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Student Perspectives on Capstone Design Learning

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Abstract

Capstone courses represent a critical juncture in engineering students' careers. While much of an undergraduate engineering curriculum tends to focus on technical content, capstone courses mimic authentic engineering design experiences, in which students often have opportunities to address realistic open-ended projects and interact with real clients and industry professionals. Further, in many programs capstone courses play a critical role in developing professional skills necessary for effective engineering practice, including project management, communication, and collaboration. Reports by several researchers indicate that capstone faculty treat such professional skills as central learning outcomes. However, few studies have sought to explore student perspectives on the learning that occurs in these project-based environments. To address this gap and broaden our understanding of student experiences in capstone design, we ask: How do students in capstone courses describe their learning gains?

To address this question, we present findings from a larger multi-case study of capstone teaching and learning. The full data set for each case includes classroom observations, faculty interviews, and student interviews gathered at multiple points in time across the capstone experience; this paper focuses specifically on data from student interviews and focus groups. These interviews explored students' perceptions of capstone design, including their experiences with mentors, the challenges they faced, their beliefs about what they learned, and their perceived level of preparation for the future. Interviews were audio recorded, transcribed verbatim, and analyzed using an open coding process.

Preliminary findings suggest that students perceive a wide range of both technical and professional learning gains, many of which align with intended course outcomes. Overall, six salient themes emerged in students' discussion of their learning: 1) development of an engineering identity; 2) knowledge of the design process; 3) connections to the "real world"; 4) project management; 5) self-directed learning; and 6) teamwork skills. While several of these outcomes intersect with those identified by faculty and industry practitioners, we focus on here on development of an engineering identity because it represents an important, but under-explored, area in design education. Analysis of learning in capstone design suggest that although critical contextual boundaries between engineering school and engineering practice may be present, students recognize the relevance of the experience more generally. This research improves understanding of the processes by which student learning outcomes are achieved in capstone design courses.

Introduction

Senior design is a critical course in engineering curricula, in large part because it sits on the border between school and work and intentionally seeks to move students from one to the other. The course exposes students to authentic, real-world problems that can vary dramatically from the closed-ended problem sets they have encountered in previous years. Working alongside and under the guidance of industry and academic professionals, students engage in projects designed to mimic those of a professional engineering workplace. [1]The capstone experience typically spans an entire year and often results in students producing some kind of artifact for the particular stakeholders involved (e.g., industry sponsors, national competitions). In these settings, students incorporate technical and professional skills as they work on teams to develop, implement, and communicate solutions to their problems. This synthesis of skills is a critical learning outcome of the capstone course, as it provides students with an understanding of the work they will be doing when they graduate.

There are a variety resources that describe the topics covered and desired outcomes of capstone design courses. Surveys of capstone instructors [1-3] show that instructors teach a wide range of subjects, including oral communications, teamwork, project planning, and ethics, among many other aspects of engineering design. Moreover, the *Engineering Profile* [4], developed using data from both industry practitioners and design faculty, highlights the importance of both professional and technical skills, describing engineering roles such as "communicator," "collaborator," "analyst," and "practitioner." These roles point to the need for a diverse set of skills in order to engage in effective engineering practice. Engineering capstone instructors are intentional in developing competences that students will need to successfully transition into the engineering profession.

These data-driven approaches to learning outcomes echo criteria developed by professional organizations to more broadly describe the characteristics and skills necessary for competent engineering practice. Most notably, ABET's student learning outcomes (criteria a-k)[5] emphasize the importance of both professional and technical skills in engineers graduating from accredited universities. For example, criterion (g) states that engineers should have "an ability to communicate effectively" while criterion (a) requires students to have the "ability to apply mathematics, science and engineering principles." Similarly, *The Engineer of 2020*[6] discusses the rapidly changing nature of today's world and the diverse array of skills engineers will need to possess in order to change with it. No longer confined by disciplinary or geographic boundaries, engineers must be able to adapt and learn as they progress through their careers in order to be effective in practice.

As the intersection between these broader outcomes and studies of capstone design in particular suggest, the capstone course is often designed to provide students with opportunities to synthesize and demonstrate important skills as they work through a real world engineering design project. Moreover, the shift to outcomes-based accreditation has positioned assessment of student learning as central to improving engineering education, including capstone design courses. There are numerous methods for measuring, evaluating, and understanding (engineering) design learning. For example, Safoutin, et al. [7] developed a "design attribute framework" which combines Bloom's Taxonomy with specific components of outcome (c) from ABET criterion 3. By discretizing the phases and elements of the engineering design process, instructors can identify the design outcome as well as the cognitive level at which it demonstrated by their students. Further, the Transferrable Integrated Design Engineering Education (TIDEE) project has yielded assessment tools intended to measure engineering design learning outcomes, including communication, teamwork, and design outcomes. [4, 8, 9]

Missing from these measures of student outcomes, however, are reflective accounts from the students themselves, though Pierrakos et al. did explore student perceptions of learning using a 50-item survey instrument. [10] But capstone design is a complex instructional environment that often results in a diverse array of learning experiences; surveys or rubrics may overlook additional or unanticipated outcomes. To address this gap, we present an exploratory, qualitative study of student perceptions through thematic analysis of multi-site interviews and focus groups conducted with students currently enrolled in capstone design courses. This analysis allows us to gain a deeper understanding of how design experiences result in student learning within capstone courses and how such learning may align with programmatic accreditation criteria. In order to broaden our understanding of design teaching and learning, we use the data to answer the following research question:

How do students in capstone courses describe their learning gains?

Methods

As noted above, this paper presents an exploratory qualitative study of students' perceived learning gains. To explore student accounts of learning in the capstone environment, we draw on data collected from a multi-case study that examined three capstone courses, each in a different institution; the entire study was conducted with approval from the researchers' Institutional Review Board (IRB #08-465). Each course was treated as a case, and data at each site included interviews and/or focus groups with 8-12 students, interviews with faculty, and observations of faculty-student interactions. Case study methods were selected to adequately capture the dynamic, ill-structured environment that is characteristic of many capstone courses. Collecting data from multiple sources at each site, as well as looking across sites allows for triangulation of findings and provides opportunities for more in-depth analysis, both within and across cases. [11] In this paper, we focus on the student data to better understand their perceptions about learning.

Sites

Data for this study was collected as part of a larger project examining teaching and learning in design courses. Sites for the case study phase were selected based on the expertise of the faculty mentors; expert design educators were identified through a combination of survey data[1], interview data[12], and snowball sampling via experienced design course coordinators who could identified highly successful faculty mentors. Selection was then refined to provide representation across institution size, discipline, program size, and geographic location.

The research team collected data at three sites, all of which had full-year capstone courses. Table 1 identifies the salient site characteristics. Note that for the first two case studies, data was collected at the project mid-point as well as at the project conclusion to establish context; at the third site, interviews were conducted only at the end of the project to provide additional triangulation of student experiences.

Table 1: Site Summary

Site	Discipline	Course Structure	Site Visits	Sample Population
LP1 Large, public	Mechanical Engineering	>200 students 1 coordinator Multiple projects, with 1 faculty mentor per project	2 Visits: End of fall semester; end of spring semester	1 faculty mentor working with two separate teams

		Coordinator provided regular lectures relevant topics		
SP1 Small, private	General Engineering	<50 students 1 coordinator Multiple projects with industry liaisons/mentors Coordinator provided regular lectures relevant topics	2: End of fall semester; end of spring semester	Course coordinator and all teams
LP2 Large, public	Chemical Engineering	100-150 students 1 coordinator Multiple projects with industry mentors Coordinator provided regular lectures relevant topics	1: End of spring	Course coordinator and all teams

Data collection and analysis

Prior to each site visit, emails were sent to the sample population inviting them to participate in interviews regarding their experiences in capstone. All students who responded positively to the email were interviewed. Data collection involved individual semi-structured interviews, although the site visit to at LP1 included one multi-student interview (focus group) with 5 students. In general, at both LP1 and SP1, the same students participated in the fall and spring interviews, though there was some attrition due to scheduling at SP1 and some additional students at LP1. In total, 19 students participated in the fall of 2013 and 31 students (5 of which constituted the focus group) participated in the spring of 2014. Shown below in Table 2 is a breakdown of the data collections sources by site and time.

Table 2: Participant Summary

Site	Fall	Spring
LP1	10	13
SP1	9	7
LP2	N/A	11

We note that while the interview population does not include all students from each case, the sampling method and number of interviews at each site is consistent with accepted qualitative research methods,[11, 13] and data analysis achieved saturation. Moreover, given the exploratory nature of the qualitative study and the focus of the research question, our goal was not to demonstrate the degree to which students achieved any particular outcome. Instead, our focus here is to explore how students perceive and describe their learning gains, and to compare students' open self-reports with existing work on design course outcomes to inform future work.

The interview protocols were developed based on the prior phases of this study. [14] Although the student interviews, particularly in the fall, were intended to explore students' interactions with their mentors and how those interactions impacted their course experiences, they also included significant discussions about what and how students were learning through these capstone experiences. Based on the emergence of students' discussions of their own learning, a thematic analysis was conducted to better understand and characterize student accounts of capstone design outcomes.

All interviews were transcribed verbatim. To analyze the transcripts with respect to student learning, the team used an open coding approach consistent with Strauss and Corbin's (1998) recommendations. Initial codes were grouped thematically into broader categories, and codes were combined, divided and refined through an iterative process. To ensure validity of results, multiple researchers used the final codebook to analyze two transcripts independently (Creswell, 2009, p. 191). Discrepancies between coders were discussed and the codebook was revised based on these differences.

Results

Six primary themes were salient among students' discussions of capstone learning, as shown in Table 3.

Table 3: Primary Themes

Theme	**Operational Definition**
1. Development of Engineering Identity	Seeing oneself as an engineer or identifying with engineering
2. Self-Directed Learning	Taking control and ownership of learning on the project
3. Connections to the "Real World"	Awareness of bridging the gap from school to the engineering profession
4. Teamwork Skills	Interpersonal and communication skills related to teaming
5. Project Management	Planning, delegating, scheduling, and keeping track of the project
6. Design Knowledge	Skills and knowledge gained through implementation of the design process

Together, these themes represent a diverse array of student outcomes that emerge as the byproduct of the experiences and interactions facilitated by the work on their projects. Reassuringly, these outcomes reflect the learning desired by capstone faculty nationally[1] and supported by design education researchers. [16, 17]

While all of the themes noted in Table 3 are critical outcomes, we focus here on "development of engineering identity" because it appears unique to this study. That is, the studies and reports described earlier address Themes 2-6, but few if any studies explore the ways in which students experience design courses relative to their identities as engineers (though we note that Tonso's work[18, 19] does explicitly address identity in design teams). Subsequent work will provide more detailed discussions of these themes and how students' perceptions of learning intersect with faculty and industry accounts of those skills and practices.

Throughout their discussion, students frequently referenced ideas related to developing identities as engineers. While an overall discussion of engineering identity development is outside the scope of this paper (see Tonso [20] and Stevens et al. [21] for fuller discussions), students' reflections suggest that their interactions and experiences in the capstone course help them come to view themselves as real engineers. For the participants in this study, this process of identity development encompasses three facets: entering a community, thinking like an engineer, and increasing role competence. In the following sections, consistent with established practices for reporting qualitative research [11, 13, 22], we include representative quotations from participants to illustrate these three facets.

Entering a community

One way students develop an engineering identity is through becoming part of a community of engineers – that is, they engage in authentic work in collaboration with more experienced professionals, be they faculty advisors or industry mentors. Mentors and coaches integrate students into the engineering community by providing opportunities to operate as colleagues rather than students. Students are aware of this marked difference between the capstone experience and other coursework, as illustrated through the following participant comments:

> *I feel like his more, treats us like a peer versus… ah… he's not like "I'm your professor and you're gonna do as I say because I am higher up in the food chain than you." It's more of "Okay we're working together, I am your boss so at the end of the day you need to listen to me." But we can have a discussion with him. Like we can argue with him and give differing opinions. And I mean there have, well, have we ever been right? I don't know. He's usually right. [Student Interview, LP1]*

Many students in this study describe their relationship with their mentors as ones in which they were colleagues and working together. By treating them like professionals, the mentors in this study helped students begin to navigate the working relationship between manager and engineer and begin to see themselves as legitimate members of a professional engineering design team.

At the same time, as indicated by the quote below, students also have to interact with professionals outside the classroom:

> *So just kind of like we're talking to vendors, you know, working with people at the [company], just working with other people in industry, just something you don't get to do every day in a classroom. You're kind of always surrounded by either teachers or people your own age, and this, you know, we kind of worked with people with engineering backgrounds, biology backgrounds, business, you know, kind of across the board, just working with different people of industry, that was, I think it was the biggest. [Student Interview, LP2]*

As the comment suggests, by engaging with "other people in the industry," students have the opportunity to enact their engineering identities in contexts outside the safety of the university and thus begin to enter and function within the wider professional community.

Thinking like an engineer

Students also develop their engineering identities through cognitive shifts in the way they approach problems, or how they begin to "think like an engineer." Engineering thinking requires (among many other things) an ability to break down complex problems and processes, identify relevant aspects of the design, and make decisions based on the information gathered. [23] When discussing outcomes of their capstone experience, some students described a change in the way they thought about and looked at problems; the following exchange demonstrates this change in thinking:

> *Interviewer: …once you graduate, what do you think you're learning from [your mentor] that will be most helpful as you move into your career as an engineer?*
>
> *Respondent: Probably mindset.*
>
> *Interviewer: Mindset, what do you mean by that?*
>
> *Respondent: An approach to tackle a problem. A lot of times, a lot of our work, in my opinion at least, is geared too much towards, I mean you kinda have to do it, but having very set book problems. He's been probably the biggest influence in college so far of how to look at an actual problem and not be overwhelmed by it. How to break it down. He's given a lot of, you know, rote mechanics… it's great to hear that. But more so it's the fact that he shows, he's influenced how to go about doing that. Because its, I mean you look at this [entire project]. It's really intimidating, especially around the start of the semester, to look at that and say "we can't do any of this." Because you can't, because you can't do the entire system at once but then he's definitely helped gear us towards you need to look at, you need to break down the problem into things you can do and here's the chunks you got. [Student Interview, LP1]*

Learning to "think like an engineer" is potentially a crucial step in developing an identity as an engineer; as this student explains, it includes not only possessing certain technical knowledge, but understanding more broadly where and how to apply that knowledge. Similarly, the following student comment emphasizes the design course as a space to enact that application:

> *And being able to just apply [technical knowledge] to a problem that you know, that does not have a solution and being able to think on the fly and be like. ok, I have all these. Like I can apply physics, I know mechanics, I know circuits. How do I apply this to a specific problem, and how do you look at it, how do you confront it and being able to have that creative aspect of it too, also. To not just be like, oh well, you know, I know that it's made like, I've seen other things that are made like this, so I should just follow that design. But like thinking outside of the box and being like maybe well what if like even like having those crazy ideas, even if they don't work out. But just having them, I think was, is a great learning experience right now and I have more to learn. So that's how I thought of [the design class] [Student Interview, SP1]*

Research suggests that seeing oneself and being seen as a member of a group (in this case, engineers) is influenced by the degree to which one perceives congruence between their own values, goals, and attitudes and those of the group. [24] Thus by engaging in the cognitive processes that engineers enact during design and problem solving, students perceive themselves thinking like an engineer (i.e., have an "engineering mindset"), and consequently may strengthen their engineering identity.

Increasing role competence

Finally, students' identity development is also related to perceptions of competence in an engineering role. This perception of competence goes beyond students' ability to demonstrate technical mastery by solving textbook problems, and encompasses their ability to perform in an engineering workplace. Perceptions of their ability to enter and contribute to the engineering profession were enhanced by the capstone course, as these students frequently described a new sense of confidence arising from their design experiences, as illustrated by the following comments:

> *And for me I learned a lot about just if you set your mind to something, you can do it. I mean, I didn't really know too much about cars in general before I started this project. I feel like I learned a whole bunch about cars just through the other team members. And then, beyond that, like I just knew that going into the engineering field now that I feel totally comfortable that I can do the job that they expect me to do. And so, I think it's helped out a lot that way. [Focus Group, LP1]*
>
> *You know, I think at the beginning of the semester I was definitely like, I don't know if I'm ready to graduate, I don't know if I'm ready for this, but I think just going through, you know, senior design, just, we got more hands-off, right? Like we didn't have classes, if we had classes, it was seminars, just listening to people talking, what they had to say, and just being able to act independently, I think that really gave me the knowledge that I can actually do this [chuckles]; the future's not so scary. [Student Interview, LP2]*

These students are not only describing the acquisition of discipline-specific knowledge, but also focusing on how their use of that knowledge supported their confidence in being able to continue learning and practicing engineering on the job.

Research on competency beliefs, including both Bandura's concept of self-efficacy[25] and Eccles' concept of expectancy[26], shows that perceptions of competence on certain tasks are generally good predictors of subsequent performance on those tasks [27] and are positively correlated with different identity-related constructs like attainment value and identification. [28] Consequently, self-efficacy or other perceptions of competence for performing engineering tasks seems a potentially important outcome for capstone design in terms of both performance and identity development.

Discussion and Implications

As the results above indicate, students in this study described outcomes from the capstone design experience that align with various facets of their identity as engineers. Their sense of entering into a community as colleagues represents an interpersonal component, in which experienced engineers recognize them as engineers. The recognition of an "engineering mindset" represents a cognitive engagement with the habits of mind associated with how engineering professionals approach problems. And finally, their sense of role competence indicates a move from simply "knowing the material" to a broader sense of their ability to use that knowledge to function successfully as an engineer.

The processes these students describe in many ways echo Lave and Wenger's (1991) description of situated learning communities of practice, in which individuals gain entry to a community and over time take on increasingly central roles through what they term "legitimate peripheral participation." Newcomers first participate peripherally, doing smaller and simpler tasks, and gradually move to increasingly central and complex roles in a community, provided that their participation is legitimate. That is, individuals that do not engage or participate in the community in ways that actually reflect the goals, values, and culture of that particular community may not necessarily become more central participants over time. For example, while engineering design involves complex social processes, decision-making, communication, and analysis, it may at times involve rather mundane calculations. Therefore, a team member who contributed only to the trivial calculations, although contributing to overall team progress, may not necessarily be engaging in *legitimate* participation in engineering design. What this means for students in senior design is that when given chances to engage in legitimate engineering practice – to operate as colleagues, to engage in engineering thinking, and to develop role competence in addition to technical mastery – capstone courses can help students to see themselves as engineers as they transition to professional workplaces.

The current study thus enhances our understanding of how the students experience senior design, which in turn can support design educators. While further research is needed to better understand identity development during design projects across a broader population, these exploratory findings nonetheless suggest several implications for faculty as they consider how they interact with students. In particular, the study suggests that educators interested in supporting students' professional identities can consider

- Working with students as colleagues – that is, as engineers engaged in joint professional work. While students may still be novice engineers, faculty can establish a relationship in which they treat students as professional partners.
- Being explicit with students about how and why they approach aspects of the problem in particularly ways. By exposing their own thought processes, faculty can help students see, and thus practice, the kind of thinking that characterizes engineering work within a field.
- Providing students with opportunities to fill professional roles, rather than just solve problems. By enabling students to manage project timelines, organize work plans, engage with vendors, contact experts, shape project directions, and more, faculty can help students enact the full range of practices associated with engineering work, and in doing so increase students' sense of competency.

Further research is needed to fully investigate the relationship between various approaches to mentoring students and resultant learning outcomes of capstone design, but the data presented here provides some important first steps.

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References

[1] J. Pembridge and M. Paretti, "The current state of capstone design pedagogy," in *American Society for Engineering Education*, 2010.

[2] S. Howe and J. Wilbarger, "2005 national survey of engineering capstone design courses," in *ASEE Annual Meeting, Chicago*, 2006.

[3] R. H. Todd, S. P. Magleby, C. D. Sorensen, B. R. Swan, and D. K. Anthony, "A survey of capstone engineering courses in north america," *Journal of Engineering Education,* vol. 84, pp. 165-174, 1995.

[4] D. C. Davis, S. W. Beyerlein, and I. T. Davis, "Development and use of an engineer profile," in *Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition*, 2005.

[5] ABET Engineering Accreditation Commission *Criteria for accrediting engineering programs*. Baltimore, MD: ABET, Inc., 2012.

[6] National Academy of Engineering, *The engineer of 2020: Visions of engineering in the new century*. Washington, D.C.: The National Academies Press, 2004.

[7] M. J. Safoutin, C. J. Atman, R. Adams, T. Rutar, J. C. Kramlich, and J. L. Fridley, "A design attribute framework for course planning and learning assessment," *Education, IEEE Transactions on,* vol. 43, pp. 188-199, 2000.

[8] D. C. Davis, K. L. Gentili, M. S. Trevisan, and D. E. Calkins, "Engineering design assessment processes and scoring scales for program improvement and accountability," *Journal of Engineering Education,* vol. 91, pp. 211-221, 2002.

[9] D. Davis, M. Trevisan, P. Daniels, K. Gentili, C. Atman, R. Adams, *et al.*, "A model for transferable integrated design engineering education," *World Federation of Engineering Organizations,* 2003.

[10] O. Pierrakos, M. Borrego, and J. Lo, "Assessing learning outcomes of senior mechanical engineers in a capstone design experience," in *American Society for Engineering Education Annual Conference and Exposition,* Pittsburgh, PA, 2007, pp. Session AC 2007-894.

[11] R. K. Yin, *Case study research: Design and methods*, 5th ed. Thousand Oaks: Sage Publications, 2014.

[12] J. J. Pembridge, "Mentoring in engineering capstone design courses: Beliefs and practices across disciplines," Virginia Polytechnic Institute and State University, 2011.

[13] M. Q. Patton, *Qualitative research & evaluation methods*, 3rd ed. Thousand Oaks: Sage Publications, 2002.

[14] B. Lutz, C. Hixson, M. C. Paretti, A. Epstein, and J. Lesko, "Mentoring and facilitation in entrepreneurship education: Beliefs and practices," presented at the National Collegiate Inventors and Innovators Alliance, San Jose, CA, 2014.

[15] J. W. Creswell, *Research design: Qualitative, quantitative, and mixed methods approaches*: Sage, 2009.

[16] D. Davis, S. Beyerlein, P. Thompson, K. Gentili, and L. McKenzie, "How universal are capstone design course outcomes," presented at the American Society for Engineering Education Annual Conference and Exposition, Nashville, TN, 2003.

[17] D. C. Davis, S. W. Beyerlein, and I. T. Davis, "Development and use of an engineer profile," in *American Society for Engineering Education Annual Conference and Exposition* Portland, OR, 2005, p. Session 3155.

[18] K. L. Tonso, "Teams that work: Campus culture, engineer identity, and social interactions," *Journal of Engineering Education*, vol. 95, pp. 25-37, January 2006.

[19] K. L. Tonso, *On the outskirts of engineering: Learning identity, gender, and power via engineering practice*. Rotterdam: Sense Publishers, 2007.

[20] K. L. Tonso, "Engineering identity," in *Cambridge handbook of engineering education research*, A. Johri and B. M. Olds, Eds., ed Cambridge, UK: Cambridge University Press, 2014.

[21] R. Stevens, A. Johri, and K. O'Connor, "Professional engineering work," in *Cambridge handbook of engineering education research*, A. Johri and B. M. Olds, Eds., ed Cambridge, UK: Cambridge University Press, 2014, pp. 119-137.

[22] M. B. Miles, A. M. Huberman, and J. Saldaña, *Qualitative data analysis: A methods sourcebook*, 3rd ed. Thousand Oaks, CA: Sage, 2014.

[23] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, "Engineering design thinking, teaching, and learning," *Journal of Engineering Education*, vol. 94, pp. 103-120, 2005.

[24] R. Spears, "Handbook of identity theory and research," S. J. Schwartz, K. Luyckx, and V. L. Vignoles, Eds., ed: Springer, 2011.

[25] A. Bandura, "Self-efficacy mechanism in human agency," *American Psychologist*, vol. 37, pp. 122-147, 1982.

[26] J. S. Eccles, T. F. Adler, R. Futterman, S. B. Goff, C. M. Kaczala, J. L. Meece, *et al.*, "Expectancies, values, and academic behaviors," in *Achievement and achievement motivation*, J. T. Spence, Ed., ed San Francisco, CA: Freeman, 1983, pp. 75-146.

[27] M. Bong and E. M. Skaalvik, "Academic self-concept and self-efficacy: How different are they really?," *Educational Psychology Review*, vol. 15, pp. 1-40, 2003.

[28] B. D. Jones, M. C. Paretti, S. F. Hein, and T. W. Knott, "An analysis of motivation constructs with first-year engineering students: Relationships among expectancies, values, achievement, and career plans," *Journal of Engineering Education*, vol. 99, pp. 319-336, 2010.