AC 2010-358: SECONDARY STUDENTS' CONCEPTIONS OF ENGINEERS AND ENGINEERING: A CASE STUDY APPROACH

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Secondary Students' Conceptions of Engineers and Engineering: A Case Study Approach

Abstract

Researchers have long been interested in how to recruit and retain more and more diverse students into engineering programs. One consistent challenge in this research is understanding the impacts of interventions from the point of view of the student. This study investigated how secondary students understand the concept of engineering, including what engineering is and what engineers do. The purpose of this work was to describe students' conceptions of engineering, and to determine how those perceptions affected student interest in engineering careers. The investigation was founded on the theoretical framework of conceptual ecology. Students from one high school that are typically underrepresented demographically in engineering programs were surveyed and interviewed about their perspective on engineering. The survey results were used to group students and to help purposefully sample the most information-rich groups of students. Interviews were transcribed and analyzed using the constant comparative and thematic analysis methods. Students who were interested in pursuing an engineering career generally believed that it involved hands-on building or fixing of cars, bridges or airplanes. Students who were not interested in a career in engineering discussed a broader variety of types of engineering, and more often cited altruism and inherent interest as reasons that others would pursue such careers. Most students in this study did not express very complex or rich conceptions of engineers or engineering, but their conceptual ecologies suggest that they would be resistant to changing these conceptions. This suggests that recruitment and retention programs will need to directly address students' existing conceptions of engineering.

Introduction

Retention and recruitment of diverse and talented individuals into the engineering industry is a topic of long and increasing interest. Research investigating why students choose to discontinue science, technology, engineering and mathematics (STEM) majors has indicated that students' perceptions of engineering as a career play a major role in persistence decisions[1]. Similarly, students' definitions of what engineers do play an important role in persistence, particularly in students' identification of themselves as engineers. These conceptions change over students' college careers[2, 3], but students of all ages and stages often have great difficulty communicating or defining what the discipline of engineering encompasses[2].

In the rich body of literature exploring how individuals make career decisions knowledge of various disciplines is just one variable among many. Knowledge of the field may be treated as a binary variable (people are either knowledgeable or not) or as a more complex spectrum (people may be knowledgeable to different degrees), but in most studies it is treated as a characteristic or quantity that a participant may have. Most educators now agree that peoples' previous knowledge and ways of thinking influence learning in any field[4]. This basic assumption of learning changes the concept of knowledge from a static quantity that may be possessed or transported to a dynamic process occurring within and among people. The work presented here represents a preliminary effort to incorporate this conception of knowledge into the investigation of why students may choose to pursue a career in engineering. This study is a first step in characterizing students' knowledge about engineering that could limit recruitment and retention, and elucidating future pathways to change so that more of these students enter and succeed in the field.

Theoretical Framework

The constructivist assumption that all learning involves interactions with previous knowledge has been guiding research in science, technology, engineering and mathematics education for at least 20 years[4, 5]. The commonality of this conviction, however, has not lead to a unified description of how previous knowledge affects learning. The conceptual change approach is theoretically grounded in cognitive science and aims to describe these interactions in terms of the mental organizing structures people use to make sense of new information. These organizing structures are commonly said to be built from "concepts"— a loosely defined word[6, 7] that, in this paper, refers to any of several types of cognitive entities that are interrelated in cognitive structures. One way to describe the way concepts and their structures affect learning is that they act as a conceptual ecology.

Conceptual Ecology

Conceptual ecology represents an attempt to explain the interaction of existing knowledge and new information metaphorically as a dynamic ecosystem[8]. In a natural ecosystem all the organisms, processes and resources are balanced and fit together. When a new entity is introduced (for example a new organism, or a new inflow of nutrients), a complex chain of events can lead to any of a number of outcomes including no basic change (for example if the nutrients are simply transported through the system), small change (for example the new organism replaces another organism and fills the same ecological role), or drastic change (for example the new nutrients cause algal blooms and hypoxia). Learning is pictured as the introduction of new cognitive entities to an already complexly interacting ecosystem of information, experiences, ontological assumptions and related conceptual systems[9], and the same basic alternatives apply. The new cognitive entities could replace existing entities, be outcompeted, or find a new, unexpected niche in the ecosystem.

Just as organisms, processes and resources are all equally important features of natural ecosystems, conceptual ecologies are constructed of various forms of conceptual entities. In an article titled "Why 'conceptual ecology' is a good idea" Andrea diSessa[10] writes, "…conceptual change involves a large number of diverse kinds of knowledge, organized and re-organized into complex systems." The various types of knowledge he is referring too include memories, concepts from other fields, fundamental assumptions about knowledge and the universe, perceptual schema or organizational conceptual hierarchies. The diversity and complexity of conceptual ecologies is no less important or bewildering than that of natural ecosystems.

Engineering as a Concept

Although conceptual change research has been performed in social fields[11], it is worth developing the argument here that the conceptual approach is appropriate to the study of students' understandings of what engineering is and what engineers do. The main argument against considering students' understandings of engineering and engineers in terms of conceptual ecology seems to be that engineering is a social phenomenon, and therefore inherently subjective and impossible to define. The assumption is that the concepts typically studied, for example one-dimensional velocity, are based in the physical world, and therefore more objectively defined. The strength of the conceptual ecology approach, however, is that it includes a diversity of cognitive entities. The development of a students' conceptual ecology of physical phenomena will be different than the development of conceptual ecology for the concept of *engineering*, but only in the relative importance of specific interactions and cognitive entities. Whether a phenomena is considered to be "physical" or "social" affects the specific cognitive entities and relationships in the conceptual ecology, but the not the validity of the conceptual ecology approach.

Purpose and Research Questions

The purpose of this study is to describe how a group of high school students understands the concept of *engineering* in terms of their conceptual ecologies. This, in turn, will illuminate on how the concept may changes or resists change.

1. How do these high school students understand the concept *engineering*?
    a. How do they define it in their own words?
    b. How does this definition interact with their level of interest in becoming an engineer?
2. What conceptual ecology does the concept *engineering* exist in?
    a. What types of cognitive entities do students use to define it?
    b. How might this conceptual ecology interact with their learning about engineering?

Methods

Research Setting

This research was performed in a small, rural high school of less than 500 students. The school draws students from a wide geographic area, and serves as the primary high school outlet for several middle schools. The town in which the school is located is on the border of a large Native American reservation. The Office of the Superintendent of Public Instruction website reported that approximately half of the students in this high school are Native American, approximately 40% are Caucasian, and approximately 4% are Hispanic. Over half of the students receive free or reduced-price lunch, indicating a community with limited financial resources. A large engineering-related industry (a power-generating facility) and tourism form the backbone of the local economy. The tribal government on the reservation is also a significant employer. The school faces some historic challenges, including chronically low funding and below-average scores on standardized tests (around 20% passing the math and science sections of the state's standardized tests for 10th grade). The researchers visited the school approximately twice a month during the school year as part of an NSF-funded effort to present engineering-based math and science projects to high school students. The research reported here was performed during two such visits, but the program was primarily focused on the development and presentation of lab exercises.

Participant Selection

At the beginning of the school year, the researchers surveyed 117 students with a 90% survey return rate. The participants surveyed represented a cross-section of age, academic achievement, cultural background and gender. The survey was designed solely as an aid in participant selection, and asked students to respond to statements about engineering with Likert-scale indications of their agreement or disagreement. Example statements include:

- Engineers help people.
- Engineers affect my life.
- I want to be an engineer.
- Engineers are fun people.
- Engineers build big things, like freeways and skyscrapers.
- I could be an engineer, if I wanted.

Two groups of students were chosen for interviews based on their survey responses. The first group consisted of 10 students who indicated that while they were confident that they could become engineers, but they did not want to. These were the only students who disagreed or strongly disagreed with the statement “I want to be an engineer.” All students responded neutrally, agreed or strongly agreed with the statement, “I could become an engineer, if I wanted to.” These students form a particularly interesting group because they presumably did not like engineering for reasons other than doubting their own ability. The second group of 10 students consisted of the only students to agree or strongly agree with the statement “I want to be an engineer” in the survey. For convenience, these two groups will be referred to collectively as the participant selection groups, and as the Don’t-Want-To (survey responses indicate they believe they could be engineers, but don’t want to) and Want-To (survey responses indicate they want to be engineers) groups, respectively.

The student sample was chosen purposefully to provide the most interesting case possible. This is an example of what Patton[12] calls “purposeful sampling.” Patton writes, “…in all purposeful sampling decisions, the researcher has an obligation to present the rationale and expected benefits of this strategy as well as to note its weakness (lack of generalizability).” Obviously, generalization to the population of high school students in the United States is not the purpose of this study. Instead, the goal is to guide future studies by providing a framework, and, hopefully, a motivation to investigate students’ conceptions of engineering and engineers by describing an information-rich group. The students at the school sampled can be considered an information-rich group in terms of their conceptions of engineering because, statistically-speaking, they are grossly under-represented in engineering programs due to their academic performance, socio-economic status and ethnicity [13]. Although this study cannot make claims about demographically similar students as a group, this school was chosen for maximum illustrative power.

Interviews

The interviews were conducted by two researchers who had been working with the students throughout the school year. The interviews were conducted over a two-day period near the end of the school year, during normal classroom activities, and lasted between 7 and 15 minutes. The interviews were audio-recorded in the classroom setting to ensure that students were able to respond in the most natural way possible. With additional classroom noise, some utterances were inaudible. Usually this consisted of only a few words within a series of sentences. Inaudible portions were noted in the transcripts, and annotations from the field notes about the topic being discussed were added in brackets. No more than 10% of any interview was inaudible. Interview questions are listed below, but it should be noted that this list does not present a complete picture of the interviews because of their semi-structured nature.

1. What do you think of when you hear the word "engineer?"
2. Do you think you could be an engineer? Why or why not?
3. Why do you think some people want to be engineers?
4. Please tell me about some different kinds of engineers.
5. Do you know any engineers?
6. Do you remember when you started thinking about engineering? Has it changed recently?
7. Have you considered a career in engineering? Why or why not?
8. What do you think the difference between a scientist and an engineer is?
9. What do you think the difference between a construction worker and an engineer is?

Semi-structured clinical interviews were used to investigate students' conceptual ecologies. Clinical interviews, as described by diSessa[14] are primarily intended "…to allow the interviewee to expose his/her 'natural' ways of thinking about the situation at hand. An assumption is that subjects' ways of thinking are delicate and complex, and skill is necessary to surface them in a mutually intelligible way"[14]. The interviews in this study are clinical in the sense that they are intended to bring to light the conceptions have of engineers, including the conceptions that the students may be unaware of or unable to communicate. These interviews are semi-structured because each interview was based on the same set of standard questions, but developed differently depending on the students' responses and the interviewers' ongoing analyses. Semi-structured interviews allowed the interviewers to tailor each interview to the participant and to improve the interview protocol during data collection while allowing comparison between interviews. Because the participants were younger than the interviewers and interacted with them as instructors during class, they would likely not have been comfortable in a formal interview setting. The freedom to follow up on certain questions also made it possible to work around or clarify key vocabulary differences between the researchers and participants. For example, many students stated that engineers "fix things," but further questions about the details of "fixing" revealed that some students were using the word similar to the sense of "fixing" a game of chance to ensure a certain outcome – which is more similar to what the researchers would call design than mechanical maintenance.

Clinical semi-structured interviews allowed the researchers to investigate concepts as collections of entities in an interrelated web as required by the theoretical framework guiding this research. Many students are uncertain what engineering is, or think of it mostly in terms of another field, such as construction or research. This means that students may not be able to answer direct questions about the definition of engineering, and may not even think of engineering in the same context as the interviewers. Semi-structured clinical interviews framed in terms of conceptual ecology, however, provided a means to learn about students' conceptions of engineering by investigating related concepts.

Analysis

The interviews were transcribed and then analyzed qualitatively using the constant comparative method [15, 16]. The constant comparative method involves three primary steps that are repeated recursively until themes emerge. The first step is to familiarize oneself with the data, and this consisted primarily of reading the transcripts and listening to the audio-recorded interviews. The second step is pattern-coding[16], in which superficial patterns are recognized and recorded. In this use, "superficial" means only that they require a low level of interpretation, and are more like tags labeling groups of similar statements. The third step of this process is best explained by Braun and Clarke[17] in their article describing thematic analysis. They break this step into two sub-steps, the collection and checking of themes. In their definition, themes are groupings of pattern codes that are formed based on a theoretically important inference. Braun and Clarke describe checking themes as a process of comparing the meaning of the theme with each individual statement coded under it, and with the body of data as a whole. For example, in this study, all of the student quotes coded under "Building," "Fixing" or "Build vs. Design" during the first two steps of analysis were grouped into a theme concerning confusion about what engineers do. Then each statement reread to see if it supported the idea that students held contradictory beliefs about what engineers do. This process revealed that student comparisons between engineers and scientists were particularly rich examples of these contradictions, and the code "Engineers in Comparisons" was therefore added to the theme. In order to compare the meaningfulness of this theme to the entire data set, the overall number of statements coded under this theme was compared to other themes, as well as the number of proportion of participants who had at least one statement coded under the theme. Because a significant number of student statements included this theme, and a large majority of students made such statements, this theme was considered meaningful and used in the generation of meaningful results and conclusions.

Results and Discussion

The results section will be organized based on the guiding research questions. First, students' definitions of engineering will be summarized discussed in terms of their reported interest in becoming engineers. Then the most prominent aspects of students' conceptual ecologies will be presented, followed by a brief discussion about how these ecologies might affect student learning about engineering. Note that student names have been replaced with pseudonyms.

Students' Definitions of Engineering

By far, the most common response to the opening question, "What comes to mind when you hear the word 'engineer'?" had to do with the mechanistic work of building or fixing. Jack, for example associated construction to engineering by stating, "People building things, making things, like trying to fix them." When asked if he could become an engineer, Jack stated, "I think I could. I live on a farm, so I have to fix a lot of engines and stuff like that." Building or fixing things was the primary component of the definition of *engineering* for 20 of the 27 students interviewed. Five of those 20, however, included a variety of other jobs. For example, Jane said that engineers are "…people who help build things to make our lives easier," and Kristine said, "I think of building things, and physics, math. There's so many things that engineers do." Similarly, Wendy said, "I think of mechanics, math, science…like a motor engine. It's such a broad area."

The remaining students defined *engineering* in a variety of ways. Two students, Jane and Kristine believed that helping society was an important part of engineering. When asked why some people might want to become engineers, Jane said, "they want to make the world a safer place [Interviewer asks 'anything else you can think of?']…to help out people who need help, and just to do what they like to do," and Kristine said, "as a job, like to earn money and stuff…and to, I don't know, to help people." Wendy and Cory focused more on the academic side of engineering. Cory defined engineers as "somebody who studies things like biology, or, like chemicals or whatever to help things be more efficient in science," while Wendy said engineers "…use math in general, to figure out problems…."

Finally, a few students had much more developed and precise definitions of *engineering*. Hank, for example, consistently formulated his answers in the context of design. He said that engineers "…design things like buildings and cars," and when asked to clarify, he said that they "…work with people to figure out what they'll look like." He clarified the difference between scientists and engineers by saying that they both might "study chemicals and stuff like that… but I don't think scientists build things and help people build things."

Relationship Between Interest in Engineering and Definitions of *Engineering*

In this study, a more developed view of engineering – including it's creative and altruistic aspects, which are typically taken to increase its attractiveness as a career – made it less likely for a student to be interested in it as a career. Eight of the nine students who indicated that they were interested in becoming an engineer defined engineering primarily as either building or fixing, while only five of the 8 students in the Don't-Want-To group made that association. Students in the Don't-Want-To group seemed to be more aware of the breadth of the term "engineering" than students in the Want-To group. Three students in the Don't-Want-To group, Jane, Kristine and Wendy, all had multi-faceted opinions about what engineers do, but no students in the Want-To group made similar statements.

Somewhat surprisingly, students in the Don't-Want-To group were more able to generate reasons why people would want to be engineers when asked. The most-cited reason, as stated by Daryl, was "because it interests them." Carey similarly reasoned that there is something inherent in some people that makes them want to be engineers:

> **Carey:** Like, I can see some people, like, cousins and stuff, they've always been, like, building stuff… So maybe it's like, you're just born to be one. I don't know. It seems like some people, it just works out that way.

Interviewer: Yeah. Is it more what they like or what they're good at?
Carey: Yeah, what they would like….If they like to build stuff, then that would be a good job to go to, probably.

Students in the Don't-Want-To group also mentioned altruistic reasons and the desire to leave a lasting mark as motivations to become engineers. Cory, in particular, referred to engineers "making life better" throughout her interview. When asked if engineers invent things, she said "…they can invent things that will help everyday tasks go better or easier, and make things more ecosystem-friendly or whatever."

Student Conceptual Ecologies of *Engineering*

In general, students were not certain about *engineering* or what it entailed. As an extreme example, Vicky refused to make any guesses about what engineers did. When asked how she might explain engineering to a younger sister or brother, she said, "I'd say 'Go ask Mom.'" In terms of conceptual ecology, this uncertainty could be explained by students' conceptual ecologies lacking mental representations of engineers or engineering. Because students didn't have these to draw on, when asked direct questions about engineers they had to resort to analogies and metaphors. For example, some students relied on an array of bewilderingly specific distinctions in an effort to define *engineering*. For example, Terry said, "Engineers, I don't know, they travel a lot. And construction workers are in one spot for a really long time, and they move to another spot." Alex made almost the same distinction between scientists and engineers, saying "I don't think they [engineers] are in one spot. They're around places. Scientists are in on spot and do research there, and then move. It's more gradual." Sam focused on the popularity of the disciplines, saying "Scientists probably get paid more. They get more fame." When the interviewer queried, "But they do similar things, pretty much?" Sam continued, "Yeah, just one gets paid more and one doesn't get much credit."

The lack of *engineering* as a firmly developed concept in students' conceptual ecologies is further evidenced by their inability to meaningfully distinguish engineering from other fields. All students were asked to explain the differences between engineers and construction workers, and engineers and scientists. About half of the participants explained the difference between engineers and construction workers similarly to Hank, who said "I think an engineer decides how you build the car, and the people who build it, like, build it (laughs)." Similarly, when Jack was asked how engineers were involved with the local power plant, he said, "Yeah. They have to plan it all out, like the architecture. So, then they had to build it, like welding and all that stuff. People built it for them." Although Jack's immediate response to the question had to do with designing the building, in his clarification of that statement he returned to his core idea of engineers-as-builders. It is interesting to note that Jack apparently noticed this contradiction, and tried to clarify, stating that other people "built it for them." For most students in the Want-To group, similar statements occurred when they were asked what the difference between a construction worker and an engineer was. Adrian, for example, said, "I think engineers design it and construction workers build it." This statement isn't as clear as it seems, though, because Adrian defined design as "to create," and expressed that the activity she had done in school that was most like engineering was "building that little bridge…and testing it." Like Jack, Adrian seemed to know that engineers weren't just workers who build things, but was unclear on what else they did.

Half of the participants made a clear distinction between scientists and engineers. Many phrased this in terms of the real world and the laboratory, like Tim, who said, "I think scientists are more in labs, and engineers are a more 'open-world' kind of thing. Like, they do more stuff besides inside their office and what-not." Taylor represented this trend neatly, saying, "Scientists are indoors, engineers are out." Similarly, Cory said that an engineer is "somebody who studies a lot," so the interviewer asked "So, are most engineers at universities?" Cory seemed to agree with this logic, but was hesitant to counter her previous statement, saying "Um, like universities, or else, like, some industry-related thing like [the power plant]…or like mills, or different factories or whatever." When asked how these jobs related to the previous statements that engineers "study," Cory became confused, saying,

Cory: OK, what was the question again?
Interviewer: Just, what do they study there?
Cory: What do they study?
Interviewer: At one of those industry jobs.
Cory: I don't know. It, I mean, it would depend on what they're doing. Like at a lumber mill, they probably study what kinds of wood are best for what, and how much are sold. I don't know, because that probably crosses the line between engineering and economics.

Cory's statements again emphasize the difficulty students have in distinguishing engineering from other fields combined with a certainty that it is, in some way, different. This suggests that *engineering* is not a strongly defined concept, and its influence can easily be overwhelmed by related concepts like the definitions of similar careers or of *design*. The differences between the participant groups suggests that the multi-faceted, widely variable nature of *engineering* is of key importance to students' developing conceptual understanding of it. The students in the Don't-Want-To group were beginning to incorporate some aspects of this into their concept of *engineering*, and therefore found the concept more unintelligible than the students in the Want-To group.

Students' past experiences also played a central role in their conceptual ecologies of *engineering*. Jeremy, for example, explained how he knew what engineers are by saying, "Some people came to my house. There's electricians, there's plumbers, and they fix the bolts [referring to electrical outlets] at my house. I just always thought they worked on [the power plant], because I went inside there a couple times." Later in his interview, Jeremy described an activity requiring students to make parachutes as being the "most like engineering." He justified his statement saying, ""I think because like, the way you have to design it to make it stay [in the air] longer. And the different materials you can use." Then Jeremy and the interviewer had the following exchange,

Interviewer: OK. So how does that relate to fixing things?
Jeremy: Yeah, fixing things…making it. Like, if you put holes in it, how many strings you need.

Interviewer: So it's kind of like problem-solving. Like you know what you want, and you have to figure out what to do.
Jeremy: Yeah.
Interviewer: So would you say that plumbers and electricians do design? Is that the word that you'd use?
Jeremy: Mm [thinking], they fix the problem. Like, I don't know. They could make a new route to fix the old one.
Interviewer: OK. But if someone wanted to build a house, would you call, does the plumber and the electrician have to make up all that, where that goes? Who does that?
Jeremy: I don't know.

Many students revealed similar cognitive dissonance when asked about the local power plant. Due to its prominence, every student was familiar with the power plant and knew that engineers worked there. When asked what engineers do there many students immediately replied that they either built it, or that they perform what Cory called "higher-level maintenance." These assertions were based on students' past experience in their community, and even though they often contradicted their previous statements about what *engineering* is, they were unshakable.

Finally, students' knowledge of math played an important role in their conceptual ecologies. Twenty of the 27 students interviewed said that math was an important part of engineering. Only a few students could provide examples, however, and they only gave examples in terms of measurements and simple geometry. Hank, for example, said that bridge engineers need to know "how far apart" to put the steel pieces, and Holly said that engineers use math in the power plant to know which pieces of equipment will fit in which rooms. Students who focused on engineers as fixers had an even harder time justifying math's importance to engineering. Jack was the only student with an example: "You need the right wrenches, the right other stuff. There's a lot of math in it, I think." The case of Jack, a junior, is particularly interesting because he was interested in engineering as a career largely because he liked math as a subject in school. This shows that even when students are personally engaged and interested in the role of math in engineering, they are unable to use their knowledge of math to support their beliefs.

Relationship between Conceptual Ecologies and Learning About *Engineering*

Engineering is, apparently, a poorly defined concept that is tightly tied to both familiar (e.g. construction and stereotypical scientists) and unfamiliar (e.g. design) concepts. This means that any changes in the concept *engineering* may require accommodation in all the related concepts. The strength of students' past experiences suggests students may possess robust misconceptions that are resistant to change. These misconceptions could be beliefs about engineering based on past experience (like Jeremy's conviction that engineers fix things in his house), or they could be beliefs about design or construction. The tightness of all these connections increases the probability that students' conceptions of engineering will be resistant to change.

Students find *engineering* unintelligible, possibly because of the broad diversity of the field and the inherent contradictions that causes. For example, students may hear that engineers are involved in designing and constructing parking lots and housing developments, and that they are also involved in trying to actively solve environmental problems. Both of these statements are true, but their apparent contradiction may render *engineering* unintelligible until they can be somehow reconciled. Students strongly associate *engineering* with academic math and science, and therefore may find the social, creative and hands-on elements of *engineering* implausible.

Conclusions

Students who wanted to be engineers (the Want-To group) often described engineering as limited to the construction or maintenance of certain objects, while those less interested in engineering but confident in their ability to become engineers (the Don't-Want-To group) had a more nuanced view of the field and seemed more able to communicate its diversity. The tendency of students to define engineering as "building" matches Chacra's research with college freshmen in engineering programs[2], as well as findings from the Academic Pathways Study of the Center for the Advancement of Engineering Education[18]. The diversity, even in the small sample of students involved in this study, is unexpected, however. Although not as overwhelming as the 90% of women and minorities that cited similar concerns in Seymour and Hewitt's study[1], it should be noted that the only participants in this study who cited "helping people" as a part of *engineering* were women. Jocuns et al.[3] found that engineering students often enter engineering with a romantic image that includes opportunities to help people (altruism). Students choosing science, mathematics, and engineering (SME) majors commonly cite intrinsic interest and altruism as reasons for entering these fields[1]. This makes it particularly surprising that the only students in this study to include altruism as a reason for entering the field were not interested in engineering as a career.

These findings suggest that educators, administrators and researchers who are interested in recruiting and retaining underrepresented students in engineering programs must educate students about engineering. In order for students to learn about engineering, their conceptual ecologies must change. Because students' conceptions of engineering are closely tied to beliefs about related fields and their knowledge of math, these changes may not be inspired without directed, carefully designed interventions.

Future research with larger sample sizes will increase generalizability and allow comparisons to be drawn between groups of students based on their understanding of *engineering*. This may elucidate correlations between that understanding and students' decisions to enter or persist in engineering programs. Of particular interest would be an investigation of female or Native American students' conceptions of engineering. The importance of students' past experiences in this study, and the proven effects gender and ethnicity have on lived experience, suggest that gender and ethnicity may be important in the development of the concept of *engineering*. It remains unclear if these students would view engineering as a more interesting career if the concept were more intelligible. This research could also investigate the relative persuasive strengths of different sources of information about engineering. For example, exploring where students learn that engineers do a lot of math, and whether other information from this source is as stable and pervasive.

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