design-focused engineering capstones*, in *The 41st Annual Meeting of the Jean Piaget Society*. 2011: Berkeley, CA.