International Journal of Engineering Education Vol. 32, No. 5(B), pp. 2318–2327, 2016
Printed in Great Britain

0949-149X/91 $3.00+0.00

Exploring Diverse Pre-College Students' Interests and Understandings of Engineering to Promote Engineering Education for All*

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Engaging a representatively diverse (across class, race, gender, and cultural lines) population in a future of engineering continues to be a struggle for many countries. This paper presents a study from the U.S. context, where racial and ethnic minorities and women are significantly underrepresented in engineering. The interview study asked diverse pre-college students about their personal and career interests and how they defined engineering. These responses were coded using Holland's Career Theory framework of six interest dimensions (realistic, investigative, artistic, social, enterprising, and conventional) to categorize students' personal and career interests to see how they may or may not correspond to their understandings of what interests an engineering future may appeal to. The results illustrate that the students' personal interests map to the full spectrum of Holland's dimensions. However, students' understandings of engineering map to a more stereotypical view of engineering that does not always match to their personal interests. The paper argues for introducing engineering in ways that highlight how engineering pervades a wide array of domains and interest areas.

Keywords: diversity; personal interests; career theory; pre-college

1. Introduction

Engineers play a significant role in our society today. The work of engineers drives economic growth in countries, provides solutions to some of the world's greatest challenges, and improves our daily lives. Although engineers play many different roles and are responsible for wide-ranging projects, engineering has become a profession for a homogenous set of people. The culture of engineering has become somewhat exclusive leaving many diverse, creative people opting out of the culture and thus the profession. In line with the topic of this special issue, Engineering Education For All, we believe the aim of engineering education at all levels should be to excite a diverse group of students about the possibilities of a future of engineering.

Many countries and cultural contexts find themselves striving to create a more diverse and balanced population of engineers. The homogeneity can be found along a number of factors, such as class, race, gender, and culture depending on the country. For example, in the United States women and underrepresented minority groups (e.g., African Americans, Hispanic American, Latino/a, and Native Americans) are severely underrepresented [1]. In India certain disciplines of engineering (e.g., mechanical, chemical, and civil) are seen as for males while others (e.g., electrical and biotechnology) have much more female participation [2]. In South Korea just 15% of engineering, physics, and computer science majors are women and in Brazil just 17% [3]. Socioeconomic status or class is another factor that restricts access to higher education and as such to engineering degree attainment. For example, in Australia effects related to socioeconomic status of rural populations had more to do with access to higher education than did the physical location of the individuals [4].

Making engineering education available for all is not purely a social justice issue for equal access, but several studies and position papers have proposed a broader, more diverse profile for who becomes an engineer that could improve the work of engineers. Menzel, Aaltio & Uljin [5] made a case for the need of engineers with entrepreneurial skills. Uljin, Frankfort & Uhlaner [6] establish how social skills are important for engineers. Similarly, Del Vitto [7] proposed how emotional intelligence, social awareness, cross-cultural sensitivity, and open mindedness are important, but mostly missing attributes of engineers. Hynes and colleagues highlight that engineering takes place in social contexts, and as such requires the consideration of social science and humanities knowledge to engineer solutions for, with, and as people [8, 9]. While it may appear that students choose to pursue engineering/non-engineering careers when applying for college, studies have shown this choice is determined much sooner. Cummings & Taebel [10] show that young women and minorities display their greatest interest in STEM (science, technology, engineering, and

* Accepted 15 May 2016.

mathematics) subjects during their middle school years. Thus is it important to understand how we as educators can work to have engineering appeal to a broad audience of pre-college students before these students start making decisions that could exclude them from becoming engineers.

With this paper, we make a case for the need to expand the reach of engineering across boundaries set by culture, race, class, and gender by focusing on each individual student and the diverse personal interests and preferences they have. We posit that by appealing to the broad array of students' personal interests, engineering education can provide students opportunities to identify where their own personal interests can be expressed within the engineering profession. Research in human psychology demonstrates that a learner's interests play a role in their learning and motivation to persist in a certain domain [11, 12]. Krapp, Hidi, and Renninger [13] distinguish personal interests from situational interests along the lines of intrinsic versus extrinsic motivation [14]. Where personal interests intrinsically motivate a person to persist within a certain activity and situational interests, or the interestingness of the social or non-social environment that encourage interaction, are seen as extrinsically motivating. Our hypothesis is that current engineering education outreach is situationally interesting for many students, but not personally interesting for many students (especially those underrepresented in engineering). To reform engineering education curriculum to appeal to students' personal interests, we must first understand the diversity of these interests. This paper reports on an interview study of students from diverse backgrounds across the United States to better understand what sorts of personal interests, career interests, and engineering interests they have. We present findings that show how interests of students aged 10–18 years cover the vast expanse of personality types as defined by Holland's theory of career choice [15]. With the myriads of interests reported, we look for trends among students by race, class, and gender and to see if students' understandings of engineering are good matches to their personal interests. With this work we aim to bring to light what we expect is a gap between students' understanding of engineering and their personal interests in order to understand how student-interest-centered pedagogies could help narrow this gap.

1.1 Theoretical framework

Holland's theory of career choice connects six dimensions of personality to career choice and fit [15]. These six personality dimensions include: Realistic, Investigative, Artistic, Social, Enterprising, and Conventional (RIASEC). Table 1 gives brief definitions of each of these dimensions. These personality types are determined by analyzing people and their environment together, which go on to predict outcomes such as vocational and education choice, stability, and achievement. Engineers' personality profiles typically are skewed toward Investigative and Realistic in the RIASEC model [16]. A third dimension of either Conven-

Table 1. RIASEC personality dimensions and descriptions

Personality dimension	Description
Realistic	A preference for activities that entail the explicit, ordered, or systematic manipulation of objects, tools, machines, and animals and to an aversion to educational or therapeutic activities. These behavioral tendencies lead in turn to the acquisition of manual, mechanical, agricultural, electrical, and technical competencies and to a deficit in social and educational competencies. p. 21 [15]
Investigative	A preference for activities that entail the observational, symbolic, systematic, and creative investigation of physical, biological, and cultural phenomena (in order to understand and control such phenomena) and to an aversion to persuasive, social, and repetitive activities. These behavioral tendencies lead in turn to an acquisition of scientific and mathematical competencies and to a deficit in persuasive competencies. p. 22 [15]
Artistic	A preference for ambiguous, free, unsystematized activities that entail the manipulation of physical, verbal, or human materials to create art forms or products and to an aversion to explicit, systematic, and ordered activities. These behavioral tendencies lead in turn to an acquisition of artistic competencies (e.g., language, art, music, drama, writing) and to a deficit in clerical or business system competencies. p. 23 [15]
Social	A preference for activities that entail the manipulation of others to inform, train, develop, cure, or enlighten and an aversion to explicit, ordered, systematic activities involving materials, tools, or machines. These behavioral tendencies lead in turn to an acquisition of human relations competencies (e.g., interpersonal and educational) and to a deficit in manual and technical competencies. p. 24 [15]
Enterprising	A preference for activities that entail the manipulation of others to attain organizational goals or economic gain and an aversion to observational, symbolic, and systematic activities. These behavioral tendencies lead in turn to an acquisition of leadership, interpersonal, and persuasive competencies and to a deficit in scientific competencies. p. 25 [15]
Conventional	A preference for activities that entail the explicit, ordered, systematic manipulation of data (e.g., keeping records, filing materials, reproducing materials, organizing business machines and data processing equipment to attain organizational or economic goals) and to an aversion to ambiguous, free, exploratory, or unsystematized activities. These behavioral tendencies lead in tum to an acquisition of clerical, computational, and business system competencies and to a deficit in artistic competencies. pp. 26–27 [15]

tional or Enterprising are often present depending on the engineering discipline. While these are certainly appropriate to the engineering profession, the interdisciplinary nature of engineering today has the potential to engage people's Artistic and Social personality dimensions as well. Traditional perceptions of engineering are outdated and the need for a more holistic engineer with diverse perspectives is ever more necessary. By presenting engineering in multiple contexts and modes, there is an opportunity to attract new and different people into the engineering profession and start creating a different kind of engineering workforce.

2. Methods

This qualitative, interview study explores the nature of ages 10–18 students' interests (personal, extracurricular, academic, and career), perceptions of engineering, and their interests in engineering as a career. The purpose of this study is to identify trends within students' interests and to understand if and how precollege students make connections between engineering (or other careers) and their interests. The research questions driving this inquiry include:

1. Where do ages 10–18 students' interests lie within the RIASEC model?
2. Are there differences in ages 10–18 students' interests and engineering affinity based on race/ethnicity, gender, or participation in engineering programs?
3. Do ages 10–18 students connect their interests to careers in engineering, and do their perceptions of engineering influence this connection?

2.1 Participants

The research team recruited a diverse pool of 28 precollege students from the United States to participate in the study interviews. The students' ages ranged from 10 to 18 years old. The students were recruited from a local public school serving an economically diverse population, a summer engineering program serving students from underrepresented minority groups from across the U.S., and a woman in engineering program summer workshop. While the socioeconomic status was collected via the proxy measure of zip code, there was not a large enough pool of subjects to meaningfully analyze by this proxy measure. The demographics of the students are presented in Table 2.

2.2 Data collection

The research team conducted and audio recorded one-on-one interviews with each participant. Some interviews were conducted in person and some were conducted over the phone. The interview protocol included questions grouped in five categories: (1) students' demographic data, (2) students' personal and academic interests, (3) students' career aspirations, (4) students' perceptions and knowledge of engineering, and (5) the connections students made between their personal interests and engineering. The interviews generally took between 20–30 minutes to complete. The research team acquired Institutional Review Board (IRB) approval to conduct the research and all participants and their legal guardians consented to participating in the research.

Table 2. Research participant demographics breakdown

Category	Breakdown
Gender	12 female, 16 male
Race	10 African American, 4 Hispanic, and 14 white
Grade level	9 4th–5th grade, 12 6th–8th grade, 7 9th–12th grade
Engineering participation	19 participated in an engineering program, 9 did not

2.3 Data analysis

The student interviews were transcribed and then analyzed using various case study methods as described by Miles and Huberman [17]. Each transcript was treated as a single case. Cross-case analysis was conducted based on the entire set of transcripts as well as subsets broken down by the demographics listed in Table 2. Trends and themes were noted at both the aggregated and de-aggregated levels. Initial analysis included coding the transcripts according to the six personality dimensions of Holland's RIASEC model. The research team created code definitions for each of the six dimensions grounded in the data to ensure reliability in coding across cases. These definitions are represented in Table 3. Each member of the coding team deductively coded the same two transcripts to assess inter-rater reliability. Through an iterative process of revising the coding scheme and coming to agreement, the team achieved inter-rater reliability above 90% where for each question the presence or lack of a RIASEC code was either a match or not. There were 72 possible matches, thus 90% would signify at least 65 of 72 codes matched between reviewers. The results of the coding provided quantitative insights into the data. A deeper dive into the transcripts helped to provide further detail and qualitative insight into these quantitative insights.

3. Findings

The total set of 28 transcripts was mapped to the RIASEC framework. Fig. 1 displays how the

Table 3. RIASEC code descriptions and examples

Dimension	Description	Examples
Realistic	Hands-on, physical activities, building, fixing, repairing objects, mechanical things, working outside	Sports, creating things (context of building/making), landscaping, outdoor activity, playing instruments
Investigative	STEM related problem solving, science, intellectual challenges related to STEM, problem solving	STEM subjects, inventing/designing (when not in context of building/making), technology, cell phones, video games
Artistic	Creative endeavors without structure. Art, writing, dance (as form of expression)	Art, music, writing, sewing, journalism (depending on context)
Social	Involving people, humanity, social problems/issues, socializing, being on a team	Hanging with friends, team sports, activities with people, helping others, volunteering (with people), journalism
Enterprising	Business-minded, entrepreneurial, persuasive, motivating	Lawn-mowing business, making money, coaching/ motivating
Conventional	Repetitive tasks, memorization, accounting, organizing, filing	Memorizing stuff, organizing room, etymology

research team coded the combined interests for all participants. All students had interests that spanned multiple categories. The most common categories being realistic, investigate, artistic, and social. For example, one student's interests include participating in his school's robotics team (Realistic and Investigative), playing percussion instruments in his school band (Artistic), participating in the local YMCA Youth In Government program (Social), and working a part-time job (Enterprising). As displayed in Fig. 1, enterprising and conventional were rarely present among the students' personal interests. This is not surprising as students are unlikely to comment on Conventional activities, which do not fit well into people's individual interests, and are unlikely to have much experience with Enterprising related activities. These data illustrate students' interests are relatively balanced across the remaining RIASEC dimensions. The figure does not provide much insight into whether students' different experiences or demographics have any relation to the nature of their interest. The following sections will de-aggregate the data and present relevant trends.

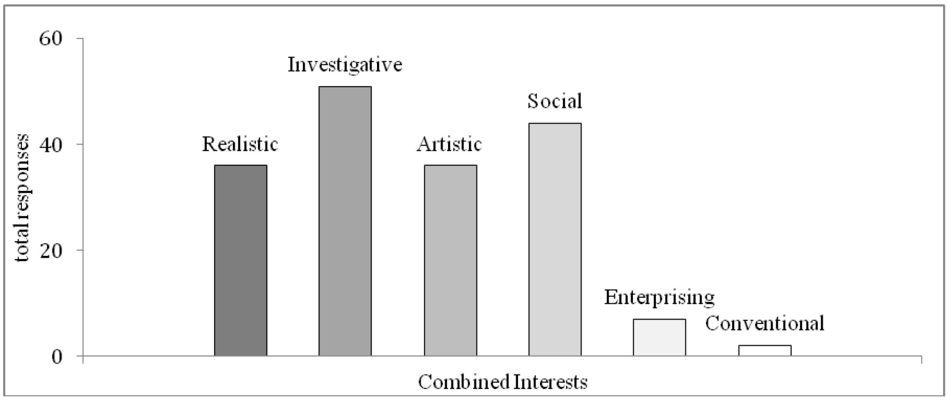

Fig. 1. RIASEC totals across all students and all personality interest questions.

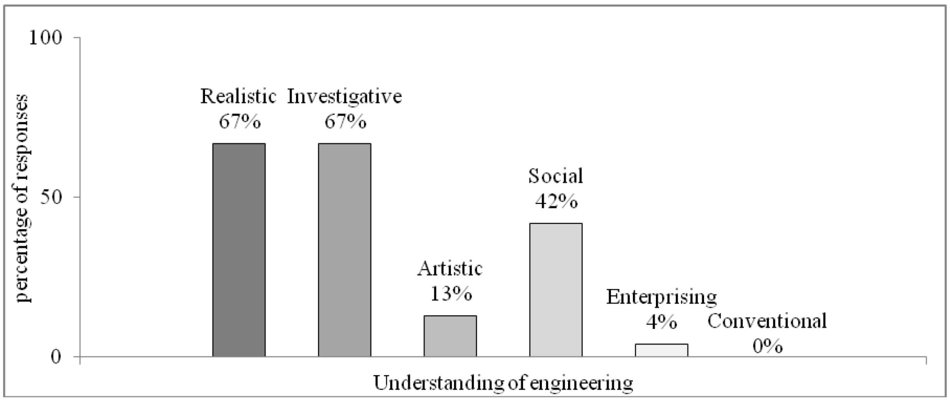

Fig. 2. RIASEC totals across all students for their understanding of engineering.

Figure 2 displays all students' understanding of engineering. Two-thirds of all responses indicated an understanding of engineering that aligned to the typical Realistic and Investigative personality profile of engineering [16]. For example, one student's understanding of engineering is that "engineers build things and invent things" (Realistic) and another student's understanding of engineering is that "[engineers] do a lot of math" (Investigative). However, we believe it is important to highlight that, although students' interests scored high in Artistic and Social categories, students did not necessarily perceive those categories as related to engineering. Less than half of the students perceived a connection between Social and engineering and less than one-fifth of students perceived a connection between Artistic and engineering. The lack of understanding engineering as a diverse field that has the potential to address many topics and interests is an area pre-college engineering programs and curricula should continue to work on to appeal to a broader audience of students.

3.1 Trends by gender

Interests of the participants are heavy in Realistic, Investigative, Artistic, and Social categories as seen in Fig. 3. With the exception of the Social category, the male and female responses were similar. For instance, many of the participants reported that they enjoyed spending time outdoors, which can be observed in the Realistic and Investigative categories above. Although more male responses indicate Social interests when compared to female responses, the responses themselves were very similar. For instance, both a female participant, and a male participant reported Social interests such as "hang out with friends. . .[and] with family," as well as "playing [team sports]." Although, the percent of students that responded with interests that fell into Investigative were slightly different between male and female respondents, the responses were similar from both genders. Both genders had multiple responses indicating Investigative interests such as video games, technology, mathematics, and science.

Both males and females reported that they thought of engineering as a heavily Investigative and Realistic field which aligns with the typical engineering personality profile. However, over 80% of female responses indicate an understanding of engineering that is Realistic (see Fig. 4). The female participants mentioned that engineers "fix cars," and "fix things," and that engineers "walk around fixing stuff."

It should also be noted that while both genders had a high Artistic response rate for personal interests (see Fig. 3), their responses indicate that they do not connect the Artistic category to their understanding of engineering. Nearly two-thirds of both genders responded with interests that fit into the Artistic category, while less than one-fifth of both genders connected engineering to the Artistic category (see Fig. 4). The same trend can also be observed in the Social category, with two-thirds of the female students and slightly more than 80% of the male students indicating Social interests (see Fig. 3), while only about one-third of the students connected engineering with the Social category (see Fig. 4).

3.2 Trends by race/ethnicity

The data suggest that white participants in our study have significantly greater interest in activities that fall within the Investigative (50%) and Realistic (44%) dimensions of the RIASEC model (see Fig. 5). This finding calls for attention due to the high correlation between Engineering personality types and these two dimensions, as mentioned previously. Consider this interview excerpt, with a white male middle school student:

> Interviewer: Okay. All right so when you are not at school, what are some of your favorite things to do?
> Student: Go on computer and usually play on scratch. . . .

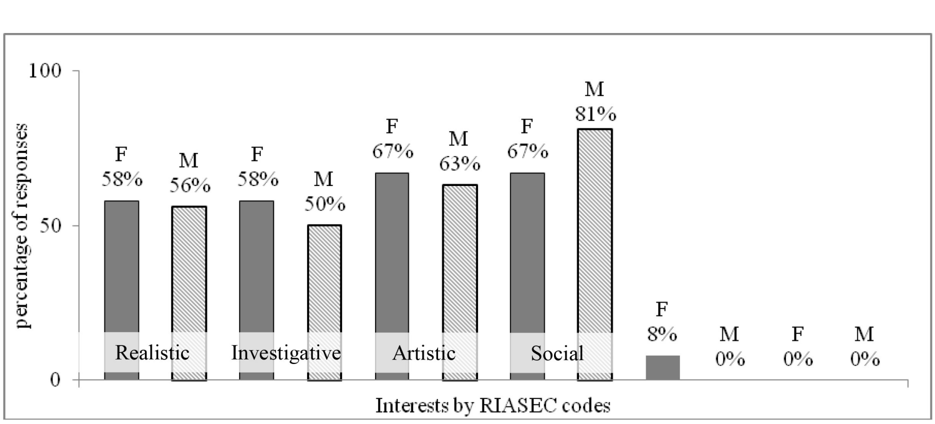

Fig. 3. RIASEC totals disaggregated by gender for students' interests.

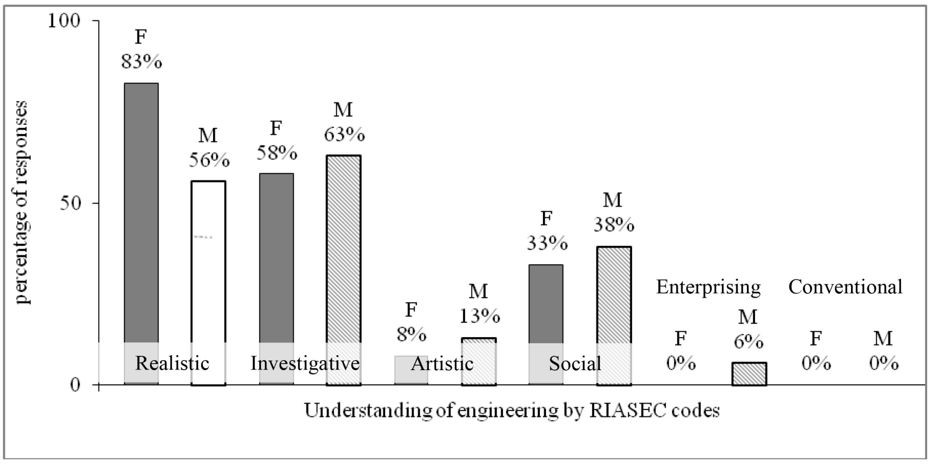

Fig. 4. RIASEC totals disaggregated by gender for students' understanding of engineering.

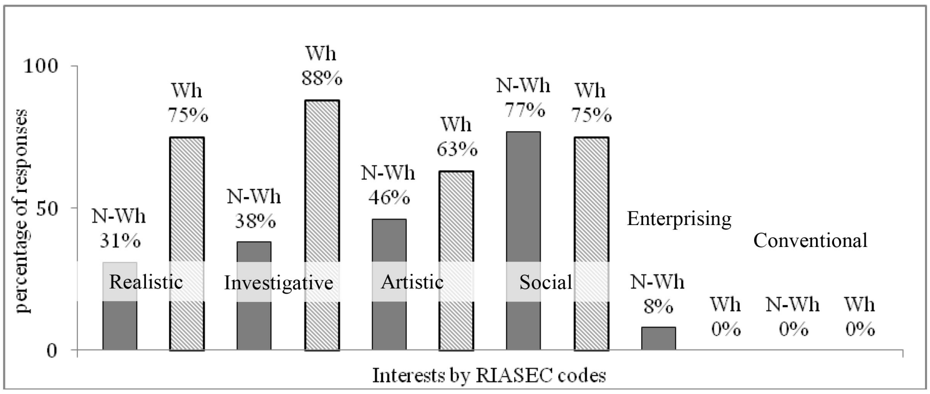

Fig. 5. RIASEC totals disaggregated by race for students' interests (N-Wh = Non-White; Wh = White).

Interviewer: Umm. So you like to play with Scratch online and you do that at home. You create things. Any other things you do on the computer besides Scratch.
Student: Minecraft. . . We can put like commands. Like programming the game.
. . .
Interviewer: Do you do any like extra or do you play sports or outdoors?
Student: I don't play sports. I don't like sports. Sometimes I do chess club . . . like thinking stuff through basically, those kinds of games.

This student expresses enthusiasm for computer-based activities and games requiring strategic thinking, both characteristic of a prospective engineering student. Underrepresented minorities (URMs) may not choose to pursue careers in engineering because the activities that they find most interesting do not present obvious connections to engineering skills and concepts. This perceived disconnection from engineering is further evident by Fig. 6, which shows

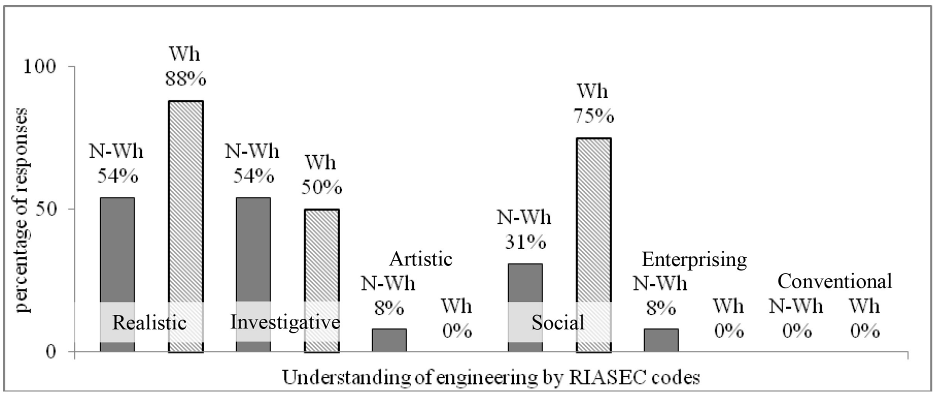

Fig. 6. RIASEC totals disaggregated by race for students' understanding of engineering (N-Wh = Non-White; Wh = White).

non-white participants' perceptions of engineering are primarily Investigative and Realistic descriptions. These findings taken together provide a clear understanding of one barrier for URMs to see themselves as potential engineers.

3.3 Trends by participation in engineering outreach program

Due to the relatively low number of interviewees who have non-participation in engineering outreach programs (NP) compared to the number of interviewees who have participation in such programs (P), it would not be realistic to try to compare the two populations. Still, one could see in Fig. 7 that the most common categories of both populations are Realistic, Investigative, Artistic, and Social. In addition, both populations have interests that scored relatively high in Artistic and Social categories.

Looking again at students' understanding of engineering we see in Fig. 8 that responses from NP interviewees aligned more to the typical personality profile of engineering than the responses of P interviewees. All of the NP responses indicate an understanding of engineering that is Realistic. For example, one student's understanding of engineering is that engineers ''walk around fixing stuff'' and another student, when asked what comes to mind when thinking of engineering, responded, ''I think of cars.'' Half of all NP responses indicate an understanding of engineering that is Investigative. Another thing we found interesting is that one NP response indicated an understanding of engineering that is Enterprising. This student's understanding of engineering is that engineers ''make a lot of money'' and engineering is a ''high paying job.'' However, P students expressed an understanding of engineering that includes the Artistic and Social categories, none of the NP interviewee responses indicated an understanding of engineering that includes the Artistic and Social categories. We believe this is important to call attention to because NP interviewees' interests scored high in Artistic and Social categories (see Fig. 7).

3.4 Addressing socioeconomic status

Another area of interests from this study is the impact of participants' socioeconomic status (SES) on their career aspirations. Studies have shown that students from lower socioeconomic

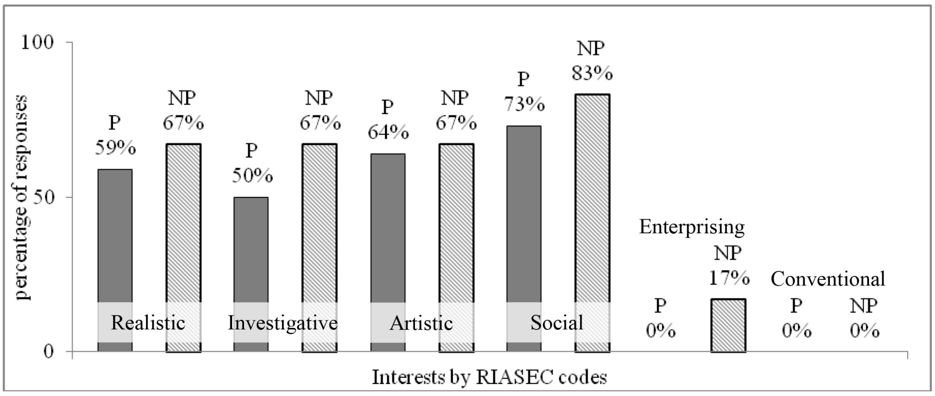

Fig. 7. RIASEC totals disaggregated by participation for students' interests (P = Participation; NP = Non-Participation).

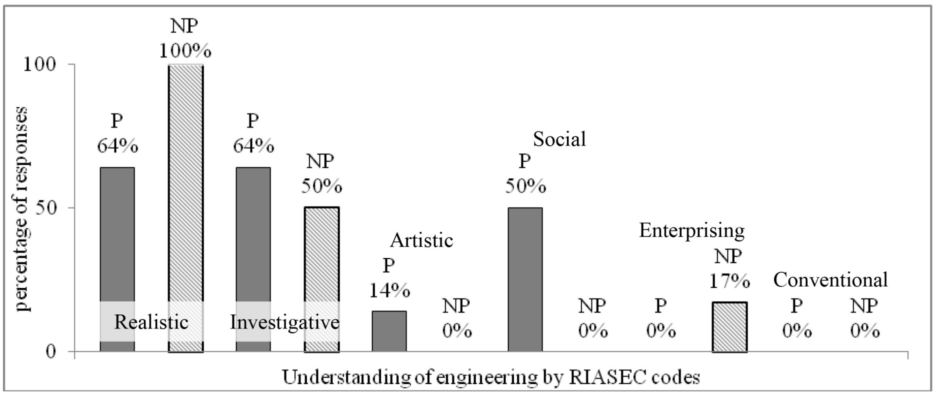

Fig. 8. RIASEC totals disaggregated by participation for students' understanding of engineering (P = Participation; NP = Non-Participation).

status (LSES) backgrounds tend to have lower academic expectations than those of their counterparts [18]. LSES students generally experience a lack of resources that would support and enhance their intellectual development and technological awareness [19]. On the other hand, students from higher socioeconomic status (HSES) backgrounds usually engage in more conversations with their parents and family members regarding educational aspirations, which allows for more encouragement toward experiences that advance intellectual development [20]. These ideas are relevant because engineering may be viewed as inaccessible and too difficult for students from LSES backgrounds, due to their unfamiliarity with technological and academically engaging resources. Demystifying engineering and identifying the skills students possess that can enrich the field may improve the participation of URMs.

While we did not have a large enough dataset to parse by socioeconomic status as we could only identify a proxy for SES through zip code, we contrast two students' responses where we can confidently assume one student is from a LSES background and another is from a HSES background. One of the participants in our study aspires to be a cashier at Walmart because "it's the most easy job to do." This response along with data that her parents currently work for Walmart and JC Penney lead us to identify this girl as coming from a LSES background and having low self-efficacy. LSES and low self-efficacy, we presume, would lead the girl to aspire to work at Walmart because it would be easy and that this is a familiar circumstance given her parents' backgrounds. A contrasting case exists of a student that desires to be an anesthesiologist, expressing the ambition to ensure "people stay safe while they're asleep." This aspiration coupled with her participation in a costly summer program allows us to assume she is of a higher SES background. This student aspiring to be an anesthesiologist likely has high self-efficacy given such a high aspiration. Such aspirations are likely to come to play as these students make choices about which mathematics and science courses to take in middle school and high school, which are likely to dictate whether or not they are able to pursue STEM degrees.

4. Implications

The findings related to students' personal interests highlight that these interests are slightly more weighted toward artistic and social dimensions than realistic and investigative dimensions. However, the students' understanding of engineering is predominantly realistic and investigative with little expectation of an artistic dimension, and only those who had participated in engineering outreach programs had ideas of the social dimensions of engineering. We believe this dissonance between the wider array of students' personal interests and more narrow view of what engineering entails predisposes many students to not be interested in pursuing engineering. We propose that presenting a more diverse perspective of engineering may help students to understand what is possible in a future of engineering. For example, engineering activities involving creating robots, bridges, and cars promote a continued stereotypical view of engineering while more open-ended activities involving solving problems for the community [21], designing solutions for characters in a novel [22], or creating an assistive device for someone with physical limitations [23] may appeal to more diverse sets of interests and consequently a broader population of students. We do not believe new engineering activities of this sort are aimed at just appealing to women or underrepresented populations, but can appeal to all students allowing them to find how the project integrates their own personal interests.

5. Limitations

During the course of our inquiry, we encountered certain activities that participants were interested in, but did not explicitly conform to a particular dimension of the RIASEC framework. Further, some of the interests we did code were coded without a depth of understanding of the context in which the students pursued their expressed interests or how the RIASEC dimensions specifically map to each interest area. Certainly, the nuance of the interests could have been lost. Similar to limitations in the RIASEC framework more generally, a singular dimension cannot unitarily and accurately be mapped to complexities of human personal interests and activity. In the context of the interviews from this study, interests could have been coded across multiple categories. For example, sports and outdoor activities could be considered Social (teamwork), Realistic (physical activity), or Enterprising (coaching/motivating). Similarly, journalism could be considered Social as well as Artistic depending upon the aspects of journalism that interest the student. There were certain other interests that could not be directly attributed to personality types, and so we explored the nature of these interests to decide the personality type they belonged to. We classified an interest in protecting/rescuing animals, as Social. An interest in etymology and memorizing things made it to the conventional category. Where most interests pertaining to investigative personality types were related to inquiry in STEM, watching Nat Geo, and playing strategic video games, were also coded within the same classification.

6. Conclusions

Students' personal interests map to a multiplicity of Holland's RIASEC framework, especially those that are not typically identified with engineering (Social and Artistic). However, their understanding of engineering map to more traditional engineering personality types. This may be a result of the widely held stereotypes and preconceptions of engineers and engineering. This is problematic because it is predisposed to students with certain interests while at the same time excluding students with various interests.

As discussed, engineering activities can cater to all these interest types. Hence, there is a need for designing and implementing engineering activities that cater to all learners' interests. Measures in this direction, would not just ensure a next generation of well-rounded engineers, but also the far-reaching outcome of equipping all students with essential engineering skills. There also appears to be an issue of equal access to engineering outreach that seems to have a positive impact on students' openness to pursue engineering education or engineering as a career. It is important for administrators and educators of these programs to carefully consider the message they are conveying to their students, as it appears the message is received and reiterated by the students participating in their programs.

These insights are not necessarily generalizable to other countries' contexts. However, we do believe a similar study replicated in other contexts could provide insights into how engineering education can reach all students no matter the country or cultural context. The insights gathered from such a study can help shape reform efforts in engineering curriculum for pre-college and undergraduate students to help recruit and then retain students in engineering programs.

Acknowledgements—This material is based upon work supported by the National Science Foundation under Grant No. 1454152.

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