Impact of Materials Science and Engineering Clubs on Student's perceptions and aspirations towards STEM

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ABSTRACT

This research evidences the impact of Materials Science and Engineering Clubs as an outreach effort to expand the education and training required for a competitive Nanotechnology workforce beyond traditional STEM areas. An engineering perception questionnaire was implemented as a pre-test/post-test to track student perceptions and goals throughout the academic year and identify trends amongst gender and school level groups. Findings (107 students) show a perceived increase in student knowledge and interest for different fields of study, based on pre/post-test responses, with differences amongst gender and school level groups (middle school and high school). Also, significant differences in students' aspirations for higher education degree were found among school level and gender. Results show that over 20% of participants increased their aspirations to higher educational degree and their interest in pursuing STEM degrees at end of the academic year. Specific findings on engineering perceptions and perceived level of knowledge and interest in science, engineering, materials, and nanotechnology as a result of club participation and student's educational aspirations, expectations and future study plans are discussed along with implications for future STEM education.

INTRODUCTION

During the last decade, the Nanotechnology Center at the University of Puerto Rico - Mayagüez established a partnership with public middle schools and high schools in the Western region of the island, to create Materials Science & Engineering (MSE) Clubs. The high demand for STEM professionals in the US has strained the nation's ability to supply trained individuals to the expanding job market if currently underrepresented populations are not engaged in STEM fields [1]. To increase the number of underrepresented minority applicants entering and receiving STEM degrees, the Nanotechnology Center developed a comprehensive outreach program for teachers and students in the public school system. Within this framework, since 2015, the Center has impacted over 17 schools, serving Hispanics from disadvantaged communities.

As part of the outreach program, detailed in Figure 1, each MSE club hosts four annual visits, and once a year the Center convenes all members to an annual club meeting on the Mayagüez campus. During this meeting, a faculty expert provides an inspiring technical presentation that is followed by a hands-on activity where students collaborate to build a large-scale balloon structure to represent either a nanomaterial or a process at the nanoscale. Furthermore, every academic semester the Center's undergraduate and graduate students, and faculty present educational modules and hands-on activities during MSE club visits. Educational modules cover specific Nanotechnology and Materials Science topics targeted to middle or high school students; these modules are specifically designed to motivate students to learn about and aspire to a profession in STEM-related fields. Some of the themes covered include self-assembly of nanoparticles, surface-to-volume ratios in nanoparticles, or diffraction in crystalline materials, among others [2].

Many outreach programs seek to create pathways to recruit new and future talents. Accordingly, diverse outreach methods have been used to increase interest in STEM areas for pre-college students, underrepresented communities as well as to assess the impact of such activities with respect to perceptions and attitudes towards engineering [3]. The literature reports high-impact one-time activities, such as the celebration of an Engineering Week, with hands-on activities for middle schoolers [4] and although there are some limitations in the process, long term partnerships between universities and K-12 schools has been used [5]. Within such framework, the National Academy of Engineering [3] reported detectable gender differences in teenagers' perceptions with respect to preconception and knowledge about the Engineering profession. In particular, researchers identified the need to continuously expose

middle school students to Engineering-related activities to prevent the decrease in interest and, in particular, among middle school girls before the outreach activities began [4]. Also, the development of didactic material has been a resource created as part of the partnerships between universities and K-12 schools to improve student's Engineering skills, interests and attitudes [5]. These findings underscore the relevance of outreach activities in shaping student's perceptions.

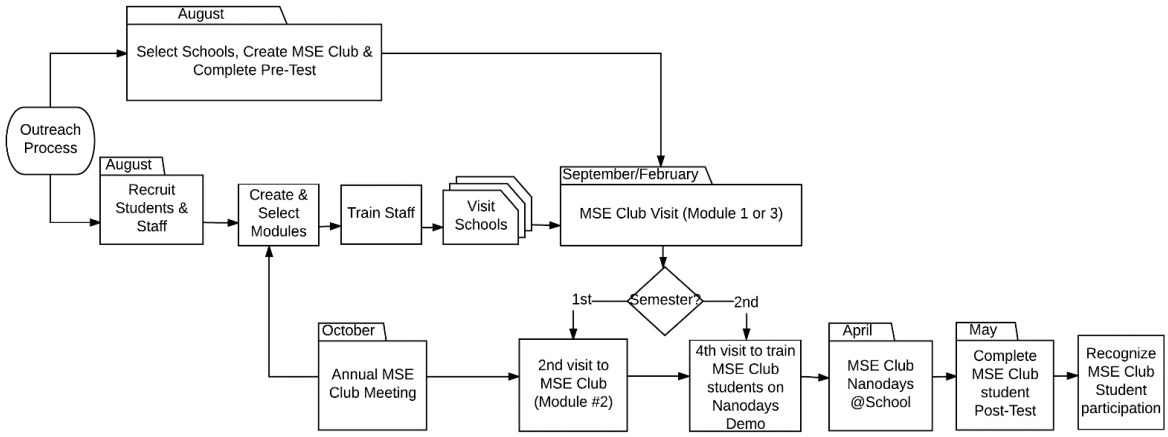

Figure 1. Nanotechnology Center Outreach Process.

Our Nanotechnology Center has been dedicated to the development of nanostructured materials and their applications while, at the same time, a special effort is invested in training students and teachers from local public schools on themes related to Nanotechnology and Materials Science [6]. For instance, every summer, the Center offers a four-week research summer camp for teachers and high school students. In this summer experience, participants receive diverse training on research and scholarly communication skills as they work with faculty, and undergraduate and graduate student mentors on a defined research problem. Meanwhile, all teacher participants create and share their own educational module, inspired on their research endeavor. The Center's Interdisciplinary Education Group (IEG) leads this effort and focuses on the creation of educational content and activities to support MSE Clubs to produce a lasting impact on the middle and high school student body [7]. Thus, the overarching goal has been to expand the education and training required for a competitive Nanotechnology workforce beyond traditional Science and Engineering concepts [6].

ENGINEERING PERCEPTION QUESTIONNAIRE

The Engineering perception questionnaire, was developed in 2010 by the IEG team to evaluate the impact of the MSE Club student participation about their perceptions, interests, and knowledge of STEM [2]. As designed, it measures attainment of expectations and interest in STEM careers, and perceived barriers in education, and was adapted from the Pittsburgh Freshman Engineering Attitude Survey (PEAS) and the Perceptions of Educational Barriers [1,8,9]. The questionnaire consists of 25 items about: courses, grades, and extracurricular activities related to Engineering (3 items); perceptions about engineering, perceived level of knowledge and interest in Engineering, Materials Science, and Nanotechnology as a consequence of club participation, (3 items); educational aspirations and future study plans (7 items); and demographic information including gender, year of birth, school, number of years of club participation, parent education level, and whether family members had completed university studies in STEM fields (9 items), and three additional questions to assess student understanding of the nature of Engineering and Engineering practice [2].

Preliminary assessment results from 2010, about the impact of MSE Clubs based on post-test results, showed gender differences with male students perceiving they knew more about what engineers do (87%) in comparison with females (50%). Also, participants expressed positive attitudes toward engineering as a career, and indicated that club activities contributed to their knowledge and interest in Science and Engineering in general, as well as Nanotechnology and Materials Science in particular [2]. Since 2010, the Center continued using the questionnaire as a pre-test/post-test to evaluate club participant perceptions and attitudes toward Engineering. Results showed that 96% of participants thought that studying Engineering was "worth the effort" and that family communication and expectations about college and STEM careers are related to the interest in Engineering careers [1].

The present study aims to evaluate the impact of the Nanotechnology Center's outreach activities on MSE Club participants during the 2015-2016 academic year. Our goal has been to understand if there are significant differences in student attitudes, perceptions toward STEM fields, motivation to pursue STEM degrees, experiences and future plans between the beginning and end of the academic term. We hypothesize that MSE Club activities have a

direct and positive impact on students' attitudes and perceptions about careers in STEM, motivating and encouraging them to learn more about and select a STEM college education. Also, we hypothesize that students' participation in STEM activities and their conversation about college preparation increases during the academic year because of the Center's outreach activities.

PARTICIPANTS

During the 2015-2016 academic year, 586 students participated as members of 17 MSE clubs sponsored by the Nanotechnology Center. According to Puerto Rico's Department of Education statistics [10], the schools hosting MSE Clubs serve households where 73% of families live under poverty levels (MIN=55%; MAX=99%). Response rate from participants was 18.2% (N=107) from 9 (52%) clubs (65% females and 35% males). Table 1 describes the number and percent of participants by gender and school level.

Table 1. Participant demographics (total and percent) by school level.

School Level	Number of Schools (%)	Number of participants (%)	Gender Demographics	
			Females (%)	Males (%)
Middle School	4 (75%)	67 (63%)	42 (63%)	25 (37%)
High School	5 (67%)	40 (37%)	28 (70%)	12 (30%)

METHODOLOGY

The questionnaire, in Spanish, developed in 2010 by Dika et al. [2] served as the instrument for data collection. After schools are selected by the Nanotechnology Center, teachers define their student selection strategy to recruit members into the clubs. Then, all club members must complete an enrollment package that includes the questionnaire along with a parental consent form, among other official documents. Thereupon, before the club visits begin, all club members complete the questionnaire as a pre-test and at the end of the semester (that is when all club activities are completed), students fill the same questionnaire as a post-test. Finally, the evaluation team collects, codes, and evaluates the acquired data and shares the results with the Center leadership as part of the evaluation process.

To test our hypotheses, questionnaire responses were coded in an Excel spreadsheet. Minitab was used to analyze significant differences in responses between pre- and post-tests using Fisher's exact test and general linear model analysis of variance (ANOVA) [11].

RESULTS

Courses and extracurricular activities related to Engineering

There were significant differences amongst student level and the number of STEM-related courses students had taken as part of their curriculum. High school students reported enrolling in significantly more courses on mathematics, technology and science than middle schoolers (P-Value=0.000). Table 2 evidences the percentage of students by level who identified taking different STEM courses by the end of the academic year.

Table 2. Percentage of students enrolled in STEM courses by school level.

STEM Area	Course Topic	Middle School	High School
Mathematics	Algebra	1%	65%
	Calculus	1%	10%
	Statistics	0%	20%
	Geometry	4%	70%
	Advanced Math	0%	45%
Technology	Computing	0%	10%
Science	Biology	1%	55%
	Physics	1%	88%
	Chemistry	0%	70%
	Environmental Sciences	1%	5%

Also, pre/post-test results reveal that at the end of the academic year students significantly increased their participation in extracurricular activities related to Engineering (F=15.00, p=0.000). In effect, Figure 2 validates this finding with a self-reported increase in Scientific Fair participation (18%) and research project involvements at the Nanotechnology Center (24%), based on pre/post-test outcomes. Furthermore, middle school students reported participating in a significantly higher number of extracurricular activities compared with high school students (F=9.32, p= 0.003). As shown in Table 3, middle school students reported more extracurricular experiences in science fair and research projects as compared to high school students. On the other hand, higher participation in summer research experiences was expected from high school students as a limited number of them can participate in the Nanotechnology Center Summer Camp experience, which is not available for middle school students.

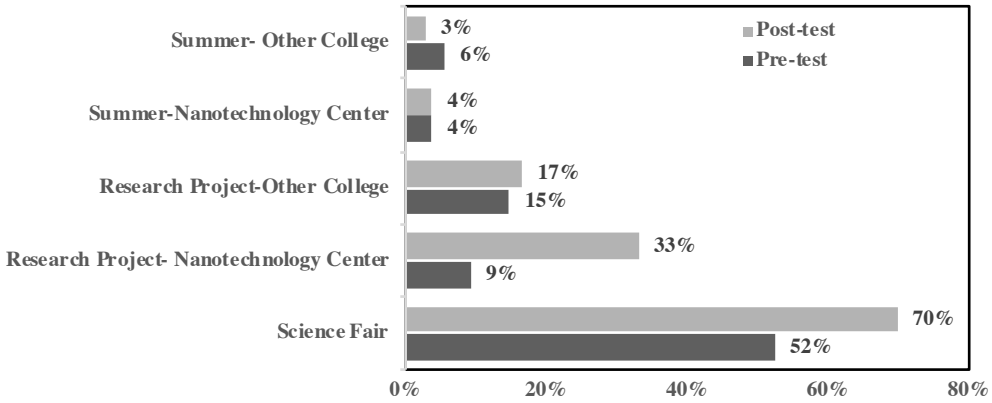

Figure 2. Percentage of students participating in extracurricular activities related to Engineering at the beginning (pre-test) and end (post-test) of the academic year.

Table 3. Comparison of students participating in extracurricular activities related to Engineering by level.

		Research Project		Summer Program	
	Science Fair	Nanotechnology Center	Other College	Nanotechnology Center	Other College
Middle School	76%	42%	25%	1%	3%
High School	63%	20%	3%	5%	3%
Difference (MS-HS)	14%	22%	23%	-4%	0%

Engineering perceptions and perceived level of knowledge and interest in science, engineering, materials, and nanotechnology as a result of club participation

The questionnaire asked participants to agree or disagree with 19 statements about Engineering preconceptions or skills to assess student general perceptions. Table 3 shows the percentage of participants agreeing with each of the statements in the pre- and post-test. Two statements (i.e. Engineering is boring, and engineers work individually) were written in negative form, which, as expected, rendered low levels of agreement. In general, students shared a positive perception about Engineering, as over 90% of participants agree that the field: "is worth studying", "is a respected profession", "requires creativity", "has contributed to solve world problems", "it is not boring" and "has had a positive effect in the world." Also, over 90% of students consider engineers as "innovators" and "working to improve the wellbeing of society."

Overall, there were no significant differences in level of agreement between participants from different gender groups. A cross tabulation with Fisher exact test [11] showed significant differences in perceptions between middle and high school students about “needing more than a bachelor’s degree to practice the Engineering profession” (X2=5.48, p=0.02). In particular, more than 65% of middle school students agreed with the statement whereas high school students correctly perceived that a bachelor’s degree was enough to practice the Engineering profession.

Participants were also asked whether they agreed with several statements pertaining to their creativity, problem solving skills, interest in technical work and preferences. Overall, students self-identified as creative (89%), bearing problem solving skills (90%), and interested in technical activities (85%) with no significant difference between school level or gender. Also 76% agreed they preferred mathematics and science than other courses, and that they like to discover how things work (95%). An interesting finding was that 64% of students stated that they understood well

what engineers, and even after exposure to MSE club activities there was only a 6% increase in agreement with the said statement.

Figure 3 shows the percentage of students who reported an increase, decrease or similar level of perceived knowledge and interest in Science, Engineering, and Nanotechnology and Materials Science fields. Even though 40% or more of all students maintained their level of knowledge and interest in the fields of interest, on average 15 % of participants reported an increase in their knowledge, as well as a 21% increase in their interest for the different fields of study based on pre/post-test responses. This increase can be attributed to the MSE Club intervention, as the ANOVA test showed a significant increase in perceived knowledge about Materials Science and Nanotechnology during the academic year (Table 4). Also, statistical tests demonstrate a significant gender difference in perceived knowledge, as male students reported higher perceived growth in knowledge about Engineering and Materials Science when compared to females. Likewise, no significant differences were identified in perceived knowledge amongst students based on their school level, nor differences in science knowledge or interest in the variables of the study.

With respect to student interests, there was a significant difference amongst participants based on their school level and gender (Table 5). Surprisingly, middle school students showed higher interest in Nanotechnology and Materials Science than high schoolers. Also, like findings in self-reported perceived knowledge, male students reported more interest in Engineering and Materials Science than females. Different from knowledge findings, no significant differences were identified in perceived interest amongst students based on the test period.

Table 4. Percentage of student agreement with different Engineering perception statements in the pre/post-test measures.

	Percentage (%)	
Statements (Key Word)	Pre-Test	Post-Test
Engineering is worth studying. (Value)	98	95
In my opinion, engineering is boring. (Boring)	6	8
Engineers are innovators. (Innovation)	91	94
I like more mathematics and science than other courses. (STEM)	71	76
Engineering is a respected profession. (Respect)	98	93
You need more than a bachelors to practice the engineering profession. (Degree)	64	75
Engineers work to improve society's wellbeing. (Wellbeing)	93	92
Generally, engineer's salary is higher than other professionals. (Salary)	75	74
Practicing engineering requires creativity. (Creativity)	95	97
Engineering graduates find good jobs easily. (Jobs)	70	72
There is not much difference between the work of scientists and engineers. (Work)	51	61
Engineering has highly contributed to solve world problems. (Solutions)	94	94
In general, engineering has had a positive effect in the world. (Effect)	95	94
I like to discover how things work. (Discover)	94	95
I understand well what engineers do. (Understand)	68	74
Engineers work individually instead of in groups. (Teamwork)	28	24
I consider myself as a creative person. (Self-Creative)	86	89
I have the skills to solve problems. (Problem-Solving Skill)	83	90
I like to work with technical things. (Self-Technical)	93	85

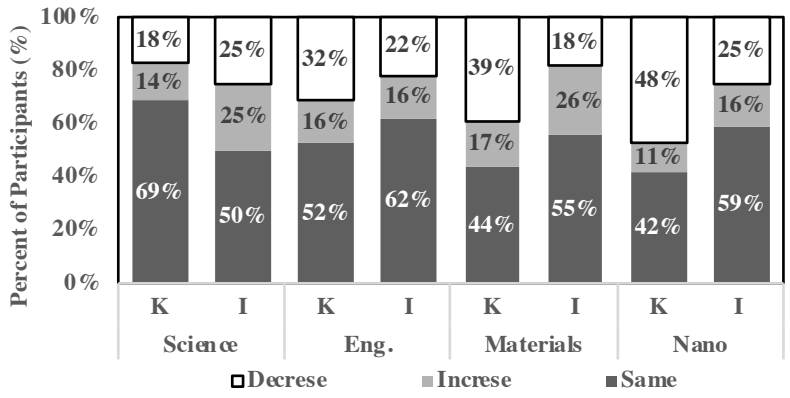

Figure 3. Changes in perceived level of knowledge (K) and interest (I) in Science, Engineering, Materials and Nanotechnology fields.

Table 5. ANOVA results for perceived level of knowledge and interest in Science, Engineering, Materials, and Nanotechnology (p-values<0.05)

Variable	Topic	Period		Gender		Level	
		F	p-value	F	p-value	F	p-value
Knowledge	Science	--	--	--	--	--	--
	Engineering	--	--	6.44	0.012	--	--
	Materials	4.68	0.032	5.36	0.022	--	--
	Nanotechnology	17.83	0.000	--	--	--	--
Interest	Science	--	--	--	--	--	--
	Engineering	--	--	4.33	0.039	--	--
	Materials	--	--	8.05	0.005	4.11	0.044
	Nanotechnology	--	--	--	--	4.74	0.031

Educational aspirations, expectations and future study plans

One of the goals of the clubs is to inspire students to pursue higher educational degrees. The analysis of variance results showed significant differences in students' aspirations for higher education degree, among school level and gender. Females (F=13.83, p=0.000) and high school students (F=3.83, p=0.052) aspired to pursue higher level degrees when compared to male students or middle school participants. Mean scores suggest female and high school students aspire to bachelors' or postgraduate degree, whereas males aspire to associate degrees or higher, and middle schoolers aspire to bachelors' degree.

The questionnaire inquired about students' perceptions about their tutors' expectations of advanced degrees. There was a significant difference amongst gender (F=8.33, p=0.004), as female students perceived their female tutors had higher expectations about their future aspirations (i.e. bachelors' or graduate degree) than male ones (i.e. bachelor's degree). Also, there was no significant difference in the perceptions about male tutor expectations by school level or gender, with an average expectation of a bachelor's degree. In this analysis, participants' responses corresponding to "I don't know" (7% of responses) were not considered in the analysis. As shown in the pie-chart within Figure 4, on average 66% of students maintained their future aspiration goals during the academic year and 21% increased their aspirations to higher educational degree by the end of the academic period. Previous research has evidenced the influence of parents' expectations in explaining students' aspirations [12].

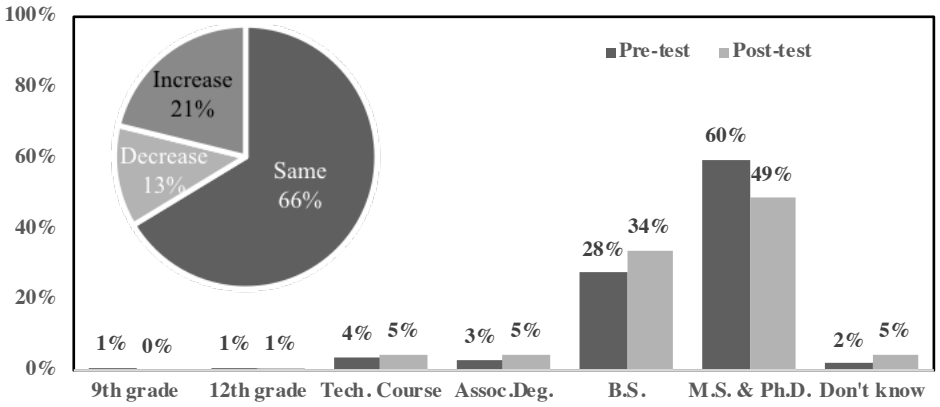

Figure 4. Students' aspirations of advanced or professional degrees.

As club activities revolve around STEM topics, students were asked to identify their future interest to study degrees in these fields. Figure 5 illustrates that on average 23% of participants increased their interest in pursuing STEM degrees at end of the academic year. An in-depth analysis using an ANOVA test, showed significant differences in participant responses by gender and school level (Table 6) on one or more fields. Middle school students reported significantly higher interest in pursuing degrees in Technology and Engineering fields when compared to high school students. On the other hand, high school students were more interested in pursuing degrees in Science than middle schoolers. Not surprisingly, males had more interest in pursuing Technology-related degrees than females.

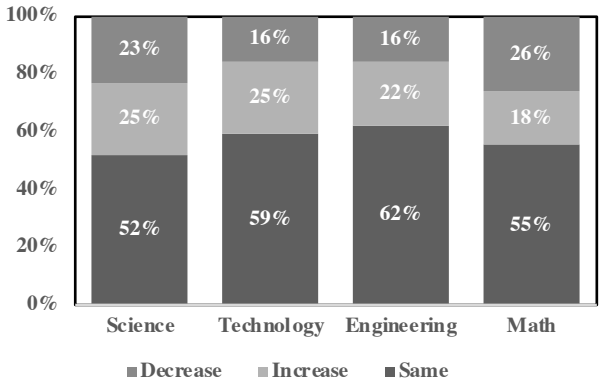

Figure 5. Change in interest for pursuing degrees in STEM fields.

Table 6. Significant ANOVA results for interest in pursuing STEM fields (p-values<0.05).

Topic	Gender		Level	
	F	p-value	F	p-value
Science	--	--	4.63	0.033
Technology	10.22	0.002	12.40	0.001
Engineering	--	--	3.77	0.054
Mathematics	--	--	--	--

Students were also asked to mention how frequently they discussed with their tutors four topics related to their future education: (1) taking advanced courses at high school, (2) College Board exam preparation, (3) possible career choice at university, and (4) financing their college degree. Independent of gender or school level, at the beginning of the academic year, students had dialogued two or more times with their tutors about taking courses to prepare for the College Board Examination (college admission test). At the end of the school year, they reported only discussing one time about this subject resulting in a significant difference based on pre-test, post-test measures (F=5.43, p=0.021). Moreover, over 69% of female students discussed more often with their tutors about potential economic support for studies than males (F=4.57, p=0.034). As shown in Figure 6, on average, only 14% of the sample increased the frequency of conversations with tutors about each of the four topics of interest during the academic year.

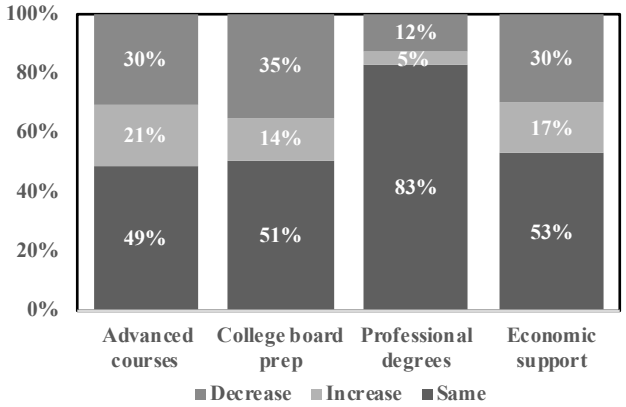

Figure 6. Change in frequency of conversations with tutors about educational decisions.

The MSE Club participants also shared whether they expected future challenges in college. Table 7 shows the Fisher's exact test results (p-values) for each challenge based on gender and school level. Even though findings show no significant differences based on pre/post-test results, there was a 13% decrease in "lack of financial support" as a perceived obstacle to start college. Most challenges were perceived as relevant for high school students when compared to middle school students. On the other hand, there was a tendency for females to perceive fitting in college and lack of financial aid as possible challenges when compared to male perceptions who had an overall tendency not to identify any of the items as challenging.

Table 7. Significant differences in perceived challenges by gender and school level (p-value<0.05*, <0.01**, <0.001***)

Item	Gender	Level
Family member's negative attitudes towards education/college	--	*
Not fitting in college	*	**
Lack of support from the college professors	--	***
Not being prepared enough	--	***
Do not know how to study well	--	***
Lack of confidence	--	***
Lack of support from friends to achieve educational aspirations	--	--
Need to work while studying	--	--
Lack of mentors or role models	--	**
Lack of financial support	*	***

Student tutor demographics showed that more than 74% of male and 61% of female tutors have technical, associate degree, high school diploma, or some level of school education. On the other hand, 24% of female tutors have a bachelor's degree, in comparison with 14% of male tutors. A similar trend is found for postgraduate degree, where 11% of female tutors have a master's degree, opposed to only 4% of male tutors. With respect to STEM fields, students mentioned that 28% of their female tutors, 17% of male tutors, 14% of their siblings and 60% of close relatives had a bachelor's or master's degree in STEM.

DISCUSSION

The Engineering perception questionnaire has been a useful tool to track student perceptions and goals throughout the academic year and identify trends amongst gender and school level groups. Although data indicate that students bear a positive perception about Engineering and themselves, in agreement with Blandino and Michael [4] and Dika et al. [2], we uncovered significant differences in self-perceived levels of STEM knowledge and interest based on gender. Even after the aforementioned sustained effort through the MSE Club intervention that showed significant differences in MSE and Nanotechnology knowledge between pre-and post- measures, findings continue to show male students with higher self-reported interest in Technology and Engineering fields than females [2,3]. These results underscore a persisting need to expose, inspire, and motivate young females so as to engage them in STEM fields [13], by impacting their self-perceived knowledge and interest. Our findings showed that females perceived that they might not fit in college, more than male students. This finding, as well as common stereotypes [14] with STEM fields, make more prominent the need to direct efforts toward inspiring young females. In particular, it is pertinent to also engage female tutors, as our findings suggest that in particular female students perceive that their female tutors had higher expectations about their future aspirations. In this respect, female tutors can become a vehicle to educate and communicate the message.

CONCLUSIONS

Since 2015, Nanotechnology Center has impacted with science and engineering activities over 1,500 Hispanic students from over 17 public schools serving communities under the poverty level. MSE Clubs have promoted a myriad of individualized activities in Materials Science, Nanotechnology and Engineering, ranging from hands-on activities on applications of nanotechnology and materials science concepts, an annual club meeting at the university campus, and a Nanodays event where each club conducts nanotechnology demonstrations at their own schools. College admissions data show that 42% of students admitted from schools with MSE clubs have enrolled at University of Puerto Rico - Mayagüez, with a 94% second-year retention rate [15]. Research evidence shows a significant increase in self-perceived knowledge in Materials Science and Nanotechnology upon the 2015-2016 academic year among Materials Science and Engineering (MSE) club members. This is directly related to MSE Club activity themes suggesting a direct impact from club membership. Also, within study timeframe, the data shows consistent levels of dialogue between

parents and students about college issues. As described by Dika et al. [1], these conversations between students and parents could be related to student interest in Engineering careers. In addition, students' participation in STEM-related activities increased through the academic year, not only via Science Fair projects at school but also in collaborative research activities with universities or through summer camps.

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