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Fundamental Research: Characterizing Underrepresented Students' Interest in Engineering Careers and Their Teachers' Beliefs about Practices

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Fundamental Research: Characterizing Underrepresented Students' Interest in Engineering Careers and their Teachers' Beliefs about Practices

Abstract

Despite efforts to diversify engineering, gaps persist, with few Latino/as becoming engineers. The Southwest US is an ideal place to characterize student interest development in engineering, and to relate that interest to perceptions of instructional practices. This study contributes information about teachers and their students, who are predominantly Latino/a (>90%) from some of the highest poverty schools in the US. We investigate teacher and student perceptions of connecting instruction to student interests and culture and student ownership of STEM practices (students coming up with their own ways to solve problems, posing their own questions, and developing their own conclusions). Students also provided information about the relevance of instruction for their futures, whether they had a relative/friend who was an engineer, their interest in becoming an engineer, and their ideas about an engineering lab visited by their teachers. We compared their responses to teacher responses, finding them to be similar overall. We use multiple regression to model student interest in becoming an engineer. A significant regression equation was found ($F(4, 230)= 11.26$, p less than .001). Students who viewed what they were learning as important to their futures, and who reported having opportunities to draw their own conclusions were significantly more likely to express interest in becoming an engineer. Qualitative analysis of open ended responses revealed that most students could describe normative differences between science and engineering, but very few envisioned an active role for themselves, were they to be in the lab their teachers visited. Our findings suggest students' perceptions of instruction play a larger role in engineering interest development than having a close relative/friend who is an engineer or teachers connecting to their personal interests. Providing opportunities for their students to pose their own questions or design their own procedures did not predict interest development, but they do align to the kinds of skills engineers need, suggesting that teachers may need support to develop these practices further. Taken with the qualitative analysis, such opportunities can also be used to help students envision active roles for themselves. Supporting interest development but not also supporting ability development will not address persistent gaps.

Introduction and purpose

Despite efforts to diversify engineering, gaps persist, with few Latino/as and Native Americans becoming engineers. The Southwest US is an ideal place to characterize student interest development related to becoming an engineer. This study contributes information about teachers and their students, who are predominantly Latino/a or Native American, from some of the highest poverty schools in the US. Our purpose is to characterize these students' perceptions of classroom practices and to link these to their teachers' perceptions of their own classroom practices; we then model their interest in pursuing engineering using their perceptions of classroom practices. We investigate their perceptions of what engineers do as a means to explore their willingness to try on engineering as a career.

The teachers in this study are science and mathematics teachers who are aiming to incorporate engineering into their curriculum, following participation in a Research Experiences for Teachers (RET) program. Our purpose is not to evaluate their capacity or success at this, or to detail the experiences they had in the RET, but rather to better understand the perceptions they and their students bring, as a means to consider how to design professional development experiences that aim to enhance diversity of the engineering pipeline.

Conceptual framework

Recruitment and retention of students from groups underrepresented in engineering has been the focus of a great deal of recent research. We take that stance that interest development is the first step for recruitment of students who otherwise might not consider engineering. Interest development is needed but insufficient for real change, as students who become interested but are poorly prepared are not likely to persist in engineering [1]. We therefore focus on strategies that develop interest and understanding.

We review research on four meta-strategies for enhancing diversity by cultivating interest and/or developing understanding of engineering practices; we bring these together in our conceptual framework (Figure 1). First, connecting to students' prior experiences and culture encompasses a range of student-centered strategies. A second strategy involves supporting student ownership of learning and providing students with opportunities to make and carry out decisions related to their learning (agency). A third strategy involves enhancing the perception that what students are learning is relevant for their future success. A fourth strategy involves engineering professional development for teachers as a means to provide students with access to someone with understanding of engineering.

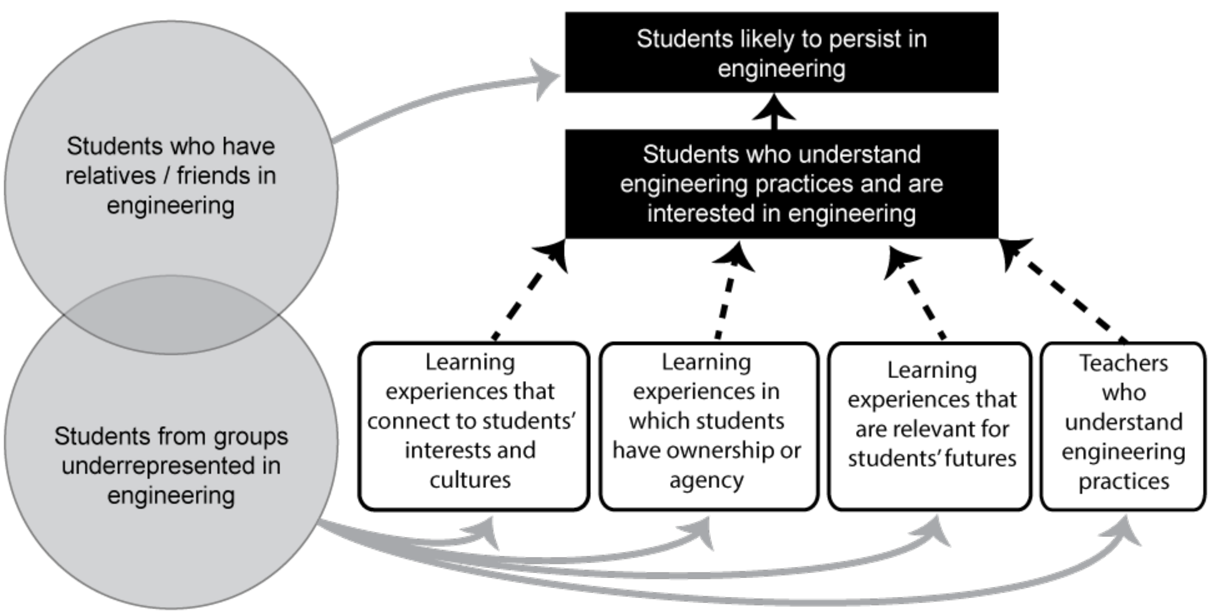

Figure 1. Conceptual framework guiding the study. We hypothesize that students from groups underrepresented in engineering are more likely to persist in engineering if they have access to one or more promising meta-strategies capable of developing their understanding of and interest in engineering.

We review literature about each of these meta-strategies, and we surveyed students and teachers about each of these topics.

Connecting to students' prior experiences and culture

Providing interesting educational materials can lead to deeper engagement and understanding because students make more associations with the material [2]. Connecting to students' prior experiences and culture can support learning [3-7]. Such approaches help learners construct new understanding by building on what they already know [8]. We see approaches that connect to culture as a critical extension of such teaching; culturally relevant pedagogy connects to students' cultural experiences and understanding [9-13]. In such approaches, students' "funds of knowledge" are leveraged, using the resources students bring from their experiences in home and other culturally-specific out-of-school settings [14]. Such approaches reflect a range of student-centered teaching, including using students' strengths to introduce new instruction, supporting collaborative learning spaces, adapting curriculum, engaging in social justice and community engaged learning, etc. [15]. These approaches align to engineering education, as students can design solutions for their communities [16-18]. We investigated whether teachers and their students perceived that teachers were connecting instruction to their students' interests and cultures.

Ownership of learning

In traditional classrooms, students seldom have opportunities to pose their own questions, design their own investigations, and solve problems of their choosing; commonly, a well understood problem is set for students to solve, and questions posed are examined for their alignment to the intended curriculum. Thus, in traditional school settings, opportunities for students to have agency and ownership over their learning are rare [19, 20], yet ownership can support persistence [21].

In order for students to understand STEM practices, they need opportunities to develop ownership of these practices by coming up with their own ways to solve problems, posing their own questions, and developing their own conclusions [22]. In engineering, in particular, they need opportunities to have ownership over the design problem; although posed by a customer or client, design problems are framed by the designer [23], leading to a sense of agency [24] and ownership [25].

Interest can drive a sense of ownership over learning [26], which in turn can foster a mastery-oriented stance on learning [27] and help students make decisions about their futures [28]. One approach to support ownership development is through the use of project-based instruction [29]; creating artifacts that reflect learning can support ownership of learning [30] because students "can create themselves in the world and see themselves reflected back through the independent behavior of their creation" [31]. In project-based classrooms, more of the locus of control is shifted to the students than in traditional settings [32], providing that sense of agency and ownership. Because the teachers and students in this study were in science and mathematics classrooms, we asked about student opportunities to engage in science and mathematics practices that we see as relevant to engineering but also understandable to students in science and mathematics classrooms.

Instrumentality: relevance of learning for future

One way to examine career interest development is through the lens of *instrumentality*, which describes the degree to which an individual considers something s/he is learning to be useful in his/her future. Measures of instrumentality have been shown to predict course performance in a variety of settings, including engineering [33, 34]. Essentially, when students don't see a need to learn something, their learning tends to be negatively impacted. Commonly, the courses that gate-keep advanced coursework—such as capstone design courses—include a large component of introductory or basic content that stands in as disciplinary knowledge [35]; in such cases, students who don't see these components as useful will tend to perform less well. Increasing instrumentality for struggling and underserved learners is one way to support them. For instance, in project-based classrooms, instruction provides context that helps students connect what they are learning to why it matters and what it is useful for [36-39]. Project-based courses can change students' minds about the usefulness of content they are learning [40]. We asked students to evaluate whether what they were learning mattered for their future careers.

Projective identification: knowing an engineer, or someone who knows about engineering

Having a relative—not necessarily a parent—can strongly influence students' choices about wanting to become an engineer [41]. Some studies have found a greater impact on women, and that "engineering family members are passing on engineering-related knowledge, interests, and aspirations" [42]. Thus, having a family member who is an engineer can inspire interest in becoming an engineer. However, students underrepresented in engineering are less likely to cite parental influence as important for their career choice [43], in part because few had parents who worked as engineers, a trend that reflects the overall issue: if having an engineer parent is an important influence on choosing to become an engineer, and few engineers are from groups already underrepresented in engineering, it is unlikely to positively influence a large number of students who might consider becoming an engineer. However, for such students, their broader family and close friends can serve as sources of information about becoming an engineer [44].

Such relationships provide opportunities to have insight into the daily experiences of an engineer; they also provide opportunities for family members to *project* their *identities* as engineers onto younger family members, allowing them to try on engineering as a possible career. The construct *projective identification* was introduced in psychoanalysis to examine how parts of oneself are projected into or placed on someone else; we co-opt it as a metaphor to consider how engineers—or those who understand engineering—might project interest and understanding into students who might not otherwise consider engineering.

Some have advocated for having engineers as guest speakers in classrooms [45]. Others have argued for "fictive kin," including teachers, who might serve in this role to support diverse undergraduate students to persist in engineering [46]; this approach is sensible given that teachers have been shown to influence career choice in other STEM fields [47].

NSF funds the Research Experiences for Teachers program as a means to aid teachers in getting first hand experiences they can then bring back to their classrooms. In the sciences, such experiences support teachers by engaging them in authentic science research, increasing their content understanding and enthusiasm for science [48, 49], as well as their awareness of career pathways [50]. In engineering, RET programs have been shown to help teachers develop confidence for teaching engineering [51, 52], understand the nature of engineering [53] and understand engineering research [54]. Teachers who have participated in RET programs have reported that their students became more active and engaged when using materials they had developed [55]. Because engineering is not yet commonly taught as a stand-alone subject, engineering RETs often provide science and mathematics teachers opportunities to learn to integrate engineering into their existing teaching of science or mathematics [56-59]. Such approaches can positively impact student achievement [60, 61]. This also provides an opportunity for students who might not select into an engineering course to be exposed to and develop interest in engineering. We asked students if they had any relatives or close friends who worked as engineers.

Research contribution and questions

While the literature review highlights a number of practices that support the development of interest in and understanding of engineering, many of these studies focus on majority settings. Less is known about the relative value of these approaches for fostering interest development in classrooms that serve predominantly Latino/a and Native American students. Regression modeling was selected as a means to relate a range of variables to students' reported interest in becoming an engineer. We focused on interest in becoming an engineer, rather than student understanding of engineering practices because the survey was given to students from a range of grade (and therefore reading) levels, and because we saw it as a likely precursor to the development of understanding.

We sought to answer three interrelated research questions: (1) To what extent do teacher and student responses about STEM practices in the classroom agree with one another? (2) Which variables (connecting instruction; ownership of STEM practices; seeing instruction as instrumental for their futures; having a friend or relative who is an engineer) predict student interest in becoming an engineer? (3) How do students envision the lab experiences their teachers had?

Methods

Participants included 28 New Mexico teachers who participated in an NSF-funded Research Experiences for Teachers program, and their students, who are predominantly Latino/a (>90%) or Native American (approximately 7%) and come from some of the highest poverty schools in the US. Teachers were embedded in engineering research labs at a research university for 7 weeks during the summer.

Teachers completed surveys as part of their participation in the summer RET program. They were provided with student surveys and asked to give the survey early in the school year (Appendix A). A subset of teachers returned the completed, de-identified surveys, which were entered into spreadsheets, resulting in a student sample of 263 (additional surveys are anticipated at a Spring 2016 workshop). Because student data were collected using a waiver of consent process, no identifiers could be collected linked to the data (e.g., gender, ethnicity).

The surveys included questions about whether teachers connect instruction to culture and interests and about whether students have responsibility for coming up with their own ways to solve problems, posing questions, and drawing conclusions. Students were also asked whether they viewed what they were learning as important for their future careers and whether they had a close relative/friend who works as an engineer.

Survey responses to Likert items were replaced by numeric scores (e.g., Strongly agree = 5, Strongly disagree = 1). Descriptive statistics were calculated for all survey items. We calculated regression models stepwise for each variable set (connecting; ownership; instrumental; relative). To reduce the chance of colinearity, we chose the best fitting variable from each set.

Open-ended responses were reviewed for trends. We focused in particular on students' understanding of the lab and how they envisioned themselves in it, as they responded to the prompt, "Imagine you were working in the lab your teacher visited. What do you think it would be like? What would you be doing?" We coded their responses using a simple coding scheme to focus on the accuracy of their perceptions of science and engineering and their willingness to envision themselves as engineers (Table 1).

We then triangulated our findings to consider our regression modeling in light of the qualitative results.

Table 1. Coding scheme for open ended questions

Question prompt	*score = 1*	*score = 0*
Imagine you were working in the lab your teacher visited. What do you think it would be like? What would you be doing?	Active participation, with student as actor, carrying out experiment, designing or building, fixing, even if action represents an alternative conception (e.g., fixing car engines). Also counted if student described taking notes or recording observations, provided active voice is used ("I would be taking notes").	Passive participation with student as observer, listener, watcher, but without taking notes or recording observations, unless passive voice is used ("notes would be taken").
What, in your view, is science?	Student provides normative explanation of science as the study of natural systems, life. Includes specific descriptions (e.g., study of the earth) provided they are normative.	Student provides vague (e.g., "science is everything"), non-normative response, or description of school-based science experiences that represent a significant departure from science (e.g., "science is worksheets")
What, in your view, is engineering?	Student provides normative explanation of engineering, such as "solving problems through designing or making things"	Student provides vague or non-normative response (e.g., "engineering is fixing cars")

Results: To what extent do teacher and student responses about STEM practices in the classroom agree with one another?

Connecting to culture and interests: Teachers and students both reported being neutral or agreeing that teachers connect instruction to students' culture (students: M=3.6, SD=0.90; teachers M=3.5, SD=0.90). Teachers agreed that they connected instruction to students' interests, but students reported being neutral (students: M=3.2, SD=0.90; teachers: 4.25, SD=0.75).

Ownership of STEM practices: Students agreed more than teachers that students had responsibility for coming up with their own ways to solve problems (students: M=3.6, SD=0.9; teachers: M=3.0, SD=0.43), but teachers agreed somewhat more that students were responsible for posing their own questions (students: M=3.2, SD=1.00; teachers: M=3.5, SD=0.52) and drawing their own conclusions (students: M=3.5, SD=0.90; teachers: M=4, SD=0.85).

Results: Which variables (connecting instruction; ownership of STEM practices; seeing instruction as instrumental for their futures; having a friend or relative who is an engineer) predict student interest in becoming an engineer?

A multiple linear regression was calculated to predict interest in becoming an engineer based on connecting instruction to interests, drawing their own conclusions, instrumentality, and having a close friend or relative in engineering (Table 2). A significant regression equation was found ($F(4, 230)= 11.26$, $p<0.01$). Over one quarter of the students reported being interested or very interested in becoming an engineer (28%). Students were neutral or agreed that their teachers connect instruction to their interests (M=3.6, SD=0.90) but this did not significantly predict their interest in becoming an engineer. 27% reported they had a close relative/friend who worked as an engineer; this did not significantly predict interest in becoming an engineer. Students agreed or were neutral that what they were learning was important for their future careers (M=3.8, SD=1.0); those who reported higher agreement were significantly likelier to be interested in becoming an engineer. Students who reported more opportunities to draw their own conclusions (M=3.5, SD=0.90) were significantly likelier to be interested in becoming an engineer.

Table 2. Regression model of expressed interest in engineering as a career

Unstandardized Coefficients			Standardized Coefficients	
	B	Std. Error	β	t
Intercept	0.129	0.436		0.30
Connecting instruction to interest	0.125	0.97	0.083	1.30
Having an engineer/scientist relative/friend	0.104	0.179	0.035	0.58
Instrumentality	0.311	0.074	0.260	4.18**
Drawing own conclusions	0.295	0.089	0.211	3.31**

$r^2 = .16$; **p < .001

Results: How do students envision the lab experiences their teachers had?

Our analysis of qualitative responses suggests that while most students possessed understanding of the differences between engineering and science (e.g., science is "the study of the world" or "understanding all things in nature" and engineering is "creating new things to help the world" or "making and building things, especially technology") many of these students displayed beliefs suggesting that the lab their teachers worked in seemed out of reach to them. In response to the question, "Imagine you were working in the lab your teacher visited. What do you think it would be like? What would you be doing?" we found many students reluctant to envision themselves as engineers, and instead primarily described relatively passive roles:

- Not working in a lab
- I don't know
- It would be calm, organized work
- There would be lots of notes being written
- I would be watching
- We will be sitting quietly unless told other *[sic]*

Most of the (few) students who reported an active view of the lab held alternative conceptions about the work of engineers. They explained that engineers worked on cars and fixed engines, and that's what they would do if they were in the lab.

Triangulation and discussion

Our findings suggest students' perceptions of instruction play a larger role in interest in becoming an engineer than having a close relative or friend who is an engineer. The specific instructional approaches we surveyed teachers and students about include those endorsed by recent curricular standards (NGSS, CCSS) in the US. The teachers generally agreed they provide students with opportunities to draw their own conclusions, but fewer provide opportunities for their students to pose their own questions or design their own procedures. While these did not predict interest development, they certainly align to the kinds of skills engineers need, suggesting that teachers may need support to develop these practices further.

We found students' perceptions of their teacher connecting instruction to their interests and culture did not predict interest in becoming an engineer. We do not argue that teachers should discontinue connecting their instruction to students' interests and culture. Rather, we infer that this could indicate the need for supports for teachers to develop ways to help students bridge their existing interests with engineering. Engineers address a broad range of problems; thus helping students identify interests they have and understand how engineers have contributed or could contribute to that area would be one strategy for fostering such connections. For instance, a student who is interested in music could investigate sound engineering, acoustical engineering, etc.

The qualitative analysis showed that few students envisioned accurate and active roles for themselves in the lab their teachers visited. Taken with the findings from regression modeling and the descriptive statistics, we see this painting a picture of students who receive few opportunities to actively engage in engineering practices. We argue that it is particularly important for such students to have experiences that cultivate a sense of ownership and agency over their STEM learning, by having opportunities to participate in all engineering practices, from problem framing to to designing and evaluating. Opportunities to engage in these practices will support a sense of agency [24] and ownership [25].

Given that students from groups already underrepresented in engineering are less likely to have relatives in engineering, programs like the NSF RET program have great potential to contribute to narrowing gaps. In order for teachers to sit in such "fictive kin" roles [46], they need to understand engineering practices and be willing to engage their students in such practices. RET participants get opportunities to "try on" being an engineer, but in order for them to *project* these somewhat tentative, liminal *identities* as engineers onto their students, they need to be able to project both interest and understanding into students who might not otherwise consider engineering.

Previous research on engineering RETs suggests this may be possible, given that such programs can help teachers develop confidence for teaching engineering [51, 52], understand the nature of engineering [53], understand engineering research [54], and foster active engagement [55]. Further, because many of these teachers do so in science and mathematics courses [56-59] there are opportunities to reach students who might not otherwise be reached. However, in order to effectively support teachers to bring engineering practices back to their classrooms, professional development programs may need to include a focus on instructional strategies such as design pedagogy or in project-based learning, especially given previous research showing that such approaches can change students' minds about the usefulness of content they are learning [40]. Such approaches also support the development of ownership [29], and therefore of persistence [21].

Limitations and future directions. Our study relies on self-reported data; a further limitation to this is that due to our waiver of consent process—which allowed us to collect data from every student without consenting them—we were not able to ask questions that could potentially identify a student (such as gender, ethnicity, etc.). Future directions address this gap by triangulating teacher responses to the curricula they designed and to their enactment of it, as well as to student work and evidence of student learning. Despite these limitations, we see this analysis as a contribution because it offers insight into a group of predominantly Latino/a students' perceptions and relates them to their interest development. This study provides additional backing for the need to engage students—especially those from groups underrepresented in engineering—in high quality STEM learning.

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Appendix A: Student survey

Name 3 things engineers do in their work that you think you do in your class.

Imagine you were working in the lab your teacher visited. What do you think it would be like? What would you be doing?

What, in your view, is science?

What, in your view, is engineering?

Place an X in the column for each question to show how much you agree with the statement.

In this class:	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly agree*
My teacher helps me connect what I am learning to my interests.					
My teacher helps me connect what I am learning to my culture.					
I am responsible for coming up with and using my own ways to solve science or math problems.					
I come up with my own research questions.					
My teacher gives step-by-step instructions before we conduct investigations or solve problems					
My teacher conducts the investigation or solves the problem as a demonstration in front of the class					
I determine what data to collect					
I understand why the data I am collecting is important					
I develop my own conclusions for investigations					
My teacher helps me understand what scientists, engineers, or mathematicians do.					
What I learn relates to my everyday life.					
What I learn in this class will be important for my future career.					
In the future, I think I would like to be a scientist.					
In the future, I think I would like to be a mathematician.					
In the future, I think I would like to be an engineer.					

Are any of your parents or close relatives/friends engineers? Yes No