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School fieldtrip to engineering workshop: pre-, post-, and delayed-post effects on student perceptions by age, gender, and ethnicity

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ABSTRACT
This article presents a large-scale evaluation study of over 3000 9–14-year-old students who participated in an engineering workshop during their school fieldtrips. Student perceptions right before and after, as well as two weeks after the workshop were captured and examined. Before the workshop, younger students and boys, generally exhibited higher interest, higher self-efficacy, and less negative stereotypes for engineering than their counterparts. Also, Caucasian students had higher self-efficacy and lower negative stereotypes than Hispanic students. Students' interest, self-efficacy, negative stereotype, and utility perceptions of engineering were significantly improved right after the workshop, and improved perceptions were maintained at the delayed-post (follow-up) survey. The results indicate that fieldtrips can significantly improve students' perceptions towards engineering and improved perceptions are not limited to the workshop day, but persist afterwards. The gender and ethnic differences in engineering perceptions in the youngest age group indicate that outreach interventions should begin in elementary school.

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KEYWORDS
Delayed-post survey; engineering workshop; interest; negative stereotypes; pre-college students

1. Introduction

1.1. Motivation for engineering outreach to K-12 schools

1.1.1. Need for STEM professionals

As the need for professionals in the Science Technology, Engineering, and Mathematics (STEM) fields continues to grow (NSB 2016; NSF 2015), there are significant concerns among policy makers about how to engage students with STEM and how to prepare them to pursue further studies in STEM fields (Archer et al. 2010; Gumaelius and Kolmos 2016). In line with these concerns, various initiatives have developed engineering outreach programmes and curricula to promote engineering knowledge and interest in engineering of students in grades K-12 (5–17 year old students), for example the Infinity project (Orsak et al. 2004), the Junior Engineering Technical Society (JETS 2009) programme, the Project Lead the Way (http://www.pltw.org), and the Massachusetts K-12 Engineering Standards (Massachusetts Department of Elementary and Secondary Education 2016). Additionally, advisory organisations, such as the National Academy of Sciences, and Institute of Medicine of the National Academies (2006), called for a comprehensive, coordinated effort to assure more students pursue STEM fields. Professional societies, such as the American Society for Engineering Education (ASEE) and the National Academy of Engineering (NAE), called for new educational approaches that focus on early exposure through the integration of hands-on, interdisciplinary curricula, and socially relevant STEM aspects into school

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curricula, specifically highlighting engineering as a discipline that can meet these goals (Douglas, Iversen, and Kalyandurg 2004). In 2009, President Obama, called for STEM initiatives in schools by emphasizing that great teaching is a key part of any child's success in the STEM fields and that it is very important to create educational experiences that are project-based and hands-on for developing students' continuous interest in the STEM fields (https://www.whitehouse.gov/issues/education/k-12/educate-innovate, President's Council of Advisors on Science and Technology 2010).

Research has shown that early exposure to STEM initiatives and activities positively impacts K-12 students' perceptions and dispositions (Anderson 2017; Bagiati et al. 2010; Bybee and Fuchs 2006; Carroll et al. 2017; Chirdon 2017; Dabney et al. 2012; Jones and Stapleton 2017; Kitchen, Sonnert, and Sadler 2018; Kutnick et al. 2018; Levine and DiScenza 2018; Miller, Sonnert, and Sadler 2018; Pratt and Yezierski 2018; Purzer, Strobel, and Cardella 2014; Ross, Whittington, and Huynh 2017). However, studies have also found that students may leave a STEM field of study because they lack early experiences in math, science, and engineering (Adelman 2006; Anderson and Kim 2006; Hagedorn and DuBray 2010). A thorough understanding of engineering outreach that is designed to integrate relevant math and science experiences is therefore important for ensuring that K-12 students receive sufficient and appropriate exposure to engineering.

1.1.2. Gender and ethnic disparities in engineering

Given the underrepresentation of ethnic minorities in engineering (MacPhee, Farro, and Canetto 2013; Tan 2002) and the increasing proportion of ethnic minorities in the population of the U.S. and other highly developed countries, it is important to examine the development of attitudes of various ethnicities and both genders towards engineering (Aswad, Vidican, and Samulewicz 2011; Barnes, Lenzi, and Nelson 2017; Becker 2010; Bonny 2018; Capobianco, Ji, and French 2015; Chachra et al. 2008; Cummings, Cheeks, and Robinson 2018; Kant, Burckhard, and Meyers 2018; Little and Leon de la Barra 2009; Ozogul, Miller, and Reisslein 2017; Powell, Dainty, and Bagilhole 2012; Wiseman and Herrmann 2018). While there are likely many factors that contribute to the gender and ethnic disparities in engineering, social and developmental psychologists have focused on students' interests and perceptions. Prior research has found that gender and ethnic differences in students' interest toward engineering appear as early as middle and high schools (Aschbacher, Li, and Roth 2010; Salmi, Thuneberg, and Vainikainen 2016; Wingenbach et al. 2007). Also, prior research found that science interest is usually ignited before middle school and early exposure is instrumental in motivating students to develop their talents to pursue science related careers (Maltese and Tai 2010).

1.2. Opportunities and challenges for engineering in K-12 schools

Engineering incorporates working with materials while building artifacts that are relevant and interesting to students (Karataş, Bodner, and Unal 2016; Jones et al. 2018; Strawhacker, Sullivan, and Portsmore 2016). Thus, the integration of engineering curricula and activities into elementary schools (typically grades K, 1, 2, 3, 4, and 5 for students that are 5–10 years old) and middle schools (typically grades 6–9 for students that are 11–13 years old) has the potential to naturally ignite student interest. Engineering by its nature supports the philosophy of building solutions, by motivating students to learn science, math, writing, reading, and systematic thinking, as well as designing and taking ownership of the product (Aguirre-Muñoz and Pantoya 2016; Anthony et al. 2016; Milto et al. 2016; Rogers and Portsmore 2004; Sánchez-Martín et al. 2017; Wendell, Watkins, and Johnson 2016). Not only do STEM lessons and activities excite young learners, but they also build their confidence and self-efficacy in relation to their own abilities to be successful in more advanced math and science courses in later school years (DeJarnette 2012; Khanlari 2016; Ogle et al. 2017). Engineering related activities are powerful strategies for systematic exposure to science, mathematics, technology, and for attracting a broad student population.

Even though there is a vast potential to integrate engineering naturally into the curriculum, most science textbooks for grades 4–12 incorporate minimal engineering content and activities (Cantrell and Robinson 2002). Bencze (2010) states, ' … although there is considerable academic and official curricular support for promoting student-directed, open-ended science inquiry and technological design projects in schools, the reality is that they rarely occur.' (p. 58). As STEM exposure (aside from introductory science instruction) typically does not happen on a regular basis in schools, alternative approaches are needed. One alternative approach to address the problem of poor mathematics and science performance of U.S. students and the low enrolment in US engineering colleges has been engineering outreach to the K-12 community (Carlson and Sullivan 2004). Historically, engineering education has been the realm of higher education, and the scope of engineering education has not evolved to specifically inform the needs of K-12 education (Chandler, Fontenot, and Tate 2011). Thus, outreach efforts are highly important in increasing the potential pool of young learners interested in pursuing technical and engineering careers or employment in a technical area requiring STEM knowledge (Brophy et al. 2008).

Generally, engineering outreach to K-12 schools can be categorised according to the context of interactions with the K-12 students (Tillinghast, Petersen, and Mansouri 2018; Vennix, den Brok, and Taconis 2017; Young, Ortiz, and Young 2017). In-school programmes interact with all the students in a given class in their customary classroom setting (Colston et al. 2017; Fogg-Rogers, Lewis, and Edmonds 2017; Lottero-Perdue and Parry 2016; Reisslein et al. 2013; Shyr 2010; Varney et al. 2012; Watkins et al. 2018), whereas after-school programmes typically engage the students in clubs on a regular basis (Karp et al. 2010; Sahin, Ayar, and Adiguzel 2014; Stoeger et al. 2013). Summer programmes engage the students for a few consecutive days during school holidays (Kong, Dabney, and Tai 2014; LoPresti, Manikas, and Kohlbeck 2010; Nugent, Barker, and Grandgenett 2012; Yilmaz et al. 2010). In contrast, on-campus programmes bring K-12 students to university campuses, usually for a day, to tour engineering facilities and engage in engineering lab activities (Gumaelius et al. 2016; Hazzan, Levy, and Tal 2005; Molina-Gaudo et al. 2010). Fieldtrip workshops are similar to on-campus programmes in that students leave their school setting to fully focus on the engagement with engineering for the day. However, in contrast to on-campus laboratories that are mainly designed for university students, workshop facilities can be specifically configured for K-12 student engineering activities (Innes et al. 2012).

1.3. Contributions of this study with respect to existing literature

This study focused on the evaluation of school fieldtrips to an engineering workshop. The effects of such engineering workshops on students' perceptions have received relatively little research interest to date. We are only aware of one prior evaluation study that specifically examined engineering outreach in the form of school fieldtrips, namely the study by Innes et al. (2012). This prior study was limited, as students were not tracked throughout the study and the students were only surveyed immediately before and after the workshop. Thus, only very limited general analyses could be conducted. In contrast, the present study tracked the students throughout the workshop and included surveys immediately before and after, as well as a delayed-post (follow-up) survey two weeks after the workshop. The present study allows for the detailed analysis of the workshop effects on students' perceptions by student characteristics, such as age, gender, and ethnicity, as well as the examination of the students' perceptions after the immediate workshop excitement has worn off.

This study contributes also to the understanding of the gender and ethnic differences that exist in the engineering perceptions of the examined student population of 9–14-year-old students prior to participating in the engineering outreach, i.e. the fieldtrip workshop. Prior studies have examined some aspects of these perceptions. For instance, Guzey, Harwell, and Moore (2014) have compared the perceptions of a total of around 660 students in grades 4–6 from STEM focused schools and non-

STEM focused schools. Similarly, Wendell and Rogers (2013) compared the attitudes of around 250 5th grade students that participated in a Lego based science curriculum with about 200 students that were taught with the conventional curriculum. Hutchinson, Bodner, and Bryan (2011) have examined the interest of about 400 students in U.S. middle schools (typically grades 6–8, ages 11–13 years) and high schools (typically grades 9–12, ages 14–17 years) towards nanoscale science and engineering. Our study complements these existing studies by surveying the pre-existing perceptions of over 3000 9–14-year-old students towards engineering.

1.4. Background and overview of the Arizona Science Lab (ASL) engineering workshop

Outreach programmes focus on increasing engineering enrolment and technological literacy by providing educational opportunities and resources that make learning about engineering and technology relevant to young learners. With this philosophy, and in order to address the needs of the STEM talent pipeline and promoting the interest of young generations, the Phoenix chapter of the Institute of Electrical and Electronics Engineers (IEEE) founded the Arizona Science Lab (ASL, www.azsciencelab.org) in 2009. The primary goal of the ASL is to motivate pre-college students to take advanced science and math courses so as to keep the door open to future careers in STEM. The primary objective of the ASL is to encourage students to become interested in STEM through experiential learning. The secondary goal is to provide an opportunity for 4–9th grade students to interact with engineers (both retired and employed) and university engineering students who share their knowledge, expertise and, passion for engineering.

The ASL offers fully provisioned project-based STEM workshops to students in grades four through nine. The students participate in the one-day workshop during a regular school day. The workshops are offered free of charge. This no-cost aspect has been found to be vital for the acceptance of the programme by the schools as the schools and teachers have typically only very limited resources to spend on activities outside the regular classroom. The workshops are promoted as a fieldtrip destination for elementary and middle schools in the Phoenix metropolitan area. As suggested by Durik et al. (2015) students' early interests depend largely on external support in the form of attention-grabbing stimuli, engaging presentation of the subject content, and encouragement. Accordingly, the ASL workshops emphasize the Wow! factor of the projects and are designed to impress the students about science and engineering principles at work, while explaining the background concepts of engineering in detail, and through hands-on experiences.

Each workshop is conducted in a single four to five hour session. Each workshop includes a hands-on building project that reinforces the underlying STEM principles, and provides a technology solution to a given problem. At the end of the day, the students get to keep what they built. An ASL workshop is designed to include three main phases: (i) demonstration phase, (ii) design, build, and test phase, and (iii) wrap-up phase, as detailed in Section 2.2.1. Students work in teams consisting of two students and they are challenged to engineer a working technology solution, with an emphasis on design, test, re-engineer, and re-test to optimize their solution. The workshop topics intentionally combine various sub-areas of engineering, such as electrical engineering and civil engineering, and introduce students to engineering projects in these areas.

The main philosophy of the ASL workshops is that if students are to become interested in engineering, they have to see and understand how scientific principles and engineering are relevant to their everyday life. Hands-on activities designed by the ASL allow students to directly manipulate the tools and materials that are put to use by practicing engineers. According to situated cognition and constructivist perspectives, learning occurs in a specific social and physical context and individuals learn through social interactions and imitation (Brown, Collins, and Duguid 1989; Jonassen and Rohrer-Murphy 1999; Lave and Wenger 1991). Learning contexts involving hands-on practice with expert practitioners, e.g. apprenticeships and guided hands-on experimentation, provide a greater degree of social interaction and authentic activity than traditional didactic instruction; thus, such informal learning approaches have great potential to promote learning. Specifically, the informal workshops in the ASL create ideal conditions for the social interactions and authentic practice necessary for acquiring scientific principles and problem-solving skills involved in engineering. The workshops integrate numerous simple hands-on demonstrations to illustrate scientific principles; authentic examples of everyday objects to illustrate how the scientific principles affect the engineering design project and the operation of the gadget; and a hands-on collaborative construction project to reinforce the science principles and the engineering design, build, and test cycle (Delaine et al. 2010).

Throughout, the ASL workshops emphasize the informal aspect of the learning experience. The ASL activities are not graded so as to avoid performance pressures and related anxieties of the regular classroom. In contrast to graded classroom science experiments, the ASL activities encourage failures and learning from failures. Students receive direct feedback from the implementations of their design ideas, from the outcomes of their design, build, and test cycle, and from the direct interactions with engineers.

1.5. Theoretical framework

We mainly based our investigation of the perceptions of 4th through 9th grade (ages 9–14 years) students towards engineering within the framework of Expectancy Value Theory developed by Eccles (1983). The theory suggests constructs that aid in explaining students' achievement and achievement related choices. Expectancy value theory has been widely employed in education, and in recent years a few engineering education research studies have been based on this theory (Jones et al. 2010; Matusovich, Streveler, and Miller 2010; Matusovich et al. 2008). In this theory, expectancies are defined as specific student beliefs regarding their success on certain tasks that they will carry out in the immediate or long-term future (Eccles et al. 1999; Eccles and Wigfield 2002).

A key construct in expectance value theory is interest, which is related to a construct similar to intrinsic motivation, i.e. corresponds to engaging in an activity because the student likes and enjoys the activity (Eccles 2005; Hulleman et al. 2008; Lauermann, Eccles, and Pekrun 2017; Wigfield and Eccles 2000). We therefore included the construct of interest in our study. A few engineering education researchers investigated ways to make K-12 students interested in engineering by integrating engineering in science classes, and by teaching students major concepts in engineering to improve their feelings of attainment towards engineering (Donna 2012; Marulcu and Barnett 2013; Cejka, Rogers, and Portsmore 2006; Kazakoff, Sullivan, and Bers 2013; Marulcu 2014; Schnittka 2012; Stohlmann, Moore, and Roehrig 2012; Wang et al. 2011; Yoon et al. 2014). These studies generally found that elementary school students' knowledge of the content of the specific engineering project and the interest and attainment values associated with engineering fields increased after the integration of engineering related projects or programmes.

Expectancy of success (self-efficacy) is another key construct in expectancy value theory. Self-efficacy relates to the students' expectancies regarding being successful or unsuccessful in an activity or task (Bandura 1977; Eccles 2005; Wigfield and Eccles 2000). We included the construct of self-efficacy in our study in the context of students' expectancies regarding being successful or unsuccessful in an engineering course or discipline. This engineering self-efficacy is one of the key factors that influences students' retention and achievement in engineering programmes (Eris et al. 2010; Holmegaard, Madsen, and Ulriksen 2016; Lent et al. 2003; Micari and Pazos 2016; Seymour and Hewitt 1997; Shull and Weiner 2002). Engineering self-efficacy also plays a role in students' future career choices (Lent, Brown, and Hackett 2002). Self-efficacy has been an important predictor of persistence and performance in science and math related fields (Betz and Hackett 1986; Fouad and Smith 1996; Lent et al. 2008). Previous research has shown results of building self-efficacy towards engineering when K-12 students are exposed to pre-college engineering activities, engineering classes, or engineering related hobbies (Innes et al. 2012; Fantz, Siller, and DeMiranda 2011;

Feldhausen, Weese, and Bean 2018; Johnson et al. 2013). Expectations of success in engineering need to be taken into account, and diverse future strategies for attracting diverse students to engineering should be investigated (Kolmos et al. 2013).

Expectancy value theory includes the construct of utility which relates to the extrinsic reasons for engaging in a task, i.e. the extrinsic motivation for completing a task because it helps to reach some goal. That is, in expectancy value theory (Eccles 2005), task value includes a utility value relating to how useful the task is. A student finds utility value in a task if s/he believes that the task is useful and relevant for other aspects or goals in her/his live. Inspired by recent studies that derived utility related constructs from expectancy value theory (Harackiewicz et al. 2012; Rozek et al. 2015), we consider utility in a broader sense in our study. In particular, we consider the construct of utility to broadly relate to the overall perceived usefulness and importance of the engineering field. Previous research showed that when students perceive utility value in a topic, they develop interest and take advanced courses in those academic disciplines (Durik, Vida, and Eccles 2006; Durik et al. 2015; Harackiewicz et al. 2002; Hulleman and Harackiewicz 2009; Nagy, Berninger, and Abbott 2006; Shechter et al. 2011). These studies suggest that direct communication of utility value information may be an effective tool to stimulate interest in tasks. Even when students may not have high expectancies for success, the utility value information may motivate them to try harder.

In addition to the constructs of interest, self-efficacy, and utility, that were derived from expectancy value theory, we considered the construct of negative stereotypes towards engineering. Stereotypes in the society and cultural norms can have strong influences in the STEM fields, as these fields have traditionally been dominated by white males (Bystydzienski and Bird 2006; Riegle-Crumb and King 2010), and are associated with negative stereotypes for females and certain ethnicities (Beasley and Fischer 2012; Schinske, Cardenas, and Kaliangara 2015). Extensive prior research investigating ethnic and gender differences in negative stereotypes and beliefs towards engineering (e.g. Aschbacher, Ing, and Tsai 2014; Besterfield-Sacre et al. 2001; Brainard and Carlin 1998; Chan, Stafford, Klawe, and Chen 2000; Gibbons et al. 2004; Guzey, Harwell, and Moore 2014; Hutchinson, Bodner, and Bryan 2011; Schaefers, Epperson, and Nauta 1997; Wendell and Rogers 2013; Wright and Terry 2010) has consistently found that there are differences in students' negative stereotypes towards engineering based on gender: Female students have more negative attitudes towards engineering compared to male students, and female students enter engineering careers with lower confidence in their engineering knowledge and abilities compared to their male counterparts.

1.6. Research questions

In the present study, we examined the immediate and delayed effects of an engineering workshop, where students interacted with engineers and completed an engineering project, on 9–14-year-old students' perceptions of engineering. In particular, we examined interest, self-efficacy, and perceptions regarding utility of engineering, as well as negative stereotypes towards engineering. These perceptions of engineering were captured at three points in time: immediately before the engineering workshop, immediately after the engineering workshop, and two weeks after the engineering workshop. We also investigated if these perceptions are the same or different between different age levels, and between the different genders and ethnic backgrounds. The main research questions addressed in this study are:

(1) Are there gender, age, or ethnic differences in students' perceptions of engineering at pre-survey?
(2) Do students' engineering perceptions improve immediately following the workshop (from pre-survey to post-survey)?
    a. Are immediate workshop effects moderated by age and gender?
    b. Are immediate workshop effects moderated by ethnicity?

(3) Are gains in students' engineering perceptions maintained at the delayed assessment (delayed-post-survey)?
   a. Are delayed workshop effects moderated by age and gender?
   b. Are delayed workshop effects moderated by ethnicity?

2. Method

2.1. Participants and design

The participants (total $N = 3344$) were 9–14-year-old students from elementary and middle schools in the Southwestern US (Phoenix metropolitan area). All of these students attended an ASL workshop in person. The data were collected between 2014–15 ($N = 2557$) and 2015–16 ($N = 862$). The gender distribution of the participants was; boys ($N = 1647$; 48.2%); girls ($N = 1772$; 51.8%). As is common for U.S. education research, we collected the participants ethnicity. Generally, the U.S. Census Bureau defines race as a social characteristic, and not in terms of anthropological or genetic characteristics. That is, a person is expected to self-identify with a social group that reflects the person's race. The main five races are Black or African American, American Indian or Alaska Native, Asian, Native Hawaiian or Other Pacific Islander, and White. Moreover, the U.S. Census Bureau defines ethnicity as the characterisation whether a person is of Hispanic origin or not. Based on these U.S. Census Bureau definitions, we considered for this research study the following characterisation categories, which are commonly considered in U.S. education research and which we refer to as ethnicities: Black/African American, Asian, Caucasian/White, Hispanic, Native American, and Other. The participants reported the following ethnic identifications: Black/African American ($N = 170$; 5.1%); Asian ($N = 132$; 3.9%); Caucasian/White ($N = 1444$; 43.2%); Hispanic ($N = 1197$, 35.8%); Native American ($N = 178$; 5.3%); Other ($N = 223$; 6.7%). All $N = 3344$ students completed the pre- and post-survey, and 1093 students completed and returned the delayed-post-survey. For the analysis of the workshop effects by age, we formed three age groups: 9- and 10-year-old students ($N = 1515$), 11- and 12-year-old students ($N = 1160$), as well as 13- and 14-year-old students ($N = 669$).

2.2. Materials and data collection instruments

2.2.1. Workshop structure and curriculum

The ASL curriculum has a portfolio of seven workshop topics that focus primarily on a variety of electrical and mechanical engineering topics. The workshops topics and corresponding participant numbers are: Ciphers and Codes (information representation and encryption, $N = 88$), Solar Cars (design and build a solar car, $N = 811$), Motors (build and electric motor, $N = 786$); Sail Away (design and build a sail boat, $N = 94$); Waterwheels (design and build a watermill, $N = 705$); Popsicle bridges ($N = 89$); Rockets (design and build a bottle rocket, $N = 771$). All workshops are aligned with US National Science Education Standards, which were produced by the US National Research Council and endorsed by the US National Science Teachers Association. Even though there is an informal learning atmosphere at each workshop, the following structure is preserved in each ASL workshop:

Demonstration Phase: The demonstration phase introduces students to the underlying science (physical) principles of the workshop project topic. These principles are exploited in the design and building of the project gadget (e.g. solar car). The level of presented detail is adapted to the students' grade level. The demonstration phase involves a combination of a slide presentation and hands-on demonstrations by two facilitators. One facilitator concentrates on the introduction of the principles through the slide presentation, and the other facilitator conducts the demonstrations illustrating the principles. Both facilitators frequently involve the students through questions, through student participation in the performance of the demonstrations, and through sharing their own engineering experiences.

Design, Build and Test Phase: In the design, build and test phase, the students work in two-person teams. There are typically around 15 teams per workshop. Based on the principles that the students learned in the demonstration phase, they are challenged to engineer a working technology solution (gadget). The engineering process should involve design, test, re-engineer, and re-test so as to optimize the solution. A total of six engineer facilitators (the two demonstration phase presenters, plus four additional facilitators) mentor the student teams. The facilitators only assist students that have difficulties by asking questions and encouraging the students to progress themselves to a design solution; the facilitators do not disclose a solution. The facilitators prompt the teams to first design their solutions on paper and, then, judge whether a team can proceed to the construction of the design. The students are encouraged to build their designs quickly and not to worry about making the designs look cosmetically appealing. A built design is tested with a facilitator to see how the design performs. During the testing, the students are continuously encouraged to re-examine their designs, to assess what worked well or did not work well, and to look for improvements. Modifications or complete re-builds are encouraged and the design – build – test – modify – retest cycle can be repeated as many times as the available time permits. At the end of the design, build and test phase, a competition is held to see which design performs the best.

Wrap-up Phase: In the wrap-up phase, the students are encouraged to explain the test results for the different designs and discuss tradeoffs within the engineering design guidelines that they learned in the demonstration phase. The aim of the wrap-up session is to reinforce the key science principles and the engineering design, build, and test cycle. The facilitators also initiate a discussion of studies and careers in STEM fields, emphasize that STEM careers are exciting, fun, and well-paid, and answer any student questions.

2.2.2. Data collection instruments

Data for the study were collected using a 12-item survey developed specifically to assess the effects of the ASL workshops. The construct validity of the survey items had been verified with the judgment of subject matter experts (Aiken 1997). The survey includes four subscales containing three items each: interest (e.g. I would like to learn more about engineering; $\alpha s = .81–.87$), self-efficacy (e.g. I could succeed in engineering; $\alpha s = .77–.85$); negative stereotypes (e.g. Engineers are boring people; $\alpha s = .75–.79$), and utility (e.g. Engineers help solve important problems; $\alpha s = .69–.75$). Items were rated on a 5-point scale (*strongly agree, agree, not sure, disagree, strongly disagree*). All students completed the survey immediately before the workshop (i.e. pre-survey) and immediately after the workshop (i.e. post-survey), and a subset of students ($N = 1093$) completed the survey again two weeks later in their classrooms (i.e. delayed-post-survey). The two-week delay was adopted based on general recommendations for research (Brown, Irving, and Keegan 2008; Campbell and Stanley 1963) and the practical constraints of the teachers conducting the delayed-post-surveys in their classrooms. Each of these three surveys, i.e. pre-survey, post-survey, and delayed-post-survey, contained the same survey questions; however, the questions were randomly reordered. At pre-survey, students also reported their age, gender, and ethnicity to allow for the exploration of group differences in students' engineering perceptions.

2.3. Procedure

Elementary and middle school teachers in the Phoenix metropolitan area were recruited to bring their students for a full-day field trip to the ASL during a regular school day. When entering the ASL workshop facility, each student received a workbook with a unique ID number on the front of the workbook. As a first workshop task, the students were asked to copy the ID number from their workbook onto the pre-survey and to individually complete the pre-survey. Upon completion of the pre-surveys, the pre-survey sheets were collected by the facilitators. The students then completed the above described workshop activities while taking notes, making design sketches, and noting observations in their workbooks. At the end of the workshop, the students were provided with post-survey sheets and were asked to copy the ID number from the front of their workbook to the post-survey and to individually complete the post-survey. The completed post-surveys were collected by the facilitators. The students kept their workbook and were instructed by their teachers to include the workbook into their regular class notes (binder). The teachers were instructed to administer the delayed post-survey in the school sites two weeks after the workshop. The teachers distributed the post-survey sheets to the students and asked the students to copy their ID number from the front of the workshop workbook from their class binder onto the survey sheet and to individually complete the post-survey. Later, the teachers mailed in the completed delayed posts-surveys to the ASL facility by using a pre-addressed envelope.

3. Results

3.1. Overview of analyses

We conducted three sets of analyses to examine the research questions in this study. The first set of analyses explored group (i.e. age, gender, and ethnic) differences in students' engineering perceptions at the pre-survey. The second and third set of analyses examined whether the engineering workshop positively influenced students' engineering perceptions at the post-survey and whether any effects were maintained at the delayed-post-survey, respectively.

For each set of analyses, we examined two models: one group of models explored age and gender differences using the full sample ($N = 3344$); the other group of models explored ethnic differences using only data from Caucasian ($N = 1444$) and Latino students ($N = 1197$), which were the predominant ethnic groups in this study. We did not have enough students from other ethnic groups (e.g. African-American, Asian) to make meaningful comparisons between these groups. Therefore, examining age/gender and ethnicity in separate models simplified the analyses and allowed us to maintain the full sample in the age/gender models.

3.2. Preliminary analyses

Preliminary analyses examined whether our data met the assumptions of our statistical models. All variables displayed approximate normal distributions based on skewness except the negative stereotype (pre-survey = 1.12; post-survey = 1.44; delayed-post-survey = 1.50) and utility (pre-survey = −.65; post-survey = −.90; delayed-post-survey = −.97) variables. Log transformations were applied to these variables to address skewness; however, analyses performed on the transformed and raw variables showed similar results. Therefore, only the analyses and findings on the raw variables are presented below.

Table 1. Means, standard deviations, and bivariate correlations of pre-, post-, and delayed-post-metrics: interest, self-efficacy, negative stereotypes, and utility for engineering.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	*M*	*SD*
Pre-Int.	–												3.46	.90
Pre-Eff.	.68	–											3.33	.81
Pre-Neg. St.	−.30	−.25	–										1.88	.86
Pre-Util.	.30	.34	−.35	–									4.08	.73
Post-Int.	.59	.46	−.17	.19	–								3.59	1.05
Post-Eff.	.48	.56	−.13	.22	.72	–							3.56	.96
Post-Neg. St.	−.22	−.18	.51	−.21	−.28	−.26	–						1.70	.85
Post-Util	.23	.26	−.21	.55	.30	.33	−.31	–					4.32	.69
Del.-Int.	.49	.34	−.09	.16	.64	.49	−.18	.21	–				3.66	.94
Del.-Eff.	.44	.47	−.08	.20	.56	.64	−.18	.26	.65	–			3.51	.93
Del.-Neg. St.	−.26	−.18	.38	−.19	−.28	−.23	.54	−.21	−.29	−.29	–		1.65	.82
Del.-Util.	.22	.23	−.14	.52	.26	.28	−.22	.62	.31	.35	−.31	–	4.33	.68

Notes: All correlations are significant at $p < .01$. Pre-survey and post-survey statistics were calculated on the full sample ($N = 3344$); delayed-post-survey statistics are only based on students who completed the delayed-post-survey ($N = 1093$).

Table 1 presents the Pearson inter-correlation coefficients of all study variables and overall means and standard deviations. All variables were significantly correlated with each other. It is noteworthy that all constructs showed moderate to strong stability across time points.

3.3. Group differences in students' pre-workshop engineering perceptions

3.3.1. Gender and age differences

To explore age and gender differences in students' engineering perceptions, 2 (gender) × 3 (age) analyses of variance (ANOVAs) were conducted on students' interest, self-efficacy, negative stereotype, and utility pre-survey scores. All follow-up (post hoc) analyses were conducted using the Sidak adjustment for multiple comparisons.

For *interest,* the 2 × 3 ANOVA revealed a main effect for gender, $F(1, 3338) = 168.53$, $p < .001$, partial $\eta^2 = .05$. Boys ($M = 3.66$, $SD = 0.89$) reported a stronger interest than girls ($M = 3.28$, $SD = 0.87$). There was also a main effect for age, $F(2, 3338) = 26.56$, $p < .001$, partial $\eta^2 = .02$; pairwise comparisons revealed that the oldest students ($M = 3.24$, $SD = 0.90$) reported less interest than both the middle ($M = 3.48$, $SD = 0.90$) and youngest ($M = 3.55$, $SD = 0.89$) students. The age by gender interaction was also significant, $F(2, 3338) = 10.65$, $p < .001$, partial $\eta^2 = .01$; tests of simple effects comparing gender within each age group showed that boys displayed stronger interest than girls at all age levels; however, gender differences were strongest for the older age groups.

Similar to the results for interest, the 2 × 3 ANOVA for *self-efficacy* revealed significant main effects for gender $F(1, 3338) = 120.24$, $p < .001$, partial $\eta^2 = .04$, and age, $F(2, 3338) = 26.51$, $p < .001$, partial $\eta^2 = .02$, and a significant gender X age interaction, $F(2, 3338) = 7.70$, $p < .001$, partial $\eta^2 = .01$. Boys ($M = 3.48$, $SD = 0.80$) reported higher self-efficacy than girls ($M = 3.19$, $SD = 0.79$), and the oldest age group ($M = 3.13$, $SD = 0.82$) reported less self-efficacy than both the middle ($M = 3.36$, $SD = 0.82$) and youngest ($M = 3.40$, $SD = 0.78$) age groups. Again, simple effects indicated that, at all age levels, boys reported higher self-efficacy than girls, but that the gender difference was greatest in the older age groups.

The 2 × 3 ANOVA for negative stereotypes revealed a marginal gender effect, $F(1, 3338) = 3.61$, $p = .057$, partial $\eta^2 = .01$, suggesting that boys ($M = 1.85$, $SD = 0.84$) endorsed stereotypes less than girls ($M = 1.91$, $SD = .88$) and a significant age effect*,* $F(2, 3338) = 16.75$, $p < .001$, partial $\eta^2 = .10$. Follow-up analyses indicated that the oldest age group ($M = 2.04$, $SD = 0.82$) endorsed negative stereotypes more strongly than both the middle ($M = 1.80$, $SD = 0.76$) and youngest age ($M = 1.87$, $SD = 0.94$) groups. There was not a significant interaction effect.

The utility 2 × 3 ANOVA showed significant main effects for gender, $F(1, 3338) = 41.89$, $p < .001$, and age*,* $F(2, 3338) = 13.45$, $p < .001$. Overall, boys ($M = 4.17$, $SD = 0.69$) provided higher utility ratings than girls ($M = 3.99$, $SD = 0.75$). Pairwise comparisons for age revealed that the middle age group ($M = 4.16$, $SD = 0.68$) reported higher utility than both the younger ($M = 4.06$, $SD = 0.78$) and oldest ($M = 3.98$, $SD = 0.66$) age groups; the mean differences between the youngest and oldest groups were also significant. There was not a significant interaction effect.

3.3.2. Ethnic differences

Differences between Caucasian and Hispanic students' engineering perceptions were explored with a one-way multivariate analysis of variance (MANOVA) on pre-survey outcome variables. The effect for ethnicity was significant, Wilk's $\Lambda = .96$, $F(4, 2636) = 27.32$, $p < .001$, partial $\eta^2 = .04$. Follow-up ANOVAs were conducted using the Bonferroni method (each test was conducted at the .01 level). Results revealed significant differences for self-efficacy (Caucasian: $M = 3.39$, $SD = 0.80$; Hispanic: $M = 3.26$, $SD = 0.80$), $F(1, 2639) = 17.59$, $p < .001$, partial $\eta^2 = .007$, negative stereotypes*,* (Caucasian: $M = 1.80$, $SD = 0.87$; Hispanic: $M = 1.96$, $SD = 0.85$), $F(1, 2639) = 22.26$, $p < .001$, partial $\eta^2 = .008$, and utility (Caucasian: $M = 4.22$, $SD = 0.72$; Hispanic: $M = 3.95$, $SD = 0.70$), $F(1, 2639) = 94.67$, $p < .001$, partial $\eta^2 = .035$. There were no differences between Caucasian and Hispanic students on their interest in engineering ($p = .30$).

3.4. Workshop effects

To examine the effect of the workshop on students' engineering perceptions, two sets of analyses were conducted. First, we examined change from pre-survey to post-survey using the full sample. Then, we examined if any changes in students' engineering perceptions were maintained at the delayed-post-survey using only the students who completed the delayed-post-survey ($N = 1093$; Caucasian = 572; Hispanic = 264).

3.4.1. Gender and age differences of immediate post-workshop perceptions

To explore immediate workshop effects and whether effects depended on age and gender, a series of 2 (gender) × 3 (age) × 2 (outcome variable: pre-survey, post-survey) mixed-design ANOVAs were conducted with gender and age as between-subjects factors and outcome variable (interest, efficacy, negative stereotype, and utility) as a within-subjects factor. All follow-up analyses were conducted using the Sidak adjustment for multiple comparisons.

The 2 × 3 × 2 ANOVA for assessing changes in students' interest in engineering revealed a main effect for interest, $F(1, 3338) = 66.14$, $p < .001$, partial $\eta^2 = .02$; interest showed a significant increase from pre-survey ($M = 3.46$; $SD = 0.90$) to post-survey ($M = 3.59$; $SD = 1.05$). There was a significant interest X age interaction, $F(2, 3338) = 3.06$, $p = .047$, partial $\eta^2 = .002$; tests of simple effects examining changes in interest within each age group revealed that there was a significant increase in all age-groups, but that the strongest change was for the oldest age group. The interest X gender and 3-way interactions were not significant.

For self-efficacy, the 2 × 3 × 2 ANOVA uncovered a main effect, $F(1, 3338) = 252.87$, $p < .001$, partial $\eta^2 = .07$, indicating that students' self-efficacy increased from pre-survey ($M = 3.32$; $SD = 0.81$) to post-survey ($M = 3.56$; $SD = 0.96$). This main effect was qualified by significant efficacy X age, $F(2, 3338) = 5.12$, $p = .006$, partial $\eta^2 = .003$, and efficacy X gender, $F(1, 3338) = 4.21$, $p = .04$, partial $\eta^2 = .001$, interactions. Follow-up analyses revealed that increases in self-efficacy were significant for all groups, but strongest for girls and students in the oldest age group. The three-way interaction was not significant.

The 2 × 3 × 2 ANOVA for negative stereotypes showed that students' endorsement of stereotypes decreased from pre-survey ($M = 1.88$; $SD = 0.86$) to post-survey ($M = 1.70$; $SD = 0.85$), $F(1, 3338) = 119.86$, $p < .001$, partial $\eta^2 = .04$. There was a significant stereotype X age interaction; $F(2, 3338) = 12.72$, $p < .001$, partial $\eta^2 = .008$. Tests of simple effects indicated that decreases in stereotype ratings were significant for all age groups, but the youngest age group showed the largest change. The stereotype X gender and 3-way interactions were not significant.

The utility 2 × 3 × 2 ANOVA revealed a main effect, $F(1, 3338) = 388.633$, $p < .001$, partial $\eta^2 = .10$; students' perception regarding the utility of engineering increased from pre-survey $M = 4.08$; $SD = 0.73$) to post-survey ($M = 4.32$; $SD = 0.69$). None of the interactions were significant.

3.4.2. Gender and age differences of delayed-post-workshop perceptions

To explore if students maintained their positive improvements in engineering perceptions at the delayed-post-survey, a series of 2 (gender) × 3 (age) × 3 (outcome variable: pre-survey, post-survey, and delayed-post-survey) mixed design ANOVAs were conducted with gender and age as between-subjects factors and outcome variable (interest, utility, negative stereotype, and utility) as the within-subjects factor. This analysis considered only the $N = 1093$ students that completed the delayed-post-survey. All follow-up tests were conducted using the Sidak adjustment for multiple comparisons.

The 2 × 3 × 3 ANOVA revealed a main effect for interest, $F(2, 1086) = 29.18$, $p < .001$, partial $\eta^2 = .051$, pairwise comparisons indicated that post-survey ($M = 3.64$; $SD = 1.02$) and delayed-post-survey ($M = 3.66$; $SD = 0.94$) scores were both significantly higher than the mean pre-survey score ($M = 3.46$; $SD = 0.88$). There were no significant differences between post-survey and delayed-post-survey. None of the interactions were significant.

For self-efficacy, the $2 \times 3 \times 3$ ANOVA also revealed a main effect; $F(2, 1086) = 35.34$, $p < .001$, partial $\eta^2 = .061$. Pairwise comparisons uncovered that post-survey ($M = 3.60$; $SD = 0.94$) and delayed-post-survey ($M = 3.51$; $SD = 0.93$) scores were significantly higher than the average pre-survey score ($M = 3.37$; $SD = 0.77$); the post-survey scores were also significantly higher than the delayed-post-survey scores. None of the interactions were significant.

The $2 \times 3 \times 3$ ANOVA for negative stereotypes revealed a significant main effect, $F(2, 1086) = 27.41$, $p < .001$, partial $\eta^2 = .048$. Follow-up tests indicated that, compared to pre-survey ($M = 1.85$; $SD = 0.84$), students' endorsement of stereotypes was lower at both post-survey ($M = 1.66$; $SD = 0.86$) and delayed-post-survey ($M = 1.65$; $SD = 0.82$); there were no significant differences between post-survey and delayed-post-survey means. None of the interactions were significant.

The $2 \times 3 \times 3$ ANOVA for utility also showed a significant main effect, $F(2, 1086) = 65.56$, $p < .001$, partial $\eta^2 = .11$. Follow-up tests indicated, compared to pre-survey ($M = 4.16$; $SD = 0.71$), students rated utility higher at post-survey ($M = 4.40$; $SD = 0.65$) and at delayed-post-survey ($M = 4.33$; $SD = 0.68$); the mean for post-survey was also significantly higher than the mean for delayed-post-survey. None of the interactions were significant.

3.4.3. Ethnic differences of immediate post-workshop perceptions

To examine if immediate workshop effects differed for Caucasian and Hispanic students, a series of 2 (ethnicity) × 2 (outcome variable: pre-survey, post-survey) mixed-design ANOVAs were conducted with ethnicity as a between-subjects factor and outcome variable (interest, efficacy, negative stereotype, and utility) as a within-subjects factor. In all analyses, the 2-way interactions were not significant, which suggests that Caucasian and Hispanic students responded similarly to the workshop.

3.4.4. Ethnic differences of delayed-post-workshop perceptions

To explore if delayed effects differed for Caucasian and Hispanic students, a series of 2 (ethnicity) × 3 (outcome variable: pre-survey, post-survey, and delayed-post-survey) mixed design ANOVAs were conducted with ethnicity as a between-subjects factor and outcome variable (interest, utility, negative stereotype, and utility) as the within-subjects factor. This analysis considered only the $N = 1093$ students that completed the delayed-post-survey. All follow-up tests were conducted using the Sidak adjustment for multiple comparisons.

The 2×3 ANOVAs for interest and utility did not reveal significant two-way interactions, suggesting that Caucasian and Hispanic students showed similar patterns in their score changes over time. For self-efficacy, the 2×3 ANOVA revealed a significant efficacy X ethnicity interaction, $F(2, 833) = 3.58$, $p = .028$, partial $\eta^2 = .009$. For Caucasian students, pre-survey efficacy ($M = 3.45$; $SD = 0.73$) was lower than both post-survey ($M = 3.63$; $SD = 0.92$) and delayed-post-survey ($M = 3.54$; $SD = 0.92$) efficacy, and post-survey efficacy was significantly higher than delayed-post-survey efficacy. For Hispanic students, pre-survey efficacy ($M = 3.27$; $SD = 0.79$) was lower than both post-survey efficacy ($M = 3.56$; $SD = 0.94$) and delayed-post-survey efficacy ($M = 3.53$; $SD = 0.85$); however, there were no significant differences between post-survey and delayed-post-survey efficacy scores.

A 2×3 ANOVA revealed that the two-way interaction for negative stereotypes was also significant, $F(2, 833) = 3.25$, $p = .039$, partial $\eta^2 = .008$; however, follow-tests revealed similar patterns for both Caucasian and Hispanic students. Pre-survey negative stereotypes (Caucasian: $M = 1.79$; $SD = 0.81$; Hispanic: $M = 1.97$; $SD = 0.86$) were higher than both post-survey (Caucasian: $M = 1.61$; $SD = 0.82$; Hispanic: $M = 1.73$; $SD = 0.89$) and delayed-post-survey negative stereotypes (Caucasian: $M = 1.62$; $SD = 0.78$; Hispanic: $M = 1.64$; $SD = 0.79$), and there were no significant differences between post-survey and delayed-post-survey negative stereotypes. The significant two-way interaction was likely due to the difference in the level of non-significance between post-survey and delayed-post-survey negative stereotype scores (Caucasian: $p = .93$; Hispanic: $p = .15$).

4. Discussion

The results of this study showed that the school fieldtrip to an engineering workshop with a carefully structured curriculum increased all participating students' interest, utility and self-efficacy perceptions towards engineering and decreased their negative stereotypes towards engineering. Additionally, the delayed-post-survey data collection showed that these improved perceptions sustained for two weeks after the workshop experience.

4.1. Pre-workshop group differences

4.1.1. Gender and age differences

Before the workshop, older students reported lower interest, lower self-efficacy, and more negative stereotypes towards engineering compared to younger students. These results for the engineering domain are consistent with prior studies on other knowledge domains, e.g. mathematics and English (Eccles et al. 1993; Simpkins, Fredricks, and Eccles 2012), that found declining student perceptions as students grow older. The prior studies considered knowledge domains that are commonly taught in schools and that the students are exposed to regularly, such as mathematics and English. In contrast, engineering is not yet commonly integrated into school curricula in the U.S., although there are efforts towards integrating engineering into the U.S. K-12 school curricula (Carr, Bennett, and Strobel 2012). The schools that conduct fieldtrips to the ASL engineering workshop typically seek out this opportunity to provide engineering exposure to their students as they lack other engineering elements in their curricula.

The results of this study showed that before the workshop, boys reported stronger interest towards engineering than girls, and that boys reported higher self-efficacy and utility ratings towards engineering as well as marginally less negative stereotypes towards engineering than girls. These results on the pre-existing perceptions of grade 4–9 students corroborate previous research that found gender differences in STEM perceptions in young students (Aschbacher, Li, and Roth 2010; Maltese and Tai 2010; Wingenbach et al. 2007). Prior research conducted with middle and high school students indicates that these differences occur as early as U.S. middle and high schools years (ages 11–18 years) (Aschbacher, Li, and Roth 2010; Johnson et al. 2013; Wingenbach et al. 2007). However, our study found that these gender differences exist in the student population (prior to participating in the engineering outreach) as early as elementary school (ages 9 and 10 years). Our findings indicate that it is very important to provide students with engineering experiences in early years of schooling (Bagiati et al. 2010; Bybee and Fuchs 2006; Dabney et al. 2012); it is possible that ongoing exposure to gender-fair engineering experiences could prevent gender differences from emerging.

An important factor for the retention of females in engineering is self-efficacy (Chang 2002; Goodman 2002; Marra et al. 2009). If low self-efficacy and negative stereotypes persist and are not countered by exposure to well-designed engineering interventions starting at early ages, they may discourage girls from pursuing engineering careers in the future. Therefore, it is very important to design and deliver well-designed engineering experiences to young elementary school students. These engineering experiences may help girls gain self-efficacy, and provide ongoing participation opportunities to build their self-efficacy by demonstrating competency in engineering tasks (Lachapelle et al. 2012; Lindberg, Pinelli, and Batterson 2008).

More generally, Eccles (2005) notes that students make choices that shape their lives, although they do not always consider all the options, they are not even aware of the existence of options, or they do not have an idea about their odds of achieving in that option, or have inaccurate information about an option based on cultural or gender stereotypes. Thus, it is very important to provide young students opportunities to be exposed to engineering fields, to experience success in an engineering activity, and to inform them about the wide career spectrum in engineering so as to support their interest and positive expectancies.

4.1.2. Ethnic differences

Examining the pre-existing perceptions before the workshop, this study did not find significant differences in interest towards engineering between Caucasian and Hispanic students. However, Caucasian students had significantly higher self-efficacy and utility perceptions as well as significantly lower negative stereotype perceptions toward engineering than Hispanic students. This pattern of findings highlights that while Caucasian and Hispanic students have similar interest levels towards engineering at a young age, Caucasian students have higher self-efficacy and positive perceptions towards engineering than Hispanic students. Thus, engineering interventions are needed to reinforce self-efficacy and to counter negative stereotypes of under-represented groups, while they still have interest at a young age. Access and exposure to these engineering interventions may help under-represented students build their confidence early on, by experiencing success through hands-on real world engineering experiences.

Providing free-of-charge engineering workshop experiences to ethnic minorities may help overcome major logistical and financial barriers, such as not having access to challenging courses of study at their schools (Atwater 2000), or having lower cultural capital (Cole and Espinoza 2008; Martin, Simmons, and Yu 2013; Pascarella et al. 2004), or not having engineering role models in their schools or lives (Hernandez et al. 2016; Rendón, Garcia, and Person 2004).

4.2. Immediate workshop effects: age, gender, ethnicity

The results showed significant overall increases in the interest, self-efficacy, and utility of engineering perceptions, as well as a significant overall decrease in the negative stereotype perceptions immediately after the workshop compared to the perceptions prior to the workshop. These overall results for the immediate effects of the ASL workshop are very encouraging. Similar to the findings of Durik et al. (2015), our results for the immediate workshop effects indicate that a well-designed, engaging, and attention grabbing introduction to a new subject area can significantly improve the perceptions of the subject area.

The significant interest X age interaction indicated that there was a significant increase in interest for all age groups, with the strongest interest increase in the oldest age group. The oldest age group had significantly lower interest than the young and middle age groups at the pre-survey stage before the workshop. Thus, the oldest age group may have had the highest 'potential' for increasing interest levels during the workshop. Apparently, the older students were very receptive to the engineering workshop and perceived the workshop experience to be so interesting that they experienced higher increases in interest than the middle and young age groups.

The interaction results for self-efficacy exhibited a similar pattern: Female students and the oldest age group had significantly lower engineering self-efficacy perceptions than male students and the younger age groups, respectively, prior to the workshop. The female students and the oldest age group then exhibited the highest increases in engineering self-efficacy immediately after the workshop. This pattern of results of the oldest students with the lowest interest as well as the female and oldest students with the lowest self-efficacy prior to the workshop, then experiencing the strongest increases in interest and self-efficacy appears to indicate a 'compensation effect' pattern: The workshop experience appears to provide the strongest gains in positive perceptions for the groups that enter the workshop with the least positive perceptions.

An exception to this compensation effect pattern is the interest level of the female students. Female students had lower interest than male students prior to the workshop, but did not experience higher interest increases than male students after the workshop. This may be due to the workshop topics and environment not having been specifically designed for female students. The workshop topics, see Section 2.2.1., are traditional engineering topics that may not strongly entice the interests of female students, who may be more interested in the aspects of engineering as a caring or helping profession (Burns, Lesseig, and Staus 2016; Capobianco and Yu 2014; Du 2006; Little and Leon de la Barra 2009). The workshop facilitators were retired or working engineering experts that reflected the typical gender composition of the U.S. engineering workforce, i.e. were predominantly male. This combination of workshop topics and environment (facilitators) may have led to the strong increases in self-efficacy, i.e. the female students may have realised through the workshop that they could succeed in engineering. However, the workshop may not have increased their interest level in such a strong manner to overcome the lower interest level compared to the male students prior to the workshop. Future research should examine the impact of the gender of the workshop facilitators on the perceptions of female and male students. Also, the age of the workshop facilitators should be examined, ranging from undergraduate engineering college students to retired engineers (Gamse, Martinez, and Bozzi 2017).

This compensation effect pattern did also not extend to the negative stereotypes. On the contrary, the youngest age group, which had already lower negative stereotypes than the oldest age group prior to the workshop, experienced a stronger decrease in negative stereotypes than the oldest age group. Possibly, the youngest age group had still naïve notions of engineering prior to the workshop and may have thought of 'engineers' as train drivers, which is a common cultural usage of the term 'engineer' for young children in pre-school in the U.S. (Lachapelle et al. 2012). For these young students, it may have been more likely that the workshop provided a first introduction to the field of engineering as a technical discipline that solves practical problems based on foundations provided by mathematics and science.

The analysis of ethnic differences revealed that the workshop experience was equally effective at improving all four types of considered engineering perceptions (i.e. increasing interest, self-efficacy, and utility, as well as reducing negative stereotypes) of both Caucasian and Hispanic students. Thus, there was no 'compensation effect' pattern, as we have observed for the interest perceptions of the oldest age group and the self-efficacy perceptions of the female students and oldest age group. Hispanic students had significantly lower self-efficacy and utility perceptions as well as stronger negative stereotype perceptions than the Caucasian students prior to the workshop. However, the Hispanic students did not experience stronger improvements than the Caucasian students in these perceptions. Possibly, the workshops, which were designed without specifically considering cultural contexts and were mostly facilitated by Caucasian engineers, did not fully reach the potential for improving the perceptions of Hispanic students. Hispanic youth have unique cultural knowledge and aspirational social capital (Yosso 2005). The design of engineering workshop curricula that are culturally responsive (Alemán, Delgado-Bernal, and Cortez 2015; Elenes and Delgado Bernal 2010) by specifically building on and leveraging this pre-existing knowledge and cultural capital of Hispanic youth (Villalpando and Solórzano 2005) is an important direction for future research. Also, opportunities to interact with and observe ethnically diverse engineers as workshop facilitators may further strengthen the workshop effects for Hispanic students. Nevertheless, the results are promising in that Hispanic students showed similar levels of gains as Caucasian students, although the Hispanic students started off with lower perception levels prior to the workshop. This illustrates that the workshop had positive effects for the Hispanic students.

4.3. Delayed workshop effects and sustainability: age, gender, ethnicity

A unique contribution of the current study is the capturing and investigation of delayed-post-survey assessments of the engineering workshop for a large sample of over one thousand participating students. Prior research has typically examined only the immediate effects of engineering workshops and outreach activities. The goal of the delayed-post-survey was to evaluate whether the improvements in engineering perceptions achieved immediately after the workshop persisted for the two-week period following the workshop.

For all outcome variables, analyses revealed that students' delayed scores were significantly improved compared to their pre-survey scores. This indicates that students' positive perceptions persisted after the workshop. For self-efficacy and utility there were overall drops in scores from post-survey to delayed-post-survey; however, the delayed-post-survey scores were still higher than the corresponding pre-survey scores (see Section 3.4.2). Interestingly, the interaction analysis revealed that the drop in self-efficacy perceptions from post-survey to delayed-post-survey was significant for Caucasian students, but not for Hispanic students. Possibly, the workshop was a more memorably and unique experience for Hispanic students given their unique cultural capital (Cole and Espinoza 2008; Martin, Simmons, and Yu 2013; Pascarella et al. 2004; Yosso 2005) compared to the Caucasian students. Nonetheless, this may suggest that, even though the workshop was successful in improving students' perceptions of self-efficacy towards engineering and utility of engineering, these improvements appear to fade as time passes.

The fading of the workshop effects may need to be counter-acted by providing students with ongoing engineering experiences in and out of their school settings that build on the experiences that they had in the engineering workshop. Similar with the recommendations of previous studies that provided educational interventions, we also recommend that sustainable repeated interventions should be pursued. Repeated interventions will likely preserve and possibly amplify the workshop effects through cumulative exposure to the content (Mayfield and Chase 2002) and through distributing the content exposure over time periods (Küpper-Tetzel 2014; Rohrer, Dedrick, and Stershic 2015; Yazdani and Zebrowski 2006). Additionally, a full integration of engineering interventions and activities into the school curriculum is one of the keys to success in educational innovations (Moreno and Valdez 2007). Frequent exposures to engineering content and practices may sustain and further improve the positive effects of the workshop on students' perceptions.

4.4. Limitations and future research

A limitation of the current study is that the delayed-post-surveys were given two weeks after the engineering workshop. It may be useful to investigate if the positive perceptions persist over longer time periods, such as one month, three months, or six months (Campbell and Stanley 1963). Such a more detailed study of perceptions over time may provide deeper insights into how quickly the workshop effects fade. Insights into the fading characteristics could inform planning and scheduling decisions as to how frequently these types of engineering workshops should be provided to students to have sustained effects of continuously improving their perceptions towards engineering.

The evaluation of the engineering workshop effects was limited to a survey-based evaluation of student perceptions. Future engineering workshop evaluations could incorporate tests of engineering knowledge and skills. Evaluations that combine the survey-based evaluation of student perception with the test-based evaluation of knowledge and skills could give insights into the inter-dependencies between student engineering perceptions and their actual engineering knowledge and skills. Conducting such a combined evaluation over an extended period after an engineering workshop could inform the planning and scheduling of engineering workshops so as to support both the development of engineering perceptions and of engineering knowledge and skills (competency).

Another limitation of this study is the lack of longitudinal student tracking. Future evaluations of the impact of engineering workshops should include a longitudinal student tracking component that tracks, for instance, future student enrolment and performance in STEM subjects as well as the selection of programmes of study at the university level. The triangulation of the perceptions related to the engineering workshop and the related knowledge tests with longitudinal student data can provide critical insights into the efficacy of the engineering workshop outreach programme. Additional surveys that are administered at periodic intervals, e.g. annually, as students mature towards the age of enrolling in university programmes of study could provide further insights into the impact of the engineering outreach on course selections and career choices.

Moreover, it would be very interesting to compare different K-12 engineering outreach contexts, e.g. to compare in-school programmes, after-school programme, summer programmes, and school fieldtrip workshop programmes with each other. The comparison of the different engineering outreach programmes should ideally be conducted with a comprehensive evaluation that employs the outlined data triangulation of engineering outreach perceptions, engineering knowledge, as well as a longitudinal data component.

Lastly, the ethnicity comparisons in our study were limited to comparisons between Caucasians and Hispanics, the two main ethnic groups in the schools participating in the ASL engineering workshops. Future research may specifically target other ethnic groups in order to uncover how students from a wide set of ethnic groups respond to engineering workshops over short and long time periods.

5. Conclusions

In conclusion, our evaluation study found that a field trip to a well-designed engineering workshop positively impacts 9–14-year-old students' engineering perceptions. Perceptions of interest, self-efficacy, and utility significantly increased from pre-survey to post-survey, while negative stereotype perceptions were significantly reduced. These positive perceptions were maintained two weeks after the workshop for all students. The improvements in engineering perceptions were most pronounced for girls and older students in the 13–14-year-old age group; however, both genders and all age groups significantly benefitted from the fieldtrip workshops. Caucasian and Hispanic students experienced similar improvements of engineering perceptions in terms of increased interest, self-efficacy, and utility as well as decreased negative stereotypes.

Our pre-survey results derived from over three thousand completed surveys contribute to the knowledge base of pre-existing perceptions of 9–14-year-old students in the U.S. Importantly, our study found significant gender differences in engineering perceptions for students as young at 9–10 years old; this age group had rarely been examined in prior research. These results on pre-existing engineering perceptions as well as the immediate and delayed-post-surveys provide reference points for future evaluations and refinements of engineering workshops.

Overall, our evaluation results indicate the benefits of engineering interventions/curricula to reach young students in the 9–14-year age range. In line with the previous studies, we recommend frequent and early experiences with engineering to help improve perceptions towards engineering as well as engineering skills. These experiences may then aid in addressing the need for engineering professionals, increasing ethnic representations, and closing the gender gap in engineering (Adelman 2006; Hagedorn and DuBray 2010; Aswad, Vidican, and Samulewicz 2011; Becker 2010; Powell, Dainty, and Bagilhole 2012). Ideally, teachers should integrate the concepts taught in the engineering experiences into their science/math courses to help reinforce the engineering concepts that students learned.

Moreover, aligned with the suggestions of Faria et al. (2015), we believe that it is important to provide engineering outreach programmes free of charge to ensure access for all students. We suggest that it is important for school districts and teachers to look for opportunities to bring these types of engineering workshops/outreach programmes to their students, and maybe explore possible grant opportunities to provide the workshops free of charge to all students. At the same time, we believe that it is important for universities and industry to support the provisioning of engineering outreach programmes for young pre-college students (Sadler et al. 2018). Coordinated collaborations between schools, universities, industry, as well as engineering organisations and governments are needed to broadly expose and introduce young pre-college students to engineering.

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