New Orleans JAZZED about Engineering Education
ASEE's 123rd Annual Conference & Exposition
New Orleans, LA
June 26-29, 2016
Paper ID #15562

Mapping Assets of Diverse Groups for Chemical Engineering Design Problem Framing Ability

Dr. Vanessa Svihla, University of New Mexico

Dr. Svihla is an assistant professor of learning sciences at the University of New Mexico. She is particularly interested in how people find and frame problems, and how these activities relate to innovation and creativity. She applies a range of research methods to understand learning in real world, interdisciplinary and Computer-Supported Collaborative settings. She was selected as a 2014 National Academy of Education / Spencer Postdoctoral Scholar.

Dr. Abhaya K. Datye, University of New Mexico

Abhaya Datye has been on the faculty at the University of New Mexico after receiving his PhD in Chemical Engineering at the University of Michigan in 1984. He is presently Chair of the department and Distinguished Regents Professor of Chemical & Biological Engineering. From 1994-2014 he served as Director of the Center for Microengineered Materials, a strategic research center at UNM that reports to the Vice President for Research. He is also the founding director of the graduate interdisciplinary program in Nanoscience and Microsystems, the first program at UNM to span three schools and colleges and the Anderson Business School. He served as director of this program from 2007 – 2014. His research interests are in heterogeneous catalysis, materials characterization and nanomaterials synthesis. His research group has pioneered the development of electron microscopy tools for the study of catalysts.

Dr. Jamie R Gomez, University of New Mexico

Jamie Gomez, Ph.D., is a Lecturer Title III in the department of Chemical & Biological Engineering (CBE) at the University of New Mexico. She is a co- Principal Investigator for the National Science Foundation (NSF) funded Professional Formation of Engineers: Research Initiation in Engineering Formation (PFE: RIEF) for the project- Using Digital Badging and Design Challenge Modules to Develop Professional Identity. She is a member of the department's ABET and Undergraduate Curriculum Committee, as well as faculty advisor for several student societies. She is the instructor of several courses in the CBE curriculum including the Material and Energy Balances, junior laboratories and Capstone Design courses. She is associated with several professional organizations including the American Institute of Chemical Engineers (AIChE) and American Society of Chemical Engineering Education (ASEE) where she adopts and contributes to innovative pedagogical methods aimed at improving student learning and retention.

Victor Law, Program of Organization, Information, and Learning Sciences at University of New Mexico

Dr. Victor Law is an Assistant Professor at the University of New Mexico in the Program of Organization, Information, and Leaning Sciences. He earned a Master of Applied Sciences from the University of Waterloo, and an MBA from the University of Illinois, Urbana-Champaign. Prior receiving his PhD in Educational Psychology from the University of Oklahoma, he worked as a System Analyst at HP for eight years.

His research explores the social aspects of self-regulation in collaborative learning environments. In addition, he has been conducting studies examining the effects of different scaffolding approaches, including massively multiplayer online games, computer-based simulation, and dynamic modeling, on students' complex problem-solving learning outcomes. Dr. Law has published empirical studies in national and international refereed journals such as Computers in Human Behaviors, Journal of Educational Computing Research, Journal of Educational Technology & Society, Technology, Instruction, Cognition, and Learning, and International Journal of Knowledge Management and E-Learning.

Ms. Sophia Bowers, University of New Mexico

Sophia Bowers is a PhD candidate in the Organization, Information, & Learning Sciences at University of New Mexico. She is interested in understanding how individuals and organizations learn and apply knowledge in real settings; and in creating positive learning and work environments. She has a B.S. in Engineering, an M.BA., and has worked in industry for over 18 years.

Mapping Assets of Diverse Groups for Chemical Engineering Design Problem Framing Ability

Abstract

Engineering programs across the US are engaged in efforts to increase the diversity of their student populations. Despite these efforts, students from groups underrepresented in engineering are still less likely to persist, relative to their peers. One approach taken is adding design earlier in programs, but faculty sometimes doubt that freshmen and sophomore students have the capacity to design. The students themselves may not realize they already possess skills and beliefs that are valuable for engineering design. We describe an approach to uncover potential and discover the attributes, skills, and beliefs that students hold. Students in the first two courses of a chemical engineering program at a Minority-Serving, Very High Research university (N=136) completed a survey and an assessment of their problem framing ability. We identified the following attributes, skills, and beliefs: women were significantly likelier than men to view design as a co-evolutionary process and first generation college attendees were significantly more likely to agree that design is a learning activity. Regression analysis revealed that students in the introductory course produced more expert problem framing if they viewed constraint as endemic to design. Students who rated their pre-college knowledge of and confidence in engineering lower actually framed problems more expertly. This suggests students need to learn early that constraint is endemic to design. Implications for instruction include communicating to students that the work of engineers involves framing problems and providing opportunities for them to develop these abilities. Identifying the strengths students bring could help faculty build on students' existing strengths. We should not view limited prior experience and low confidence as a deficit.

Introduction and purpose

Engineering programs across the US are engaged in efforts to increase the diversity of their student populations. Despite myriad efforts, students from groups underrepresented in engineering are still less likely to persist, relative to their peers.[1-10] To address this, many programs have incorporated design projects early in the curriculum, leading to higher overall retention of diverse students in engineering.[11-23] For instance, students from underrepresented groups were likelier to persist if they completed a first year design course, and this was attributed to the hands-on and contextual nature of the experience[12]. Elsewhere, higher retention of diverse students is attributed to the fact that students like getting exposure to authentic projects,[24, 25] because such projects provide opportunities for students to learn professional skills (e.g., project management, teamwork[26-29]) and allow students the opportunity to integrate knowledge and practice.[30, 31] However, faculty sometimes doubt that freshmen and sophomore students have the capacity to design, and students may not realize they already possess skills and beliefs that are valuable for engineering design. We contribute to this body of work by describing an approach to uncover potential and discover the attributes, skills, and beliefs that students hold.

For instance, consider students like Paloma, a first year student who sees herself as creative and who did well on high school assignments that required problem solving. She worked in a small landscape architecture business, mostly answering phones, but enjoyed when she got to sit in on meetings with clients, even if it was only to take notes, because she got to see how the landscape architects worked together to understand what clients wanted, what the constraints were, and creative ways to navigate those constraints. These attributes, skills, and beliefs are all very relevant to engineering design, but students like Paloma may not realize this, and these engineering "assets" may remain dormant.

Currently, there is no commonly used, simple way to uncover such assets. Our research aims to design and refine a simple method to reveal the assets diverse students bring as they begin a chemical engineering program. We aim to identify diverse students' assets and connect these to professional engineering practices and identities.

We argue that this effort complements other approaches to recruit and retain diverse students in engineering. Revealing engineering assets to both students and faculty can provide a firmer foundation for early design projects. It can help faculty know where students may need additional support. It can also help students connect their current identities to engineering, supporting them to begin developing professional engineering identities. We review research on one of the main predictors of persistence in engineering—knowing where you are going—and on the formation of professional engineering identities; both of these areas informed our survey development, as we sought to uncover aspects of these with our survey.

Knowing where you are going

One of the main predictors of persistence in engineering is "knowing where you are going" [1, 32-40]; students who have a parent or family friend who is an engineer tend to have a better understanding of engineering *practices*. Those who do not have such connections are disproportionately underrepresented in engineering, and they tend to make assumptions about the engineering profession from popular media, publications and early coursework. Textbooks present problem solving as a quick, elegant, linear process when it is actually a highly iterative, failure-prone approach that few students master while they are undergraduates. Core coursework tends to present the work of engineers as problem sets, always with a single correct answer. Students unfamiliar with actual engineering problem solving can be led to believe problems are best solved through a quick, elegant, linear process and that there is always one right answer. When such students encounter more authentic, complex problems late in their program of studies, they may feel engineering is a place they don't belong.

Developing professional engineering identity

When students leave engineering they cite difficulty with the curriculum or advisement, as well as feeling like they don't belong[41]; this effect is more pronounced for those already underrepresented in engineering, as difficulties with curriculum can further negatively impact their sense of belonging. When students don't see engineering as "consistent with their personal identity or sense of self," they are more likely to leave engineering.[42] Providing students with opportunities to discover their value and develop a sense of intellectual belonging can positively impact their willingness to engage academically and hence this supports retention.[8, 43]

But it is also important to recognize that students retain diverse identities—as members of families, communities, and other avocational endeavors. In this way, students' identities are like ***crystals with multiple facets.*** This concept has been referred to as the *crystallized self*,[44] a way to talk about identity that interrupts the sense of "real" versus "fake" selves[44]; for instance, in engineering, a student who questions her potential to become a "real" engineer may feel she needs to shed or sacrifice her other identities (such as mother, artist, or athlete). The notion of a *crystalized self* places more of the responsibility on the organization for cultivating a culture in which a member can live "a life wrapped in a quilt of many colors rather than one suffocated by a monochromatic blanket."

In engineering, this concept has been studied, suggesting that understanding engineering identity as multi-faceted is linked to retention.[45] We build on this notion of the crystalized identity by considering how students might come to see their various identities not only as permissible, but also as relevant to engineering. Given that engineering is one of the most human of endeavors, the other facets of one's identity can easily be called into play in engineering design. By focusing on crystallized identity, we suggest we need to acknowledge the varied ways in which facets of identities can be called into play, serving as assets. Asset mapping is an approach that focuses on the strengths students possess instead of focusing on their deficiencies.[46]

Such asset-based approaches are successful[47] in engaging rural students and Latino/a students in engineering.[48] For instance, in one study, researchers first identified the assets Latina/o high school students brought, then connected these to community-engaged design projects.[48, 49] Such approaches help develop students' self-efficacy and make engineering seem more relevant and more connected to their lives,[50] thus better supporting underrepresented minority students to learn.[51, 52] Asset-based approaches have been shown to support low income, first-generation college attendees, revealing they bring assets such as the ability to define and solve problems related to limited financial means, and having empathy for marginalized communities.[53]

However, previous work to identify assets has involved ethnographic methods, which are time and labor intensive. We investigate how a survey might be used to efficiently identify engineering assets, explore whether these vary systematically, and consider how faculty might leverage these assets in their teaching.

Research questions

We sought to answer the following research questions:

- What engineering assets do students commonly bring?
- Do any of these engineering assets vary systematically by demographics, such as rural versus urban context, gender, ethnicity, and first generation college attendance status?
- Do any engineering assets explain variance in performance on the Design Skills Test for students enrolled in the first course?

Methods

Participants included students enrolled in the first two courses of a chemical engineering program at a Hispanic-Serving, Very High Research University in the southwestern US. Students signed IRB-approved consent forms prior to data collection (N=136 students of 187 consented, 88 from the freshman course, 62 from the sophomore course, with 12 students enrolled in both courses).

Students completed surveys at the beginning of each course (124 students completed the survey). This included demographic information about ethnicity, gender, economic status, prior coursework, high school context, hours worked per week, home language, age, GPA, parent education, first generation college attendance status, and relationship to other engineers. The survey also asked about their design experiences[54], self-efficacy[55] and beliefs[2, 56, 57], with survey questions drawn from prior studies. Questions were Likert (1=strongly disagree; 5=strongly agree, Appendix A). Examples of questions are:

- Design begins with the identification of a need and ends with a product or system in the hands of a user.
- Design is as much a matter of finding problems as it is of solving them.
- Design problems have multiple possible solutions and multiple ways to get to the solution
- I am confident I could identify a need in an authentic engineering design problem
- I am confident I could develop possible design solutions to an authentic engineering design problem
- I participate in engineering-related activities outside coursework
- The faculty and staff make engineering feel like a welcoming place for me

At the beginning of each course students completed the *Design Skills Test* (DST), an instrument used to track changes in design process ability. The instrument was initially developed with biomedical engineering students learning to design,[58, 59] and adapted for other design contexts[60-62]. We adapted this instrument for chemical engineering students. This process included first identifying suitable problems. A suitable problem for the DST is defined as an authentic, real-world design problem that has yet to be solved, and that would require significant effort, time, and expertise to solve; the purpose of the DST is not to assess ability to *solve* a design problem, but rather to measure how students get started framing a design problem.

We located two appropriate problems for the DST, both from an email requesting ideas for solving technological problems, issued by Deutscher Technologiedienst GmbH (used with permission, and with minor adaptations for our purposes, see Appendix B & C).

The DST was given during class time in the first week of class. Students were given 15 minutes to complete the DST. On average, they filled one full sheet of paper with sketches, writing, and annotations. They were told that we were interested in how they got started working on the problem, but that we did not expect them to come to a solution.

The DST is typically coded using a rubric based on the Design and Learning Activity Coding Scheme.[62, 63] Using rubrics tied to the assessment results in higher reliability.[64] The rubric is analytic, meaning dimensions were scored individually; this approach tends to have greater utility but can be harder to establish reliability[65]; however, our previous work with the rubric has shown it to have high reliability.[58, 59, 62]

The initial coding scheme was developed at a research lab meeting led by the first author. The lab members all have experience conducting qualitative analysis. Members reviewed 25 samples of student work on the DST, placing sticky notes on the tests where they noted a particular code or saw something of interest. These initial ideas were turned into a coding scheme and applied to the dataset, omitting codes that were not relevant to the research focus (e.g., design aesthetics) or that were found to be redundant. This coding scheme was refined further at another research lab meeting; per recommendations for qualitative researchers, disagreements in coding were discussed.[66] The chemical engineers involved in the project reviewed the scheme and confirmed that it was ecologically valid,[67] meaning it authentically reflected their understanding of design in chemical engineering, related to the particular problems used for the DST (Appendix D).

Most of the resultant codes are low inference, meaning they are relatively objective, requiring little more than spot checking for accurate coding[68]. A few are higher inference, requiring the coder to make subjective judgments and therefore necessitating multiple coders. A common approach to establishing reliability[69, 70] is to seek interrater reliability by having a subset scored by multiple individuals (two raters have been shown to be sufficient[64]).

For regression modeling, we focused on three low inference codes, which we summed for a total score on the DST: whether the student described a use case or provided an explanation for how the proposed design could be used; whether the student approached the problem ideationally, proposing (and possibly rejecting) more than one idea; and whether the student explicitly focused on the central need (Table 1).

We summed these three variables, resulting in possible scores ranging from -3 to 3.

Table 1. Portion of the coding scheme used for the Design Skills Test

Code	*Description*	*Value 1*	*Value 0*	*Value -1*
A-Use-Case	describes how the design is used, envisions use; even if use is in violation of constraints	vivid, clear description with details, even if constraints are violated	a bit vague description of use, hard to picture	No sense of how design would be used
A-Ideation	Multiple alternative ideas presented	More that one idea present	one idea present	no ideas present
A-Needs_reduce odor	The main need is something to reduce odor to barely perceptible level; most do not mention this	mentions and suggests need to measure	mentions vaguely	no mention directly of odor

Immediately following completion and de-identification of surveys, the text responses were replaced by numeric scores (e.g., rural= -1, suburban= 0, urban= 1; Strongly agree = 5, Strongly disagree = 1). Descriptive statistics were calculated for all survey items. We reviewed means and standard deviations for demographic subgroups (e.g., by ethnicity, by high school context, by gender) and selected specific variables to compare to avoid inflated Type 1 errors.

We modeled using a sequence of stepwise multiple regression models (checking for assumptions and multicollinearity, which would be expected between some explanatory variables). Models focused on demographic/contextual variables (e.g., language, gender, home context, GPA). Factors from surveys and scores on the *Design Skills Test* were added stepwise.

Results: What engineering assets do students commonly bring?

Overall, students agreed that engineers must meet human needs in their design work (Figure 1). Students responded to three questions about this, and for all three the mean score reflected answers between strongly agree and agree. Most students agreed or strongly agreed that design is a creative process (*M = 4.56, SD = 0.67*). Most also agreed or strongly agreed that design is an ill-structured process in which the problem and solution coevolve (*M = 4.47, SD = 0.66*) and there are multiple possible design solutions (*M = 4.62, SD = 0.60*). Most also agreed or strongly agreed that design is a learning process (*M = 4.63, SD = 0.68*).

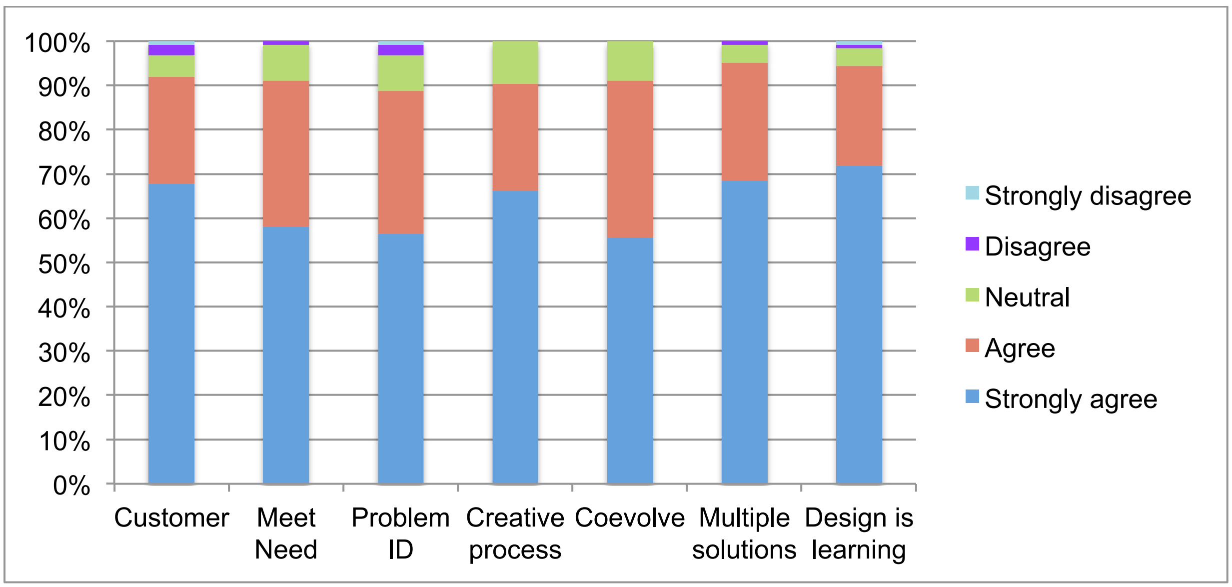

Figure 1. Student responses to survey items about design process

Results: Do any of these engineering assets vary systematically by demographics, such as gender, ethnicity, and first generation college attendance status?

We highlight two assets that varied by demographic category, specifically, gender and first generation college attendance.

Women were significantly more likely to agree that "In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem" compared to men, $t(122) = 2.69$, $p < 0.01$ (Table 2). Levene's test for equality of variances was not significant; thus we report scores for equal variances assumed.

Table 2. Likert responses to "In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem"

Gender	*Sample size*	*Mean response*	*Standard Deviation*
Men	69	3.00 (Neutral)	1.15
Women	55	3.55 (Agree/Neutral)	1.10

First generation college attendees were significantly more likely to agree that design is a learning activity, compared to their traditional peers, $t(113)= 2.50$, $p < 0.05$ (Table 3). Levene's test for equality of variances was significant; thus we report scores for equal variances not assumed.

Table 3. Likert responses to "Design, in itself, is a learning activity where designers continuously refine and expand their knowledge."

Attendance status	*Sample size*	*Mean response*	*Standard Deviation*
First generation	39	4.82 (Strongly agree)	0.45
Not first generation	84	4.55 (Agree/Strongly Agree)	0.75

Results: Do any engineering assets explain variance in performance on the Design Skills Test?

A multiple linear regression was calculated to predict scores or the students enrolled in the freshman class on the Design Skills Test (DST, $M = 1$, $SD = 1$) based on survey variables. A significant regression equation was found ($F(3, 58)= 5.25$, $p < 0.01$) (Table 4). Students were uncertain about the role of constraints in creative design ($M = 2.49$, $SD = 1.02$, neutral to disagree that constraints are beneficial). Research has shown that constraints support creative design. Students who agreed that constraints support creative design scored significantly higher on the DST. Overall, students reported being confident they could succeed as an engineering major ($M = 4.37$, $SD = 0.79$, agree to strongly agree), but students who reported higher confidence scored lower on the DST; this was not significant. Overall, students reported low pre-college engineering knowledge ($M = 2.79$, $SD = 1.26$, neutral to disagree), but students who reported higher pre-college knowledge scored significantly lower on the DST. This model was statistically significant and accounted for a small to moderate amount of variance in DST scores, $r^2 = 0.21$, $p < 0.05$.

Table 4: Models of scores on the Design Skills Test

	Unstandardized Coefficients		Standardized Coefficients	
	B	Std. Error	β	t
Intercept	2.11	0.71		2.99**
Role of constraints	0.31	0.12	0.31	2.65**
Confident can succeed as engineering major	-0.29	0.15	-0.23	-1.97
Pre-college engineering knowledge	-0.21	0.10	-0.25	-2.17*

* Significant at $p<0.05$; ** Significant at $p<0.01$

Discussion and conclusions

Overall, we found the survey to be an efficient means to identify engineering assets. We found that students generally agreed that engineers must meet human needs in their design work, that design is a creative, ill-structured process that can result in multiple possible design solutions, and that designing is a learning process. These align to expert views of engineering design and are assets that instructors could build upon in early coursework.

However, we also found that some assets varied by demographic category, specifically, gender and first generation college attendance. Women held more expert views of design as an ill-structured process than men did. First generation college attendees were more likely to agree that designing is a learning process. Both of these groups also tended to rate their confidence as lower than their peers who are more traditionally represented in engineering; women and first generation college attendees are at risk for not recognizing the assets they bring. We see an important opportunity in identifying such assets, making them explicit, and building on them in early engineering courses.

Regression analysis revealed that students in the introductory course tended to produce more expert problem framing if they viewed constraint as endemic to designing. It also revealed that students who rated their pre-college knowledge of engineering as low and their confidence in their ability to succeed in engineering as lower, they tended to produce more expert problem framing. Given that many pre-college engineering experiences treat constraint as a hardship of school settings, this suggests the need to convey the message to students early that constraint is endemic to design. This finding also suggests that students who lack pre-college engineering experience and have low confidence in their potential for success—both common characteristics of groups underrepresented in engineering—actually possess desirable problem framing skills that can serve as a foundation for developing design engineers. Implications for instruction include communicating to students that the work of engineers involves framing problems and providing opportunities for them to develop these abilities, and also considering ways faculty can build on students' assets, and not view limited prior experience and low confidence as a deficit.

We focused on design problem framing because when an engineer frames a problem, s/he gains ownership of the problem; having such ownership affirms her/his identity as an engineer. Thus, we sought to connect student assets to problem framing as a means to support a growth mindset wherein diverse students view themselves as already having the capabilities to participate in the design process.

Next steps

There have been calls for more research specifically looking at how, when and why certain groups—including Hispanics and Native Americans—initially choose and then persist in engineering.[8] This research begins to address this call. Simply identifying engineering assets and not acting on them will do little to change student persistence. This study represents a first step in a longer research agenda. Our future work includes a means to have students systematically reflect on their engineering assets and connect these to their developing engineering identities. As we integrate new engineering design challenges into early coursework, we plan to explore the impact of both of these efforts on student persistence.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. EEC #1544233. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

1. 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.
2. 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.

3. O'Callaghan, E.M. and N.D.E. Jerger, *Women and girls in science and engineering: Understanding the barriers to recruitment, retention and persistence across the educational trajectory.* Journal of Women and Minorities in Science and Engineering, 2006. **12**: p. 209-232.
4. Mau, W.C., *Factors that influence persistence in science and engineering career aspirations.* The Career Development Quarterly, 2003. **51**(3): p. 234-243.
5. Lord, S.M., et al., *Who's persisting in engineering? A comparative analysis of female and male Asian, black, Hispanic, Native American, and white students.* Journal of Women and Minorities in Science and Engineering, 2009. **15**(2).
6. Eris, O., et al., *Outcomes of a longitudinal administration of the persistence in engineering survey.* Journal of Engineering Education, 2010. **99**(4): p. 371-395.
7. Gonzalez, R.T., *Underrepresented engineering students, family characteristics, major selection, and academic persistence*. 2012, California State University, Sacramento.
8. Lichtenstein, G., et al., *Retention and persistence of women and minorities along the engineering pathway in the United States.* Handbook of engineering education research, 2014: p. 311-334.
9. Vasquez, P.L., *Achieving success in engineering: A phenomenological exploration of Latina/o student persistence in engineering fields of study*. 2007: ProQuest.
10. Kuley, E.A., S. Maw, and T. Fonstad, *Engineering Student Retention and Attrition Literature Review.* Proceedings of the Canadian Engineering Education Association, 2015.
11. 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
12. 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.
13. Fortenberry, N.L., et al., *Engineering education research aids instruction.* Science, 2007. **317**(5842): p. 1175-1176.
14. 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.
15. 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.
16. 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.
17. 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.

18. 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.
19. 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.
20. 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.
21. 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.
22. 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.
23. Al‐Holou, N., et al., *First‐Year Integrated Curricula: Design Alternatives and Examples**.* Journal of Engineering Education, 1999. **88**(4): p. 435-448.
24. Hendy, P. and R. Hadgraft, *Evaluating problem-based learning in civil engineering*, in *Australasian Association for Engineering Education 13th Annual Conference*. 2002, ACT: Canberra. p. 133-138.
25. Patangia, H.C., *A Recruiting and Retention Strategy Through A Project Based Experiential Learning Course*, in *Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition*. 2003, ASEE: Nashville, TN. p. 1-8.
26. Lehmann, M., et al., *Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education.* European Journal of Engineering Education, 2008. **33**(3): p. 283-295.
27. Kjersdam, F., *Tomorrow'neering Education—The Aalborg Experiment.* European Journal of Engineering Education, 1994. **19**(2): p. 197-204.
28. Cai, S. and Y. Zhao, *Design Project Based Modules to Promote Engineering Learning and Retention.* Technology Interface International Journal, 2010. **11**(1): p. 21-25.
29. Mills, J.E. and D.F. Treagust, *Engineering education—Is problem-based or project-based learning the answer?* Australasian Journal of Engineering Education, 2003. **3**(2): p. 2-16.
30. Clausen, T., *Project Work as an Integrating and Revenue-Making Tool.* 1998.
31. Frank, M., I. Lavy, and D. Elata, *Implementing the project-based learning approach in an academic engineering course.* International Journal of Technology and Design Education, 2003. **13**(3): p. 273-288.
32. 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.
33. 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.
34. 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.

35. O'Connor, K., et al., *Sponsorship: Engineering's tacit gatekeeper*, in *Proceedings of ASEE Annual Conference & Exposition*. 2007, ASEE: Honolulu, HI. p. 1-14.
36. Stevens, R., et al., *Engineering as lifestyle and a meritocracy of difficulty: Two pervasive beliefs among engineering students and their possible effects*, in *Proceedings of American Society for Engineering Education*. 2007, ASEE: Honolulu, HI.
37. 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.
38. 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.
39. Danielak, B., A. Gupta, and A. Elby, *The Marginalized Identities of Sense-makers: Reframing Engineering Student Retention*, in *Proceedings of the Annual Frontiers in Education Conference (FIE)*. 2010, IEEE: Washington, DC.
40. 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.
41. Marra, R.M., et al., *Leaving Engineering: A Multi‐Year Single Institution Study.* Journal of Engineering Education, 2012. **101**(1): p. 6-27.
42. Matusovich, H.M., R.A. Streveler, and R.L. Miller, *Why do students choose engineering? A qualitative, longitudinal investigation of students' motivational values.* Journal of Engineering Education, 2010. **99**(4): p. 289-303.
43. Thomason, T.C. and H.J. Thurber, *Strategies for the Recruitment and Retention of Native American Students. Executive Summary*. 1999, Washington, DC.: National Inst. on Disability and Rehabilitation Research (ED/OSERS).
44. Tracy, S.J. and A. Trethewey, *Fracturing the Real‐Self↔Fake‐Self Dichotomy: Moving Toward "Crystallized" Organizational Discourses and Identities.* Communication Theory, 2005. **15**(2): p. 168-195.
45. Forin, M.T.R., R. Adams, and K. Hatten, *Crystallized identity: A look at identity development through cross-disicplinary experiences in engineering*, in *Proceedings of American Society for Engineering Education Annual Conference*. 2012, ASEE: San Antonio, TX. p. 1-21.
46. Smith-Maddox, R. and D.G. Solórzano, *Using critical race theory, Paulo Freire's problem-posing method, and case study research to confront race and racism in education.* Qualitative Inquiry, 2002. **8**(1): p. 66-84.
47. Moll, L.C., et al., *Funds of Knowledge for Teaching: Using a Qualitative Approach to Connect Homes and Classrooms.* Theory into Practice, 1992. **31**(2): p. 132-141.
48. Mejia, J.A., *A Sociocultural Analysis of Latino High School Students' Funds of Knowledge and Implications for Culturally Responsive Engineering Education*, in *Engineering Education*. 2014, Utah State University: Logan, UT. p. 241.
49. Mejia, J.A., et al., *Funds of Knowledge in Hispanic Students' Communities and Households that Enhance Engineering Design Thinking*, in *Proceedings of American Society for Engineering Education Annual Conference*. 2014, ASEE: Indianapolis, IN. p. 1-20.
50. Mejia, J.A., D. Drake, and A. Wilson-Lopez, *Changes in Latino/a Adolescents' Engineering Self-efficacy and Perceptions of Engineering After Addressing Authentic Engineering Design Challenges*, in *Proceedings of American Society for Engineering Education Annual Conference*. 2015, ASEE: Seattle, WA. p. 1-14.

51. Deyhle, D. and K. Swisher, *Research in American Indian and Alaska Native education: From assimilation to self-determination.* Review of research in education, 1997: p. 113-194.
52. Castagno, A.E. and B.M.J. Brayboy, *Culturally responsive schooling for Indigenous youth: A review of the literature.* Review of Educational Research, 2008. **78**(4): p. 941-993.
53. Smith, J.M., *Making the Funds of Knowledge of Low Income, First Generation (LIFG) Students Visible and Relevant to Engineering Education*, in *Proceedings of American Society for Engineering Education*. 2015, ASEE: Seattle, WA. p. 1-16.
54. 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.
55. Carberry, A.R., H.S. Lee, and M.W. Ohland, *Measuring engineering design self‐efficacy.* Journal of Engineering Education, 2010. **99**(1): p. 71-79.
56. 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.
57. 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.
58. Svihla, V., *Collaboration as a dimension of design innovation.* CoDesign: International Journal of CoCreation in Design and the Arts, 2010. **6**(4): p. 245-262.
59. Svihla, V., et al., *Learning to design: Interactions that promote innovation*, in *Innovations 2009: World Innovations in Engineering Education and Research*, W. Aung, et al., Editors. 2009, International Network for Engineering Education and Research: Arlington, VA. p. 375-391.
60. Svihla, V., et al. *Supporting Practice, Integrating Research in Immersive Technologies into Educational Designs (SPIRITED): Teachers as Designers*. in *ICLS 2012, pre-conference workshop, Teachers as Designers of Technology Enhanced Learning Materials*. 2012. Sydney, Australia: ISLS.
61. Boyle, J.D., et al., *Preparing teachers for new standards: from content in core disciplines to disciplinary practices.* . STEM Teacher Preparation and Practice: Prepare and Inspire Students. Special Issue of Teacher Education & Practice, 2013. **26**(2): p. 199-220.
62. Svihla, V., A. Datye, and J. Gomez, *Mapping assets of diverse groups for chemical engineering design problem framing ability*, in *Proceedings of American Society for Engineering Education Annual Conference*. abstract accepted, ASEE: New Orleans.
63. Svihla, V., S. Knottenbelt, and J. Buntjer, *Problem framing: Learning through designerly practices*, in *AERA*. 2014: Philadelphia, PA.
64. Marzano, R.J., *A comparison of selected methods of scoring classroom assessments.* Applied Measurement in Education, 2002. **15**(3): p. 249-268.
65. Waltman, K., A. Kahn, and G. Koency, *Alternative approaches to scoring: The effects of using different scoring methods on the validity of scores from a performance assessment*. 1998, Los Angeles, CA: Center for the Study of Evaluation, National Center for Research on Evaluation, Standards, and Student Testing.

66. 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.
67. Cicourel, A.V., *Interviews, surveys, and the problem of ecological validity.* The American Sociologist, 1982: p. 11-20.
68. Anastas, J.W., *Quality in qualitative evaluation: Issues and possible answers.* Research on Social Work Practice, 2004. **14**(1): p. 57-65.
69. Jonsson, A. and G. Svingby, *The use of scoring rubrics: Reliability, validity and educational consequences.* Educational Research Review, 2007. **2**(2): p. 130-144.
70. Meisels, S.J., et al., *The Work Sampling System: Reliability and validity of a performance assessment for young children.* Early Childhood Research Quarterly, 1995. **10**(3): p. 277-296.

Appendix A: **Design experiences and beliefs about engineering survey**

Please indicate the extent to which you agree with each statement provided. (Likert scale, 1=strongly disagree; 5=Strongly agree, except where noted that the question should be negatively scored)

Factor: Designers meet needs

In design, a primary consideration throughout the process is addressing the question "Who will be using the product?"

Design is the process of devising a system, component or process to meet a desired need.

Design begins with the identification of a need and ends with a product or system in the hands of a user.

Factor: Designers find and frame problems

Design is as much a matter of finding problems as it is of solving them.

The design problem is framed by the client or customer, then solved by the designer ***(negatively scored)***

Design, in itself, is a learning activity where designers continuously refine and expand their knowledge.

Factor: Design is iterative

Design is usually a linear, predictable process ***(negatively scored)***

Design is iteration

Design is a goal-oriented, constrained activity ***(negatively scored)***

Factor: Design is ill-structured

In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem.

Design problems have right answers ***(negatively scored)***

Design problems have multiple possible solutions and multiple ways to get to the solution

Designers of equal skill and experience should come to the same design solution given the same initial design problem

An expert designer is usually right on the first try when designing ***(negatively scored)***

Factor: Designers use creativity to consider multiple possible solutions

Constraints typically hinder creative design ***(negatively scored)***

Creativity is integral to design, and in every design project creativity can be found.

Factor: Intent to persist in engineering

I intend to complete a major in Chemical engineering

I intend to complete a major in engineering other than Chemical engineering

I have considered pursuing a major outside of engineering in the past few months. ***(negatively scored)***

After graduation, I plan to go to graduate school in an engineering discipline

I plan to pursue a career in engineering

Factor: Engineering degree choice

My primary reason for pursuing engineering as a career is because a parent, guardian, teacher or guidance counselor encouraged me to do so.

My parents want me to be an engineer

My parents would disapprove if I chose a major other than engineering

Before college, I had a lot of knowledge about the engineering profession

My prior academic experiences have prepared me to be successful in engineering
Factor: Professional Identity I am familiar with what a practicing engineer does. The main reason I considered engineering as a major is that I know what engineers do and the work appeals to me I participated in some type of engineering internship, club, course, or camp prior to university I am confident that I can succeed as an engineering major Creative thinking is one of my strengths I am skilled at solving problems that have multiple possible solutions.

Appendix B: Design Skills Test for freshmen level class

Do not go over the allotted time, even if your answers are incomplete. We are interested in how you **begin to work,** and realize that you may not be able to finish. This is a very complex problem. A full solution would require more effort and a number of iterations. However, one of the keys to success in extended problem solving is how you get started. Your task is to begin designing what is described below.

Technology Inquiry TN 15 024

On behalf of a client, the Deutsche Technologiedienst company is looking for technical solutions, innovative approaches or techniques to:

“eliminate odors when loading the dishwasher.“

Technical background / general description

(Keywords: chemistry, food chemistry, biochemistry, bacteriology, VOC, odor)

In many households in which a dishwasher is used regularly, one often encounters unpleasant odors while loading the machine (i.e. between emptying it and starting the next cleaning cycle). Used crockery and glassware etc., covered in food residues, is an ideal feeding ground for germs and bacteria. The bacterial processes create the unsavory smells. The householder could use cleaning agents or detergents to combat the problem, but this is normally only a temporary solution that just attempts to hide the smell.

Description of the required technology

The householder would be less uncomfortable if the odors that arise when loading the dishwasher were eliminated. So far, the ability of active carbon and ozone to eliminate odors has been investigated. Ozone has already been put to use, but none of the alternatives are particularly satisfactory or definitive, as the odor is not actually eliminated, just altered.

The odors in dishwashers have so far been classified into the following groups:

- sulfur compounds (e.g. dimethyl disulfide)
- organic acids (e.g. butyric acid)
- aldehydes (e.g. nonadienals)
- aromatic compounds (e.g. para-cresols)
- aromatic and aliphatic heterocyclic compounds (e.g. 2, 3, 5-Trimethylpyrazine)
- ketone (e.g. 1-Octene 3-on) terpene (e.g. 1, 8 Cineol) alcohols (e.g. ethanol, butanol)

On behalf of a client, the Deutsche Technologiedienst GmbH is looking for technical solutions, innovative approaches and techniques to eliminate the unpleasant odors experienced while loading the dishwasher.

System specifications

- Reduction of odor to a barely perceptible level
- Maintenance-free
- Approx. 10 year service life (like the dishwasher itself)
- No residues or other effects on the washing up in the machine
- No inherent smell
- Easy to integrate
- Autonomous system – no need to switch on or add cleaning agents etc.
- Cheap
- Not sensitive to water and steam

Begin designing the device

If you write on any other paper while answering this problem, please attach it to this test. Please write and sketch out your ideas.

Appendix C: Design Skills Test for sophomore level class

Do not go over the allotted time, even if your answers are incomplete. We are interested in how you **begin to work,** and realize that you may not be able to finish. This is a very complex problem. A full solution would require more effort and a number of iterations. However, one of the keys to success in extended problem solving is how you get started. Your task is to begin designing what is described below.

Technology Inquiry TN 14 006

On behalf of a client, the Deutsche Technologiedienst company is looking for technical solutions, innovative approaches or techniques to:

"Innovative, electronic moisture sensor/indicator to detect the moisture content (amount of urine) in incontinence products."

Background and description

(Keywords: telemedicine, medical technology, bioengineering, sensor technology, electrical engineering, micro engineering, RFID)

The demographic change in our society is leading to a growing number of elderly people who are mostly affected by incontinence and in need of wearing an incontinence product. Staff shortages, stress and pressure to save money mean that increasingly, everyday situations arise in which there is little to no consideration of the privacy of individual patients. One example of this is the daily care for critically ill and/or dementia patients, who require a check of product saturation several times a day. This usually involves undressing the patient, which is very time consuming.

Detailed description of the required indicator/sensor system

Incontinence diapers often include a so-called moisture indicator, which is usually applied on the inside of the back sheet (the outermost layer of the product facing away from the body) as printed markings with soluble ink or as a colored hot melt stripe. In its dry state, the ink marking is clearly visible; when wet it "dissolves" off the back sheet of the diaper while the hot melt stripe changes color on contact with liquid. The disadvantage of these kinds of moisture indicators is that they do not indicate the amount of liquid present and the diaper is often changed too early. This is why the Deutscher Technologiedienst, on behalf of a client, is looking for technical approaches and R&D partners to develop an innovative, electronic moisture sensor including signal emission (alarm) for the cordless transmission of the level of moisture in an incontinence diaper.

Technical requirements/properties of the required indicator/sensor system

- It must be as simple as possible to integrate the sensor into the incontinence product, i.e. the sensor will not be fixed onto the body facing surface of the product when the product is put on the patient
- Simple application/integration into the manufacturing process (printing, coating, etc.)

- Cordless transmission of the degree of moisture to a receiver (e.g. traffic light system)
- Flexible sensor material without metal components
- Check of level of product saturation has to be possible without undressing/awakening of residents
- Low additional costs compared to modern incontinence products

Begin designing the device

If you write on any other paper while answering this problem, please attach it to this test. Please write and sketch out your ideas on the back of this page.

Appendix D: Full coding scheme for Design Skills Test

Code Prefixes:

- **A**uthentic designerly activity
- **S**choolish designing or learning
- **D**iscipline-specific

Code Suffixes

- **F**reshman course
- **S**ophomore course
- **B**oth courses

Code	***Description***	***Value 1***	***Value 0***	***Value -1***
Design requirements / constraints				
A-Cheap_B	The device must be "cheap."	mentioned	not violated, but not mentioned or not mentioned clearly	violation of this constraint
A-no residue_F	The design must not leave a residue. Some students plan for a way to wash a residue off. Others connect idea of residue to not being safe.	mentioned	not violated, but not mentioned or not mentioned clearly	violation of this constraint
A-no inherent smell_F	The design must not have it's own smell or perfume; some students mention adding a pleasant smelling compound	mentioned	not violated, but not mentioned or not mentioned clearly	violation of this constraint
A-Autonomous_F	The design must work autonomously, without needing to be turned on/off and without adding cleaning agents	mentioned	not violated, but not mentioned or not mentioned clearly	violation of this constraint
A-Not touching body_S	The design must not touch the patients skin/body	mentioned	not violated, but not mentioned or not mentioned clearly	violation of this constraint
A-Simple to manufacture_S	Manufacture process must be simple	mentioned	not violated, but not mentioned or not mentioned clearly	violation of this constraint

Code	*Description*	*Value 1*	*Value 0*	*Value -1*
A-cordless_S	Reading must be remote, not requiring patient to be changed or moved each time	mentioned	not violated, but not mentioned or not mentioned clearly	violation of this constraint
A-Alarm_S	alarm triggered automatically	mentioned	not violated, but not mentioned or not mentioned clearly	violation of this constraint
A-Flexible_S	device must flex to contours of human body	mentioned	not violated, but not mentioned or not mentioned clearly	violation of this constraint
A-No metal_S	device cannot contain metal	mentioned	not violated, but not mentioned or not mentioned clearly	violation of this constraint
Design addresses human need				
A-Roles_B	People who use the device, service it, manufacture it are mentioned.	at least one person is mentioned	"you could" or other indirect mention of someone using the design	no mention of people
A-Use-Case_B	describes how the design is used, envisions use; even if use is in violation of constraints	vivid, clear description with details, even if constraints are violated	a bit vague description of use, hard to picture	No sense of how design would be used
A-Needs_reduce odor_F	The main need is something to reduce odor to barely perceptible level; most do not mention this	mentioned	mentioned indirectly	not referenced
A-Needs_dirty dishes_F	The need is tied to dirty dishes	mentioned	mentioned indirectly	not referenced
A-Needs_check saturation_S	The need is tied to checking saturation	mentioned	mentioned indirectly	not referenced
A-Needs_do not disturb_S	The need is tied to not disturbing the patient	mentioned	mentioned indirectly	not referenced
Designers frame the problem, remaining tentative and considering multiple ideas early in the design process				

Code	*Description*	*Value 1*	*Value 0*	*Value -1*
A-Framing_B	student frames the problem by identifying constraints, bounding the problem, considering the system, posing questions about the problem space	Clear effort	NA	Only sense of framing comes from solution
A-Framed_F	Problem framing matches design brief	Problem is framed as dirty dishes sitting lead to odors	Problem framed as dishwasher collects detritus which produces odors	Problem framed as dishwasher not strong enough to clean dishes, which produces odors on "clean" dishes
A-Ideation_B	Multiple alternative ideas presented	More that one idea present	one idea present	no ideas present
S-Solution Driven_B	Novice designers jump to solution prior to understanding the problem	No solution put forth	Several solutions put forth ideationally	Solution put forth
D-ChemE-like_B	Responses engage with chemical engineering, offer ideas/solutions about chemical coatings, chemical processes	present	chemicals mentioned are vague or not as part of the problem/solution	no mention of chemicals/ chemical engineering solution
A-Tentative_B	Student uses tentative language to discuss design ideas (this does not apply to needs, such as “must be cheap” or “needs to reduce odor”)	says could be, might be, maybe	mix of both	Should, must, need to be, have to be