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Academic Problem-Solving and Students' identities as engineers

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Abstract

Socially constructed identities and language practices influence the ways students perceive themselves as learners, problem solvers, and future professionals. While research has been conducted on individuals' identity as engineers, less has been written about how the language used during engineering problem solving influences students' perceptions and their construction of identities as learners and future engineers. This study investigated engineering students' identities as reflected in their use of language and discourses while engaged in an engineering problem solving activity. We conducted interviews with eight engineering students at a large southeastern university about their approaches to open and closed-ended materials engineering problems. A modification of Gee's analysis of language-in-use was used to analyze the interviews. We found that pedagogical and engineering problem solving uses of language were the most common. Participants were more likely to perceive themselves as students highlighting the practices, expectations, and language associated with being a student rather than as emerging engineers whose practices are affected by conditions of professional practice. We suggest that problem solving in an academic setting may not encourage students to consider alternative discourses related to industry, professionalism, or creativity; and, consequently, fail to promote connections to social worlds beyond the classroom. By learning about the ways in which language in particular settings produces identities and shapes problem solving practices, educators and engineering professionals can gain deeper understanding of how language shapes the ways students describe themselves as problem-solvers and make decisions about procedures and techniques to solve engineering problems.

Keywords

Engineering Students, Identity, Language-In-Use

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Socially constructed identities and language practices influence the ways students perceive themselves as learners, problem solvers, and future professionals. While research has been conducted on individuals' identity as engineers, less has been written about how the language used during engineering problem solving influences students' perceptions and their construction of identities as learners and future engineers. This study investigated engineering students' identities as reflected in their use of language and discourses while engaged in an engineering problem solving activity. We conducted interviews with eight engineering students at a large southeastern university about their approaches to open and closed-ended materials engineering problems. A modification of Gee's analysis of language-in-use was used to analyze the interviews. We found that pedagogical and engineering problem solving uses of language were the most common. Participants were more likely to perceive themselves as students highlighting the practices, expectations, and language associated with being a student rather than as emerging engineers whose practices are affected by conditions of professional practice. We suggest that problem solving in an academic setting may not encourage students to consider alternative discourses related to industry, professionalism, or creativity; and, consequently, fail to promote connections to social worlds beyond the classroom. By learning about the ways in which language in particular settings produces identities and shapes problem solving practices, educators and engineering professionals can gain deeper understanding of how language shapes the ways students describe themselves as problem-solvers and make decisions about procedures and techniques to solve engineering problems. *Keywords: Engineering Students, Identity, Language-In-Use*

Engineering practice has been described as focused on problem-solving (Donald, 2002; Sheppard, Macatangay, Colby, & Sullivan, 2008) with most workplace problems being ill-structured (Jonassen, Strobel, & Lee, 2006; Yadav, Shaver, & Meckl, 2010; Yadav, Subedi, Lundeberg, & Bunting, 2011). Further, engineering identities are tied to engineering learning; as students become adept at solving complex problems they begin to transition from an identity as student to an identity as engineer (Tonso, 2014). However, much of the engineering curriculum does not provide opportunities for this identity development. While there are some efforts to introduce design problems in engineering curricula (Dym, Agogino, Eris, Frey, & Leifer, 2005; Marra, Palmer, & Litzinger, 2000) for the most part problems presented to students in academic settings are well-structured (Shin et al., 2003) and thus "engineering graduates are ill-prepared to solve complex, workplace problems (Jonassen, 2014, p. 103)." Although one goal of an engineering education is to establish students' identities as engineers, if the problems they generally solve remain in the academic space they may not develop these identities. Thus, we find it important to investigate how students construct identities through typical academic problems, and this paper is framed around these typical problems.

Identities, language in use, and various linguistic practices shape each other and influence the ways in which students experience and perceive themselves as learners and future professionals. By analyzing "language-in-use" (see Gee, 2011a, 2001b) educators and engineering professionals can gain a deeper understanding of how students make decisions about procedures and techniques associated with problem solving. In addition, language influences the identities taken on by individuals.

Various theoretical frameworks describe the relationship between language and identity. One classic example is that of Berger and Luckmann (1966) who describe how language (in their words, "conversation") both reinforces the taken-for-granted reality and at the same time changes that reality through what is said or left unsaid. Gee (2011a) echoes this when he says "any use of language gains its meaning from the "game" or practice of which it is a part and which it is enacting (p. 9)," and, "*language has meaning only in and through social practices,* practices which often leave us morally complicit with harm and injustice unless we attempt to transform them" (p. 12). He then extends this concept with seven "building tasks" that describe the ways in which language is used to create reality. He further explains that "an oral or written 'utterance' has meaning only if and when it communicates a *who* [socially situated identity] and a *what* [socially situated activity] (p. 30, italics in original)." Thus, examining how language is used in specific activities can shed light on how both those activities and the identities associated with them are created. In this work, we examine the language used by engineering students as they talk about a problem-solving task in order to understand how they construct their identities.

More specifically, the purpose of this paper is to describe the voiced identities of engineering students engaged in a problem solving exercise; thus yielding important insights into the ways in which students construct their identities as students, problem solvers, future engineers, and so on. As will be described in the literature review below, students' identities can have an important influence on their learning trajectories and ultimately on their identities as engineering professionals. Thus, this study is guided by the following research question: How do engineering students describe their identities when solving typical academic engineering problems?

Literature Review

While there has been much research conducted on individuals' identity as engineers (see our following literature review), less has been written about identity with respect to the act of engineering (i.e., problem solving) and engineers as individual problem solvers. One exception of particular relevance to our study is work by Downey (2008). He describes a course, Engineering Cultures, that asks students to reconsider the normative concept of engineering problem solving as being "a well-honed method of analysis (p. 436)" with no room for emotional aspects. The course challenges students to understand their own historical and social development as engineers. There is also a concern in the literature about students' abilities to adopt identities that align with professional engineering practice (Dannels, 2000; Dunsmore, Turns, & Yellin, 2011; Hult, Dahlgren, Dahlgren, & af Segerstad, 2003) . Because problem solving is seen as one essential aspect of engineering identity, it is important to explore language use surrounding the problem solving processes.

Identity has recently emerged as a topic of considerably interest in engineering education research (Johri & Olds, 2011; Tonso, 2014). Interest in identity is linked to an increasing focus on situated learning. A situated perspective views knowledge as distributed between people, and as such, learning is seen as an interactive process in which knowledge is produced through the meaning making activities within a community of practice. A student's identities, as well as those of others with whom they interact, influence opportunities to participate in the practices of a community. The identities of students therefore play a role in students' learning trajectories (Johri & Olds, 2011). From a constructivist perspective identities are ontologically socially constructed and always understood in relation to their environment.

There are several strands of literature on identity in engineering. We only briefly mention them here because they are not directly relevant to our study. In one, discussions of identity tend to focus on the socialization of students into the academic environment and into the profession (Dannels, 2000; Du, 2006; Johri & Olds, 2011). Implicit in these writings is a concern that identity affects students' persistence in engineering education and preparation for the engineering profession. Another strand of work examines what it means to be a practicing engineer (Downey & Lucena, 2004; Hult et al., 2003; Trevelyan, 2010). In a third strand, identity of undergraduate engineering students has been explored at the level of campus culture (Tonso, 2006a), within student design teams (Dannels, 2000; Du, 2006; Dunsmore et al., 2011; McNair, Newswander, Boden, & Borrego, 2011; Tonso, 2006b), as revealed in student portfolios (Eliot & Turns, 2011), and from the perspective of an individual minority student (Foor, Walden, & Trytten, 2007).

Of particular relevance to our work is the literature related to the role of problem-solving in engineering. Many authors describe engineering as being primarily a problem-solving activity (Donald, 2002; Sheppard, Macatangay, Colby, & Sullivan, 2008; Jonassen, Strobel, & Lee, 2006; Yadav, Shaver, & Meckl, 2010; Yadav, Subedi, Lundeberg, & Bunting, 2011), although Trevelyan (2010) has argued that professional engineers hide behind a technical façade, downplaying the social aspects of their work. There is also work that describes a disconnect either between engineering identity and engineering practice, or between academic and professional identities. Several studies have found that engineering students often draw a clear distinction between the classroom and the "real world." For example, Hult (2003) found that, although both freshmen and senior engineering students had a clear notion of engineering knowledge and the engineering profession, they doubted whether the two were linked. Similarly, Dunsmore et al. (2011) reported that students did not see school experiences as integral to engineering practice and Dannels (2000) found that the design processes exhibited in the classroom were primarily driven and shaped by academic discourses where the instructor and teaching assistants were the most important customers and the primary outcome was a good grade. Additionally, Donald (2002) noted that in engineering there is "a continual tug-of-war between the theoretical and the professional" (p.63). Students often feel that theory is emphasized over practice and they wish for more practical hands-on learning experiences. As a result, some graduates find the transition to professional practice to be a shocking experience.

Despite the perceived importance of problem-solving, our review shows that there is little work that specifically examines the ways in which the types of problems students encounter affect the development of their identities as engineers. While there are indications that the problems students encounter in school are seen as unrelated to professional practice (Hult, 2003; Dunsmore et al., 2011; Dannels, 2000; Donald, 2002), not much is known about how these academic problems affect their identities as engineers. Our work aims to provide an initial investigation into this area. Specifically, we examine how students describe their identities through the language they use after solving academic problems in an academic setting (i.e., individual problem-solving in a classroom-type environment).

Methods

Researchers' Positioning

Our research team represents various disciplines and backgrounds. Two of us are professors of engineering education and two have degrees in psychology. One of the authors has extensive experience in qualitative research methodology. One of the authors received formal training in engineering and has conducted research in both engineering and engineering education. Another has an undergraduate degree in engineering and a graduate degree in engineering education, with industrial experience between those two degrees. Most of us have working and teaching experiences both in K-12 and post-secondary education contexts both in the US and internationally, and some have also conducted research at labs and various field contexts.

Our experiences within K-12 and post-secondary education, industry, and laboratories and our culturally diverse backgrounds affect our views about engineering identities and the role of problem-solving in engineering. We recognize that our primarily academic (as opposed to industrial) collective experience may create a tendency for us to recognize academic over "real-world" identities. At the same time, throughout the data collection and analysis we were careful to stay sensitive to these past experiences.

Theoretical Perspective Guiding This Research

This study was guided by a constructivist theoretical perspective. It was our intention to study engineering students' individual meaning making processes and how students describe their existing and emerging identities as engineers. A constructivist perspective directed our focus on the unique features of individual experiences that highlight different perceptions and experiences of reality of each individual (Hatch, 2002). Furthermore, interviews provided insights into students' multiple voices and perspectives including their beliefs, reflections, and evaluations of the think aloud problem solving experience. The students were viewed as active agents, constructing meaning and gaining knowledge as they reflected on their learning process within a social context (Fosnot, 2005; Kincheloe, 2005; Lincoln, & Guba, 2000). However, we also acknowledge the impact that researchers can have on the construction of knowledge in social contexts.

Data Sources

Sample and data collection

Eight senior materials science and engineering students from a large southeastern university in the US participated in this study. Three of the participants were women and five were men. Seniors were recruited due to their advanced academic experience and level of content knowledge in the field. Approval from the university's Institutional Review Board was obtained and all participant names used in this manuscript are pseudonyms.

Data collection involved individual semi-structured and open-ended interviews. The interviews were conducted following think aloud sessions in which participants verbalized their thoughts while solving four materials engineering problems. These problems involved various aspects of mechanical behavior of materials and included tasks such as calculating stresses and deformations, and selecting a material to satisfy defined criteria. The specific problems used are shown in Appendix A. The problems were designed to be either closed- or open-ended, and to require either few or many decision points to reach a solution. Thus each problem occupied a unique spot on a 2x2 matrix of degree of open-endedness (closed or open) and number of decisions points (few or many). Each individual think aloud session was video recorded and transcribed verbatim. Analysis of the think aloud protocols for one of these problems is reported in another publication (see Douglas, Koro-Ljungberg, McNeill, Malcolm & Therriault, 2012). Members from the research team collectively viewed and analyzed the think aloud videos to develop an individualized interview protocol for each student. During the group video viewing sessions, key problem-solving decision points were identified and used to generate interview questions that would provide deeper insight into the beliefs, values, and attitudes that guided students' problem-solving approaches. Timestamps of the decision points were noted so that the video clips corresponding to the interview questions were available during the interview if needed for elaboration or clarification purposes. The follow-up interview was scheduled approximately two days following the think aloud session in order to promote fresh recall of the think aloud problem solving experience.

The follow-up interviews complemented the think aloud protocols, providing students space to reflect on and explain their problem-solving processes in detail. A senior and junior researcher collaboratively asked interview questions to make the interview more conversational and interactive. During the interviews students were provided with their written solutions as well as the video clips if needed. The interview protocols began with standard questions that asked students to chronologically narrate their problem-solving processes for each problem without using technical language. Specific questions tailored to individual students' critical decision points in the think aloud protocols questions (developed from the group video viewing sessions) were also asked, and additional probes were added as they were considered appropriate by the researchers. An example of a specific question is: "You eliminated composites because you said they are 'complex.' What do you mean by 'complex' and why does that eliminate them?" Questions were also asked that were intended to elicit students' beliefs about problem-solving and engineering more broadly. An example of such a question is "How do you think that the problems that you were solving here differ from the problems that you're going to face when you go to a job?" The follow-up interviews typically lasted one hour; however, up to two hours were allocated for the interviews. Students were compensated with a $60 gift card to a retail store for their participation.

Data analysis

To investigate students' language-in-use we analyzed motifs and I-statements from the interviews. First, all the interview transcripts were analyzed individually to determine key motifs, similar to the themes or sequences of labels (for the analysis of the motifs see e.g., Gee, 2011a, 2011b; Fairclough, 2003) related to the participants' values and beliefs. Key portions of data were highlighted as representative samples. We noted similarities in the ways in which participants were referring to their epistemological beliefs or behaviors (i.e., how they conducted inquiry and organized knowledge respectively). Differences were also identified based on participants' interpersonal connection and intrapersonal awareness.

To be able to focus on the most representational aspects of the data we built our analysis on the three main motifs from each participant. These were identified by determining which motifs appeared most often in the data. After the three most representative motifs were identified for each participant, we analyzed the motifs for statements where they referred to themselves (Gee, 2011a). Because it was important for us to consider how participants used language when they referenced themselves in the first person, these statements were referred to as their "I-statements." According to Gee (2011a) these I-statements can take five forms including: (1) Cognitive statements referring to what an individual thinks or knows – that is, I think, I know, I guess, (2) Affective Statements referring to what an individual talks about desiring or liking – that is, I want, I like, (3) State and Action Statements referring to an individual's state or actions – that is, I am, I worked, (4) Ability and Constraint Statements- referring to when an individual talks about being able to or having to do things - that is, I can't say, I have to do, and (5) Achievement Statements- referring to activities, desires and efforts relating to their achievement, accomplishment or distinction – that is, - I challenge myself, I aspire to go to an Ivy League School.

Lastly we analyzed the connection between language uses and identities by using Gee's identity building tasks to ask analytical questions related to the motifs and I-statements describing participants' identities and roles. Our analytical questions included questions such as what socially recognizable identities participants enact in specific situations or what identities they displayed that other people could recognize, how participants position themselves and others, and what identities participants privilege or invite others to take up. In this case, we used socially recognizable identities that we as engineers and teachers would recognize. These identities (e.g., "Expert," "Inquirer," "Organizer," and "Self-Doubter") were created through iterative research team discussions of participants' motifs, vocabularies, experiences, backgrounds, and reflections, based on various data sources and artifacts collected including, interview transcripts, students' work, video data, and field notes.

We would like to note that we only used some aspects of Gee's work to analyze students' language-in-use. We believe that every analysis including discourse analysis is always partial and incomplete. Furthermore, Gee does not provide a prescriptive case for a singular use of discourse analysis. He explicitly states:

> This book will introduce various tools of inquiry for discourse analysis and strategies for using them. It will give a number of examples of the tools in action, as well. But the reader should keep in mind that these tools of inquiry are not meant to be rigid definition. Rather, they are meant to be "thinking devices," that guide inquiry in regard to specific sorts of data and specific sorts of issues and questions. They are meant to be adapted for the reader's own purposes. They are meant, as well, to be transformed as the reader adapts them to his or her own theory of the domain. (Gee, 2011a, pp. 11-12)

Gee (2011b) also encourages researchers to develop their own approaches and contributions. "That is really what 'how to' means in this book: learn how to eventually go on your own and choose your own companions on your path to understanding and intervention in the world" (p. x)

According to Charmaz (2006) language plays a crucial how one codes and categorizes information and data. No research is neutral because language confers forms, meanings, and values. Text and data carries multiple meanings which are emphasized, highlighted, bought into the readers' attention differently based on the experiences and meaning making processes of the reader. Yet this meaning making process is interactive and researchers move between data and interpretation. As such scholars' work often responses to the cultural and socially constructed understandings about the world to generate insights that are likely to transfer to other contexts and other research settings. To increase the trustworthiness of our findings, analysis and interpretation activities were carried out collaboratively by the research team. Team members from various disciplines engaged in bi-weekly conversations about the emerging findings, their presence in data and meaningfulness to the engineering discourses. We also used our study advisory board to provide feedback on the preliminary findings and interpretations.

Findings

In this study we use Gee's (2011) definition of identity: "different ways of being in the world at different times and places for different purposes" (p. 3). Specifically, the context is an academic environment in which students individually solve academic problems. As this represents the primary approach to problem-solving for engineering undergraduates (in homework problems and on exams) it is important to understand how students identify themselves in this social setting. We would also like to note that even though each "identity" is introduced individually identities were shifting, multiple, and continuously changing in students' narratives.

Five different discursive practices and uses of language were identified in this study. Three were shared by multiple participants, while two were only associated with individual participants. We found that students used language to describe their identities in somewhat narrow ways; participants' identities, as exemplified through their use of language, were primarily constrained to an academic context. Although participants were prompted to freely rearticulate their problem solving experiences in their own words during the interviews and even though students were asked about their larger conceptual understanding of elements of the problem (e.g., what makes a material complex) they did not offer many comments that moved beyond the academic context in which they were immersed (i.e., a pedagogical use of language). Participants also did not share many details about their experiences outside of the classroom or how connections within a professional learning community including internships and work experience have helped them to solve problems. In addition, most of the participants' use of language was disconnected from expectations about future work life and their identities as problem solvers within a professional context.

Although some participants articulated their identities within the linguistic context of engineering, their language was limited to the technical aspects of engineering problem solving. In this context, the participants did not use language associated with a broader view of engineering including social, political, or environmental considerations. With one exception, participants' language also presented individualistic views of engineering problem solving.

Table 1. Identities and Their Descriptions

Identity	Description
Self-doubter	Ongoing questioning, intimidated by the problem solving process
Confirmer	Finds comfort from routines, follows text book examples
Reflector	Strong self-awareness, frequent self-reflection
Expert	Confidence in general knowledge about the field, how to locate information, trusts in math and one's existing knowledge
Practitioner	Importance of practical application and common sense
Searcher	Uses external resources and materials extensively and sometimes as the only way to approach a problem
Organizer	Importance of creating order and solving problems as a set of specific tasks, neatness, usefulness

Simplifier	Uses processes of elimination, utilizes “tricks” and shortcuts
Technocrat	Formula-based approach to problem solving, searches for quick and existing solutions
Rationalizer	Finds justifications for his choices, reasoning
Independent thinker	Personal preferences guide problem solving, uses past experiences to guide problem
Strategizer	Intentional and conscious use of resources and processes, knowledge about alternatives and their strengths and benefits
Collaborative learner	Views learning as a collaborative and collective activity
Mathematician	Conceptualizes engineering problems as math problems

Our analysis revealed that participants assumed specific situated identities as problem solvers and that these identities were also linked with language use (see Table 1). Figure 1 represents a summary of students’ different uses of language and identities, while Table 2 summarizes the conceptualizations and content of these language uses. As illustrated in the figure some uses of language were shared among multiple participants (e.g., pedagogical, engineering, and individualistic uses of language), while two students used language in more context specific ways. Michael (all reported names are pseudonyms) described his experiences through collaborative uses of language and Matthew used language describing his identity as a mathematician. As indicated, participants also constructed their identities within different linguistic contexts. In this way students described multiple simultaneous identities and their views about them as problem solvers were contextualized and varied. The exception was Jessica. Jessica positioned herself solely as a learner who was uncertain about her knowledge and skills.

Table 2. Uses of Language Linked to Students’ Problem-Solving Identities

Use of language	Description
Pedagogical	Actions and language related to learning, being a good student, expectations and values associated with teacher-student and student-student interactions.
Engineering focused	Actions and language associated with becoming an engineering professional, skills required for solving engineering problems through elimination, planning, and logical progression
Individualistic	Actions and language highlighting individualistic values such as intentionality, independence, and self-directed learning, focus on experiential processes, self-assurance and confidence
Collaborative	Actions and language emphasizing the role of peers, collaborative learning and working, using peers to inform future learning, value of collective meaning.
Math focused	Actions and language focusing on equations, finding variables and values, manipulation of equations and solving for unknown values.

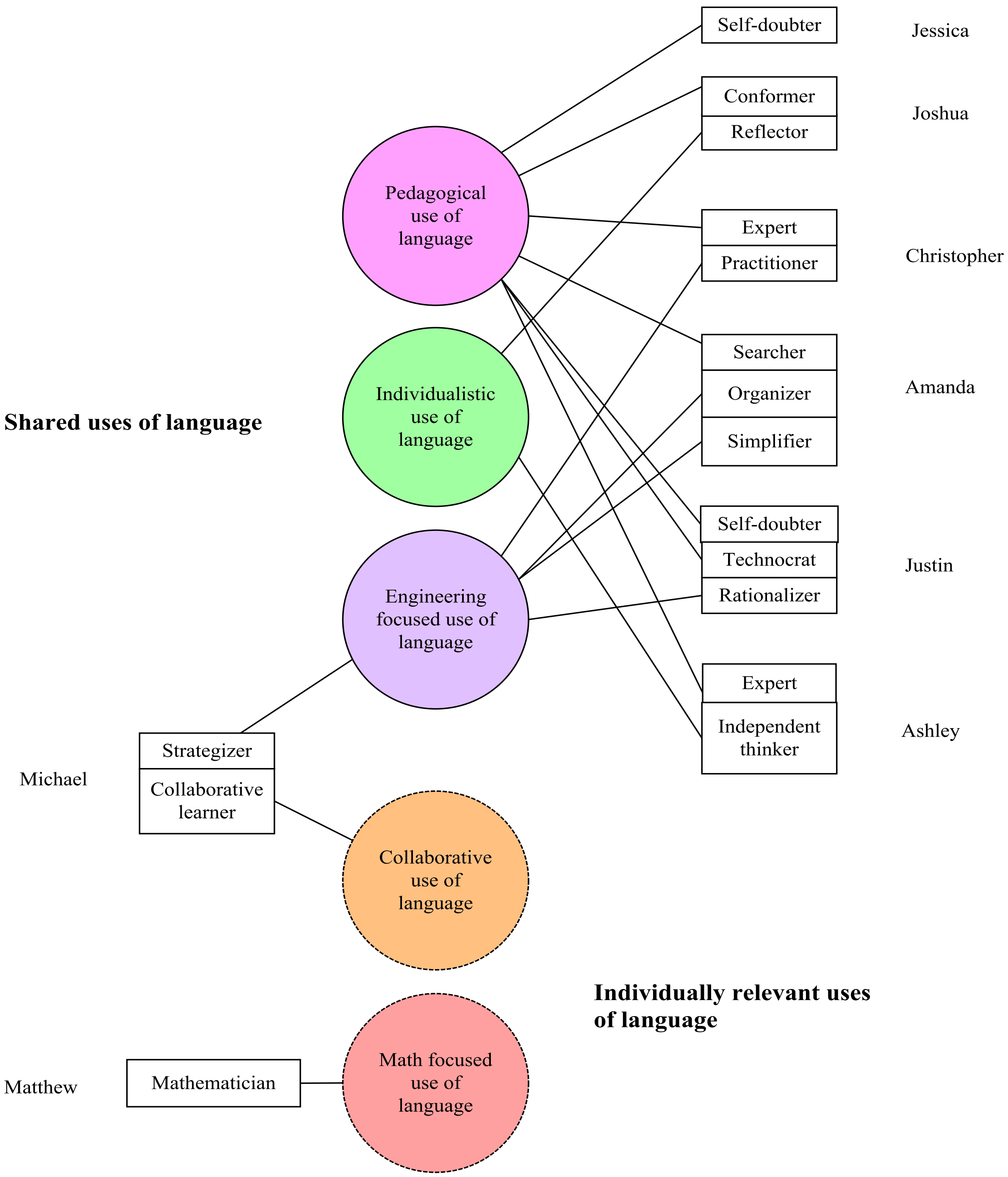

Figure 1 Summary of students' uses of language and constructed identities. All names are pseudonyms.

In the following sections we describe the language used by these students and how this language was related to their identities in this context.

Pedagogical uses of language

The pedagogical uses of language provided a context for the students to describe how they navigated within the realm of their academic majors and in the context of their classroom experiences with professors and classmates. For example, Jessica was a female from a racial group that is traditionally underrepresented in engineering who exhibited the situated identity of a "self-doubter" throughout her problem-solving experience. Furthermore, there was a strong tone of negativity throughout Jessica's reflections of her problem-solving experience. Throughout her data and present discourse, she showed awareness of her weaknesses in problem-solving and how this shaped her solution process characterizing her as a "self-doubter." "I double-check a lot…I'm generally checking for things that I know…I personally made mistakes in the past...I always mess up on my units, that's a common error." In her reflections she also exemplified a common thread of negativity and self-doubt through I-statements such as "I personally make mistakes," "I always mess up," and "I don't know" Additionally, her situated identity spoke to her tendency to focus on limitations both for herself and the problem-solving process. "I didn't know any benchmark materials to really compare it to…how could I make an assumption?" Similarly, many of her cognitive statements were framed by statements of uncertainty such as "I don't know."

Our interpretation of Joshua's data portrayed him as a "reflector" and "conformer" within the pedagogical use of language. Within his situated identity as a "reflector" Joshua had a strong sense of awareness about his actions and emotional and mental states during his problem solving experience. This was evident through frequent use of state and action I-statements. For example, Joshua stated:

> I am a much more conceptual person than detail oriented…when it comes to doing things like this I'm more apt to make a mistake…I enjoy questions that are more general and just pull on my knowledge of materials in general.

Joshua constantly referenced his own being and often compared himself to others. He was also clearly aware of his strengths and weaknesses. He made assertions about how this behavior translated to his classroom experiences through the pedagogical discourse such as, "In a test situation, I'm trying to put down a correct answer…I was just so excited to know what I was doing." Joshua exemplified a "conformer" identity in this respect as he showed a keen awareness of the processes required to gain partial credit from professors through his problem-solving strategies. As he stated, "it may not be the best answer as long as I can justify it." This example further highlighted how he conformed to different academic situations to maximize his performance during problem-solving. However, he also exhibited the "conformer" identity in his categorization of his behavior in a test situation versus a job-situation where he may have to complete a project. "I guess I started thinking of this not so much as an exam, like a test question...I just thought of it as like a project I was given."

Justin constructed his identity within a pedagogical use of language. He showed a strong sense of self-awareness and doubt during his problem-solving. He reflected on his failures and continuously processed his perceptions of doubt during the problem-solving process. He wanted to provide a solution although he knew it "was going to be wrong." Justin's self- doubt was also manifested in ways in which he described himself as an under achiever who was less concerned with the outcomes of his problem-solving and more interested in moving on quickly to other tasks. "So I saw two variables and I was like, okay, I don't have a clue how to get back there…I can just quickly solve the problem, be done with it." In addition, Justin compared his knowledge to real-life knowledge demonstrating a strong awareness of situations where he thought classroom experiences needed to be validated against a real-world context. In some instances, he described himself as a "technocrat" who focused more on equations and calculations themselves without clearly understanding the context of or reasons for using particular equations. He explained that he understood equations but "did not understand why and how they correlate with real life situations."

> It was hard to relate what I was able to calculate which was corrosion, corrosion rate but then also trying to get the fracture toughness with the applied force. I didn't know how to correlate those two things…I understood equations, I just didn't understand necessarily why and how that correlates to real life situations.

Christopher, in turn, perceived himself as an "expert" and "practitioner" in the context of pedagogical language. Christopher drew on a personal knowledge developed through classroom experience even if the concepts he was encountering were vague to him. His method of corroborating between an established lexicon and personal reasoning was to default to the first concepts to come to mind. "I just kind of went with an easy default with steel…just because it's cheaper." Additionally, in his examples Christopher moved from searching through his experience with materials mentioned in the classroom context, to memory of equations or similar problems to direct his problem-solving. "I just knew exactly…what chapter to look in and just found where it talked about that and then quickly flipped to it." As with Ashley, who also described herself as an expert, Christopher exhibited a reliance on his expertise with certain problems and procedures as a guide during his problem-solving.

In comparison to the expert identity exemplified by Christopher and Ashley, Amanda's data brought to the forefront her rather superficial conceptual connections. As a "searcher" she was constantly engaging with the textbook, flipping back and forth between various sections. She employed narrow searches for specific information in times of uncertainty. Her near constant searching in the textbook highlighted her need to constantly verify the accuracy of her work via example problems in an attempt to receive as much partial credit as possible as she would in a classroom situation. In terms of I-statements, she used "state statements" prior to ability and action statements: "I was getting irate with not being able to do anything…I can figure this out, so I'll just figure this out instead…I didn't start doing calculations...I was more trying to find relationships." These I-statements showed a pattern of reflection on her state to determine paths that would allow her to move ahead with her problem solving.

Engineering focused use of language

Engineering focused use of language shaped the perceptions of some participants, namely Justin, Christopher, Michael, and Amanda. Engineering language was reflected in the discussions of efficiency and reflections on characteristics or behaviors crucial to the engineering field in general. For Amanda, this was exemplified through her "organizer" and "simplifier" identities and in the importance of having a plan in the problem-solving process before attempting any calculations and sticking to that plan in order to achieve success. Amanda showed a preference for planning her calculations: "What's the point of solving for it now if I'm going to have to solve for it later, I might as well just get everything written out and how I want to plan everything first." She wrote "everything out" and prioritized organizing the information and having a clear plan as a first step in the problem-solving process. As an "organizer" Amanda highlighted the importance of efficiency and her ability to achieve a correct solution with minimum resources such as time, energy, and cost. Her preference for good organization was also supported through her "simplifier" identity that aimed to "look at limits and cut things out that way first" using the "process of elimination." Justin, in turn, exemplified an alternative aspect of the engineering focused use of language in his emphasis on the sales aspect of engineering as different from technical aspects. For example, he referred to the aspects of both "engineering" and "business" worlds. His dual focus on being both an engineer and "people person" exemplified his situated identity as a "rationalizer" in explaining his reasoning for taking certain problem-solving approaches.

> I can acclimate a lot better to personal relationships and the business orientation of the technical side…it's something I'm naturally inclined to do...I'm better suited for business and things like that...I want to be on the technical side of business.

Justin associated the technical side of engineering with a required knowledge base that is important in problem-solving, and saw experience in the field as crucial to developing this knowledge base. "I haven't done what some people have done like 10 years of work in the field so they just know off the top of their head." Justin had a strong awareness of his personal strengths and weaknesses and he associated his strengths with the sales aspect of engineering and his weaknesses with the technical side of engineering practice.

Christopher, also made strong differentiations between different aspects of engineering and how these differences might affect his approaches to problem-solving. It was important for Christopher to be able to communicate engineering knowledge to different audiences in various ways and he believed this skill differentiated his problem-solving approach. For this reason, he saw practical experience in the classroom context, becoming a "practitioner" as integral to his development as an engineer. While he appreciated the scientific focus in the academic context, he also valued being able to communicate meaningful information through practical terms and making science more meaningful for engineering professionals. He asserted that in his classes,

> I wish we had more…not necessarily realistic, but less science behind it, I mean the science is good…but more of how you then use that in the job…strain hardening and all these little equations are very useful theoretical, or for research, but to use that in the field if you're talking to someone...unless they're another metallurgist…they're not going to have any idea what you're talking about...I may know what I'm talking about but it doesn't help me tell them what they need to know.

Michael, in turn, operated within the engineering focused language in his situated identity as a "strategizer." He described first developing a clear conceptualization of the problem, repeatedly stating that at the beginning of each problem he solved in our study, and he visualized and contextualized the problem, "Just trying to get a full-scale representation of what it might look like," "I generally think of platforms as squares or rectangles." Michael used various strategies to understand and "frame" the problem, including drawings from information learned in previous classes, "I took a corrosion class last semester and that was one of the main points of it"; applying heuristics developed from experience, "It's a series of thin strands and thin strands to me means small…1 mm is a good starting point I would think"; and incorporating real-world constraints, "In my mind I see that big, see a steel cable that big, it's not going to be exceptionally large." For both conceptualizing and solving the problem, Michael emphasized the importance of viewing the problem within a real-world engineering context:

> Generally you have probably an expected value of what would compare it to and what I've learned is to be reasonable…if you look at a bridge and it says [the cross-section of the member's] going to be 9 feet by 9 feet, no one's going

> to believe that. If you don't compare your answers you're probably going to get it wrong to what you know in real life.

As such, Michael's reasoning strategies and decisions reflected the complex and dynamic nature of real-world engineering problem-solving. He viewed problems from different perspectives, "I picked the range of values for the strength, and then also the cost," applied complex strategies, and presented multiple possible solutions to open-ended problems.

Individualistic use of language

Ashley and Joshua made connections to the individualistic use of language when they described their problem-solving processes. For example, Ashley's descriptions made continuous references to individualistic values such as intentionality, independence, and self-directed learning. She described her "independent thinker" identity through her trust in her own experiential knowledge. She showed a strong belief in her ability to solve posited problems and suggested that learned information and her previous problem-solving experience should benefit her more than knowledge gained from other problem-solvers or second-hand notes scribbled in textbooks.

> Maybe I don't trust what other people would write in the book…I don't like books that other people have highlighted or underlined...I was sure of myself... I knew what the equation was and I didn't really need the book to validate that.

Similarly, Joshua trusted in his existing knowledge. Joshua shared that,

> as long as you know a few facts about the material and just stuff that you've learned in general like metals are good at this, steel's awesome at this. Like you could just pretty much answer it in your head. Like I could have done just about as good a job not looking at the book.

Furthermore, Ashley accessed resources such as the book simply as a point of verification or validation that she was on the right path.

> I looked it up in the book just to make sure...to make sure I had it right. I felt like this was kind of a minor unimportant calculation...I knew how to do it, it wasn't a big deal...I could just do it off on the side...I probably could've even done it just on my calculator.

She also had a strong sense of direction and confidence in her own abilities and saw this as integral to her problem-solving. "I like to do things myself, to be able to understand them...I like to write it myself or do it myself and that's how I learn." This example also supported her pedagogical value in learning through doing as important for mastery during problem-solving or conceptualization. Whereas some other participants showed a level of dependency on the textbook supplied to participants as they solved the problems, Ashley used the text solely for verification in moments of doubt, indicating that she recognizes that textbooks are not error-proof and she is considering this in her problem-solving.

> I usually think I'll be able to solve this problem and I'll be able to find the information I need…I just remembered it from learning it…I know books always have mistakes in them...If it was something I knew less about I would probably be more inclined to believe what the book has to say.

Ashley's independence was also evident through her level of confidence in drawing from past successes, whether it was in her classroom experiences or her performance as a student. "I guess I've always been a good student myself…I usually think...oh I'll be able to solve this problem and I'll be able to find the information I need." This confident approach and sense of individualism in problem solving as gained through her pedagogical experiences supported the value she placed in her abilities during problem-solving exercises.

Joshua was also confident in himself but differently than Ashley. For example, Joshua explained that individual justification is important for his problem solving: "I'm trying to put down a correct answer that I can justify. Like it might not have to be the best answer as long as I can justify it. Like it says justify your choice of material, how you arrived at this choice. So if I put down something that will hold up that thing it's good enough."

Collaborative use of language

Michael's reflections during his problem-solving processes were situated within real-life contexts, including both his present academic situation as well as his perceptions of future workplace settings. In his description, Michael showed a strong awareness for the central role of the "collaborative" use of language in real-life engineering. He stated that when solving complex engineering problems, "generally you're going to be working on a problem like this [in groups]. I mean it's a rare case that someone tasks to you figuring out what the problem is. That's generally in a group problem." He reflected on working in "a group setting," explaining that while collaborating with others, it is important to "talk it out, figure out exactly what you're trying to work for" in order to have everyone understand the "scope of the problem" and keep the common goals of the problem "in mind every time you do something." Furthermore, Michael also discussed the benefits and frustrations of talking out loud in group settings, stating that, "It's helpful to me to categorize my thought process to be able to let someone else know what I'm thinking. That probably helps me learn a lot more than just doing the problem."

Math focused use of language

The influence of mathematics was evident throughout Matthew's use of language. Matthew placed high value on his mathematical background and approached all of the materials engineering problems as merely mathematical problems. This perspective was characterized by a seemingly blind trust in mathematics as an infallible tool that leads to absolute truths. "Well, basically that if you have the right equations then you can solve anything." Matthew drew on general mathematics knowledge from fields including trigonometry and geometry, as well as more specific mathematics concepts in engineering such as Miller's indices and figures-of-merit to solve the problems. However, Matthew did not display an in-depth understanding of such mathematical concepts, but focused almost entirely upon the algebraic manipulation of equations.

> I decided that as long as I could justify the material, I could choose any material. I basically just took a material that could possibly be used in this situation and then plugged it into the equations that I had already generated.

Matthew referred to his mathematics background as a core value that defined his identity in problem solving. His mathematical training was the basis of the established patterns on which he developed his problem-solving approach. Matthew's identity as a "mathematician" was predominantly defined by his ability to find and use equations. "I knew there was an equation and I knew I could probably find the equation in the book. I couldn't remember the equation…" When unable to retrieve an equation from memory, Matthew reported consulting the textbook or other sources such as the internet for specific equations. "Because I depend a lot on equations and so I guess if I am unsure how two things relate then I go directly to a book and try to find an equation…on Google they'll pull up the equation instantly." Likewise, Matthew's main form of inquiry during the problem-solving session involved searching for equations in the textbook.

Non-contextualized pattern-based confidence emerged in Matthew's belief that a single unique solution exists for each problem. This belief was manifested in his search for an absolute, correct answer that Matthew firmly believed was attainable via a series of calculations.

> I'm not sure if that was the question that they wanted me to answer. I also remembered that there was a way to calculate the angle using Miller indices instead of pure geometry…but I didn't see it (in the book) and so I decided to just go with the geometry of the problem.

Under circumstances in which he was unsure of whether the calculations were moving him towards a solution, and even when he had a suspicion that he may not be approaching the problem correctly, Matthew still did not abandon his attempts at reaching a solution via algebraic manipulations of equations.

Matthew's problem-solving process can be characterized by somewhat limited application of equations to the variables at hand without an understanding of the underlying phenomena that the equations represent. This was exemplified by justifications of equation choices such as, "Because basically throughout the classes that I have had, every time I see a design problem the way to solve it was to use a figure-of-merit." When solving problems, Matthew focused his attention on arranging, connecting, and/or eliminating the terms of equations. Often, the goal of manipulating equations was to develop an equation, or a series of equations, that would coincide with the variables presented in the problem, or to arrange an equation similarly to equations presented in example problems in the textbook. On many occasions, Matthew's use of language revolved around his success or failure at manipulating equations which he viewed as an essential component of problem solving. "Um, was basically just playing around with the equations and trying to move them into something recognizable that I could go to the book for."

Discussion

From a constructivist perspective individuals and their identities are always constructed in a relation to the social: social norms, expectations, socially accepted behavior, roles, and interactions with others. Socially constructed identities and language practices, in turn, influence the ways in which students perceive themselves as learners, problem-solvers and also future professionals. These socio-cultural practices and discourses shape individuals' actions and language use within social groups but they are also often internalized, reflecting individual behavior. More specifically, how students situate themselves in different language practices, describe their thinking and problem solving while solving problems in the class setting can also possibly speak to the ways in which these students situate themselves when solving engineering problems as future professionals.

The language used by participants in this study exhibited a very small number of identities. While this study is specifically limited to a particular problem-solving task, much of the classroom practice in engineering is situated in this type of context. Thus, we feel that the ways in which students talked about their problem-solving processes provided an important window (although admittedly not the only one) into how they saw themselves as engineers.

For Gee (2011a, 2011b) language has a dual role. We use language to communicate based on the situation we are in and at the same time language influences that situation. This may seem circular, but Gee points out language is a process of continuous building in which "language and institutions 'bootstrap' each other into existence in a reciprocal process through time" (p. 10). We can see this process in the way many of our participants talked about their problem-solving processes. The clearest case was perhaps Matthew, who constructed a reality of the problem as an analytically solvable mathematical problem.

Similarly, Jessica's use of language kept her within the academic setting as a problem-solver. The language she used to describe her lack of self-confidence was focused on problem-solving as a pedagogical activity. As with Matthew, this limited Jessica's ability to see problem-solving as something more than academic. In this context, it is interesting to note that Jessica began the interview by asking what grade she received on the problems. Her seeking feedback is important to consider, in light of stereotype research suggesting that subtle comments about grading can introduce stereotype threat to those who are vulnerable (i.e., the false claim that women aren't as skilled at math as men; Good, Aronson, & Harder, 2008).

Some other students in this study demonstrated similar relationships between language and problem-solving reality, although these are more nuanced because they exhibited multiple identities. One of the common uses of language, exhibited by our participants (Christopher, Amanda, and Justin), is the dual use of pedagogical and engineering foci. This was exemplified in the way they talked about problem-solving as an academic exercise ("I can just quickly solve the problem, be done with it." – Justin) and engineering as "real-world" ("…these little equations are very useful theoretical, or for research, but to use that in the field…they're not going to have any idea what you're talking about…" – Christopher). This distinction between the academic world and the world of engineering practice appears consistently in our data, even outside of the I-statements that were the focus of our analytical approach. For example, Amanda compared tests in classes with engineering practice by saying, "in like the real world I guess, but there probably would still be some constraints there because it's going to be cost or it's going to be that or you'll just have a lot of ideas and like you can do this, you can do that, you can do that, you can do that. So whereas tests it's kind of like whoop, you want to make sure you learn some things." Similarly, Christopher talked about how one of the problems was structured saying that it "doesn't necessarily take into account processing and construction and labor and profit and everything else involved in the cost of building a bridge." Thus, while students' responses outside the I-statements brought up these aspects of engineering practice, these identities were seen as separate from their identities as engineering students. Additionally, students did not internalize or own these identities by referring to the "real-world" aspects of engineering within their personalized I-statements.

Again, in these statements we see both the way language expresses students' identities and the way language constructs the reality they live in. For example, Amanda's statement that in the real world you can "have a lot of ideas" while in the academic world "you want to make sure you learn some things" limits the ways in which she is able to navigate the two worlds. By limiting herself in this way she prevented herself from seeing the academic world as a place where you can have ideas, or the real world as a place where you can learn.

Conclusions

Participants' uses of language and resulting identities as problem solvers in this study were limited and connected to a specific academic context, one in which mathematical formulas, simplistic problem solving heuristics, and grades are dominant features of academic discourses. It is possible that participants' descriptions of their problem-solving processes in this type of problem solving situation did not elicit (what we would consider) creativity or out-of-box thinking; rather, our participants' language use suggests that they were more likely to adopt a passive approach. Even when the pedagogical uses of language were not explicitly identified as influencing a student's identity, elements of the academic context were clear in the language used by participants.

This study also prompted us to consider more carefully what type of assumptions about knowing and learning is embedded in "typical" classroom and research activities. Our problem-solving activity and think-aloud prompts were designed to resemble normative classroom contexts, including "typical" materials available when students are asked to solve problems in engineering education classrooms and during the tests. However, it is important to note that designing a study that centers around the think-aloud method and individual problem solving activities is likely to generate a specific type of knowledge about learning and engineering related to that context. Thus, it is likely that the setting for this study resulted in a perception by participants of the problems as being academic in nature. The problems used in this study were created to assess engineering students' abilities to solve both closed-ended and open-ended academic problems. The problem-solving activity was conducted in a university office, and presented in a paper-and-pencil format with a classroom textbook as a reference, closely reflecting the context in which students receive academic training. We also propose that when students' identities are rooted in academic and linguistic contexts in which they traditionally solve problems students might not be sufficiently encouraged and prompted to develop more complex language uses and types of problem solving skills that would be beneficial in their professional lives as engineers.

It is certainly possible that these students *are* able to see connections between the problems they solve in "school" and "real world" problems and would prefer to use language in more varied ways. However, Downey (2008) argues that the focus of problem-solving in the academic context of engineering education promotes a narrow view of engineering identity and that those who work outside the boundaries of the defined problem-solving space are judged to be "incorrect." Some of our participants did talk about grades and "being correct," suggesting that they may be limited in their views by the academic context.

Not all of the students in this study approached the problems from an entirely academic perspective or discourse. Michael was able to see beyond the academic setting and emphasized the importance of understanding the real-world context of engineering problems, suggesting that it is possible for some students to make connections beyond the academic setting. Even in Michael's case, however, the connection to the "real-world" was limited to technical considerations. Our students did not articulate complex views about clients, environment, or societal aspects of engineering problem solving during their problem solving or even afterwards when asked to reflect on the occurred problem solving processes. Although some participants in this study expressed frustration with a perceived disconnect between their academic experiences and their view of "real world" engineering practice, their use of language did not reveal a critical view of the power dynamics or values they encountered in their academic experiences. In this particular problem solving context participants constructed their identities as problem solvers primarily through or within individualistic discourses. For example, reflections on working within a team, solving problems creatively generating approaches outside text book examples, identifying with cross cultural beliefs and values were mostly absent in our data.

While our findings are based on a limited number of students in a specific context and other interpretations certainly are possible, they do reveal some fruitful areas for additional study connecting engineering students' identities as problem-solvers to the wider socio-political influences that define engineering. In particular, the apparent disconnect between "academic engineering" and engineering practice needs to be investigated further to identify whether it occurs in other contexts, and if so, how academic practices lead to this disconnect. This could involve think-alouds with student teams, students working on open-ended real world problems, or practicing engineers (for an example, see Sherrett et al., 2013). Ultimately, this line of study could begin to address important questions about the education of future engineers: What are the implications of the current academic setting for how students ultimately practice engineering? What pedagogical practices promote self-identification of students as engineers? One example of how this could be done comes from Downey (2008). He describes a course in which liberal arts is seen as a component of engineering, with the goal of moving engineering problem-solving for these students beyond traditional mathematical analysis and into the consideration of alternative cultures and perspectives. Another example comes from Paretti and McNair (2012) who describe the identity formation of students in a design class which has been deliberately formulated to involved close collaboration among engineering, industrial design, and marketing students throughout the design process. The experience of these students contrasts with the typical design course, as well as the other case examined in their paper, an industrial design team. In that industry team, the various functions were siloed, and engineering largely filled a subordinate role to the marketing decisions. As they point out, "[t]his case [the academic design class], then, suggests what engineering identities could be, given less constrained institutional expectations and more integrative discourses" (Paretti & McNair, 2012, p. 75). It might also be illuminative to study more in depth "ill-formed" problems and strategies students are using to solve these types of problems. In addition, a future study could also address how practicing engineers and students work together to solve or frame a problem. In addition to modeling how engineers think about framing/solving the technical aspects of the problem, the practicing engineers might add to the problem solving the contextual information that students might not be aware of. In order to connect students to the worldviews and language associated with broader engineering practices, alternate approaches such as these may be needed to move students beyond the limitations of the academic setting.

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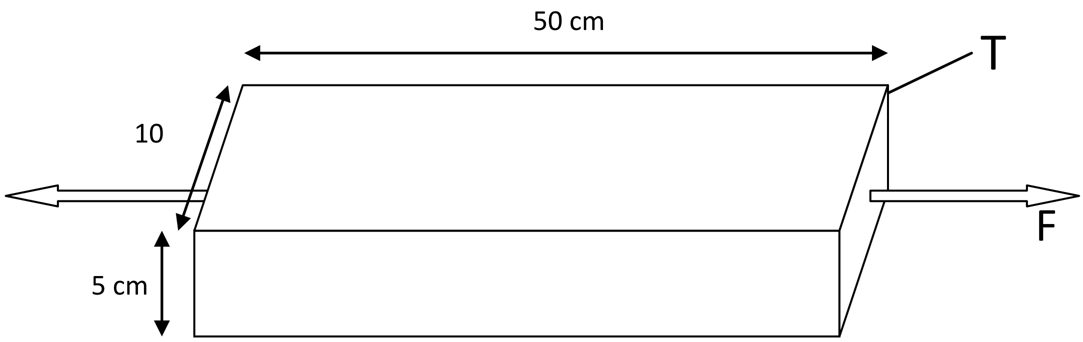
Appendix A

Engineering Problems Used During Think-Aloud

1. A cylindrical rod of single crystal nickel with a radius of 2 cm yields when a tensile force of 17.47 kN is applied along its length. This force is being applied in the [001] direction. Slip occurs on the (111) plane in the [$\bar{1}01$] direction. What is the critical resolved shear stress for this slip system?
2. An iron bar with the dimensions as shown below is being used as a structural support member underwater in the presence of HCl. Corrosion occurs only on the top surface (marked T in the figure below) and the corrosion current measured on this surface is $1.58\text{x}10^{-2}$ amperes. This structural member is inspected periodically using ultrasound, and the smallest internal crack that can cause failure is 6 mm (you may assume there are no surface cracks). The plane strain fracture toughness of the iron is 41 MPa-m$^{1/2}$. The force applied to this member is 1,750 kN in the direction as shown in the figure. How long can this member remain in service before it needs to be replaced?



3. A platform is to be suspended from a ceiling by a series of thin strands of a material. It is estimated that the load on each strand will be 12,000 N. The design requires a safety factor of 2. Select an appropriate material for these strands and the strand diameter. Justify your choice of material and show how you arrived at this choice.
4. A truss bridge requires 40 members, each of which is 12 feet long and experiences its maximum load when in tension. The bridge is designed so that the maximum stress experienced by each member is 60 MN. You are bidding on the contract to provide these 40 members. Provide a recommendation as to the specifications for these members and cost for the job.

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