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A Successful Pre-college Nanotechnology Experience for Low-income Students (Evaluation)

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A successful Pre-College Nanotechnology experience for low-income students (Evaluation)

Abstract

In three years, the Nanotechnology Center at the University of Puerto Rico-Mayagüez Campus (UPRM) has impacted with science and engineering activities a total of 1,512 Hispanic pre-college students (967 female students) from 23 low-income public schools. Socioeconomic data from the Puerto Rico Department of Education show that, on average, 73% of the participating students belong to low-serving communities under the poverty level. This pre-college program promotes and supports Materials Science and Engineering (MSE) Clubs at middle and high schools with a myriad of individualized activities in Materials Science, Nanotechnology and Engineering. Each club hosts four annual visits from the Nanotechnology Center's students and faculty, who deliver hands-on activities on applications of nanotechnology and materials science concepts. Two annual events crown the intervention: a) an annual club meeting at the university campus, and b) a Nanodays event, where each club conducts nanotechnology demonstrations at their own schools. Furthermore, a group of high school students and teachers is selected to participate in a 4-week Summer Research Program, in the Center's laboratories. College admissions data show that 75% (N=12) of the research summer program participants and 42% of students admitted from schools with MSE clubs have enrolled at UPRM, with a 94% second-year retention rate. For the schools with MSE clubs, between 49% and 75% of students who chose to major in Science, Engineering or Technology programs were active MSE Club members. The present work describes the structure and activities of the pre-college program, and presents the model for the annual club meeting and the summer program with corresponding assessment results.

Introduction

The Nanotechnology Center at the University of Puerto Rico-Mayagüez Campus (UPRM) was created to: (1) advance the state of knowledge in engineered nanomaterials, while achieving national competitiveness; (2) prepare students for successful insertion into the future Nanotechnology workforce; and (3) increase the number of minority students entering and receiving engineering degrees related to materials science and nanotechnology [1]. With regards to the third objective, since 2014 the Center has impacted with Science, Nanotechnology, and Engineering activities a total of 1,512 Hispanic pre-college students in 23 low-income public schools. Out of the total number of students, 64% are female students. As part of the outreach initiatives, the Center annually supports 15 to 17 Materials Science and Engineering (MSE) Clubs at local public middle and high schools, and a 4-week Summer Research Program for high-school students and teachers. According to socioeconomic data, students who participate in the MSE Clubs come from schools serving low-income communities, where approximately 73%

of the households live under the poverty level [2]. In the past, the Nanotechnology Center has evidenced that school-based clubs are an effective mechanism to increase student interest and knowledge in MSE and Nanotechnology [3], [4].

Pre-College Program

The main components of the Nanotechnology pre-college program are depicted in Figure 1. The program focuses on human resource development through MSE Club activities and the Summer Research Program, with a strong evaluation and assessment component, supported by Sysdat, a web-based data collection and storage system. Each academic year, every MSE Club hosts four annual visits from the Nanotechnology Center's staff and students, with hands-on activities related to MSE and Nanotechnology. In addition, the Center hosts an annual meeting with all the MSE club students, where they attend a technical, yet inspiring, presentation on fundamental Nanotechnology concepts. After the presentation by a faculty member expert, the students team up to construct a scientific model, inspired on the presentation topic, using air balloons to reinforce the technical concepts with a hands-on, interactive, and fun activity. During the activity, student teams are mentored by undergraduate and graduate students from the Center. Pictures of three MSE club meetings events and the final balloon models are shown in Figures 2a-c.

Towards the end of the academic year, MSE club members also receive training on how to perform a variety of nanotechnology demonstrations. These experiments include topics in: chemical reactions, magnetic effects, non-Newtonian fluids, thermal conductivity, and optical effects. The demonstrations are aimed at explaining fundamental concepts that are relevant in current applications such as computer hard drives, sensors, and transmission electron microscopes, among many others. As a final MSE Club activity, each school hosts a Nanodays event, where they showcase the Nanotechnology demonstrations in their schools for the enjoyment of the entire community. The materials used in these demonstrations are provided by the Center.

The Center's own undergraduate and graduate students also benefit from this engagement. As part of the pre-college program, they learn specifics on the educational modules and hands-on experiments to be presented at schools during MSE Club visits, as well as the Annual Meeting's scientific model. Thus, these students also become educators as they learn to answer questions about, not only fundamental science concepts in simple terms, but also about life in a college environment. Their intervention strengthens a social consciousness as they engage their audience mostly from challenging backgrounds.

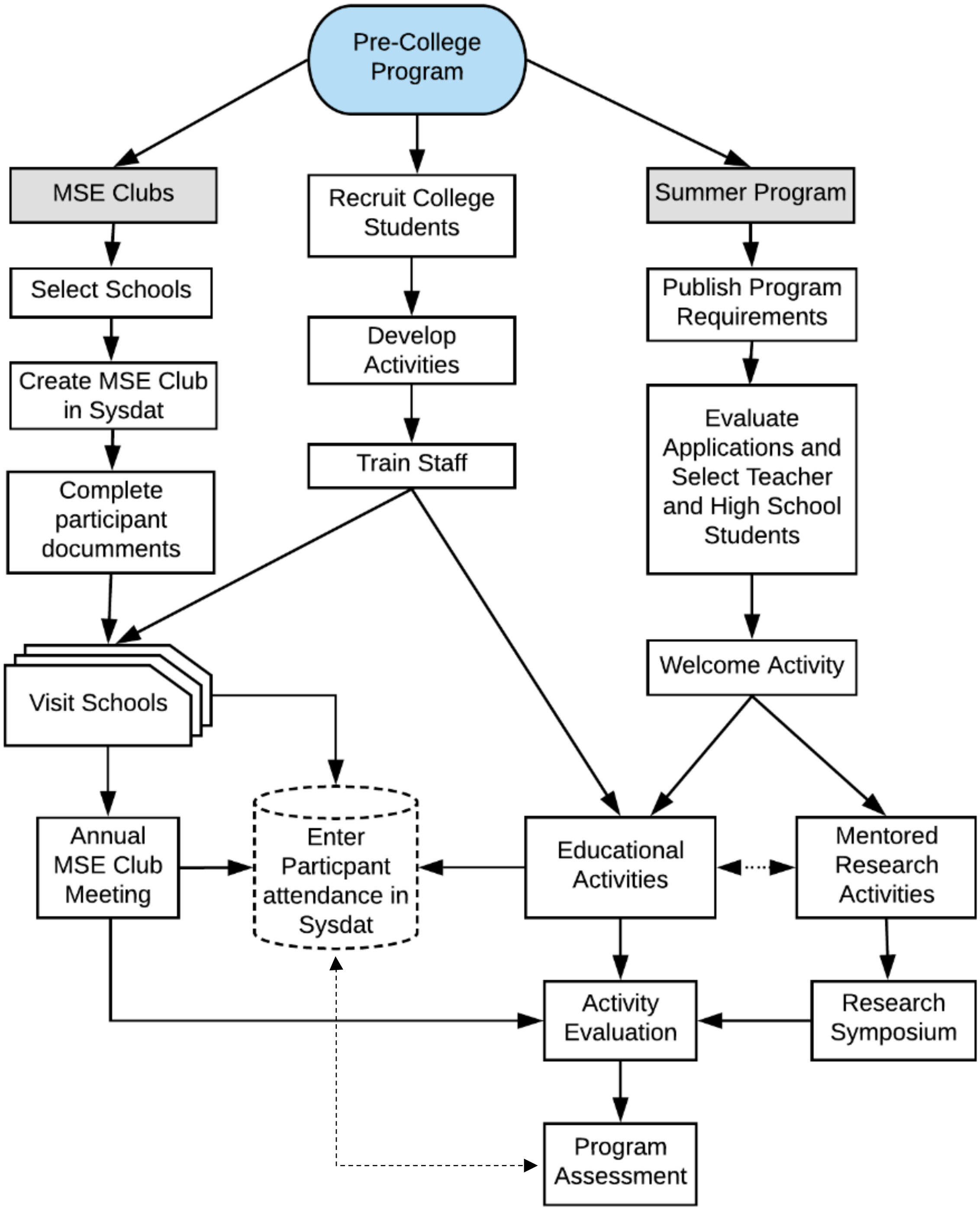

Figure 1. Pre-college program components and their corresponding assessment process.

Figure 2a. 2014 Annual Club Meeting scientific model: "Nanocomposite Polymers: 21st Century Technology."

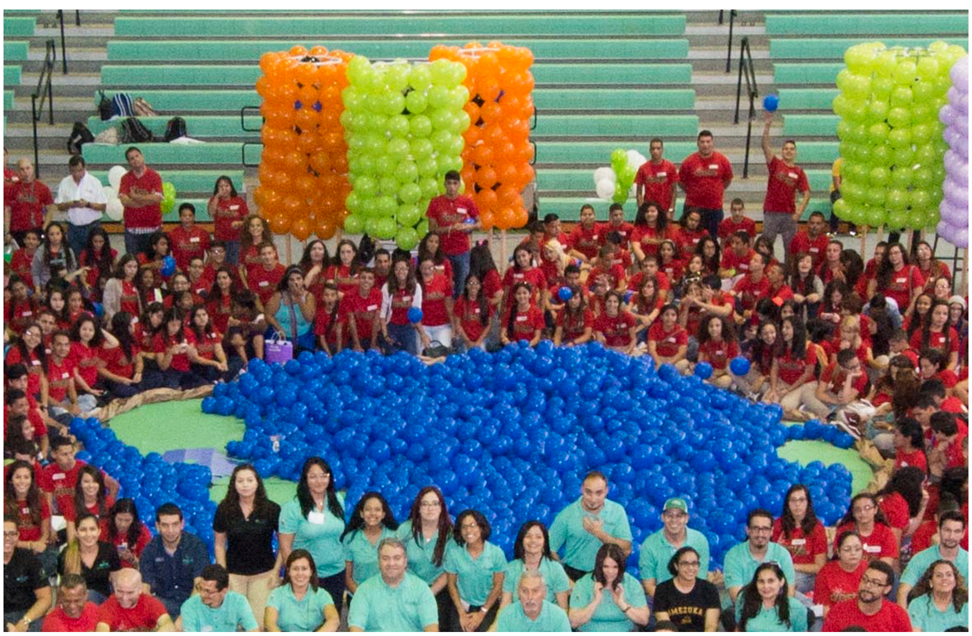

Figure 2b. 2015 Annual Club Meeting scientific model: "Emerging Contaminants in Water."

Figure 2c. 2016 Annual Club Meeting scientific model: "Light and Nano-Biomedicine: Preventing Human Diseases."

The Summer Research Program annually supports 7-9 high school students and 3-6 teachers, who conduct scientific research in the Center's laboratories under the supervision of a faculty member, as well as undergraduate and graduate student mentors. The Center provides support with high school students', teachers', and mentors' stipends, as well as for purchasing all the materials and consumables used in the summer research projects. At the beginning of the summer program, participants receive a briefing on the program objectives and expectations, and research mentors present their research projects so that participants can make their project selection. During the 4-week endeavor, participants attend bi-weekly training workshops and technical seminars aimed at providing an enriching, professional development experience, as the trainees gain hands-on laboratory data collection experience. They also acquire skills related to data management, entrepreneurship [5], information literacy, effective communication, and effective presentations. As part of their summer engagement, teachers receive a workshop on the development of educational modules with hands-on demonstrations and case studies. They acquire skills and knowledge to buttress their in-depth comprehension of relevant aspects of the research theme in which they are involved. Since they are required to translate a prominent aspect of their research into an instructional module, the training becomes critical to achieve that educational goal. This exercise seeks to develop modules that could be integrated in future MSE club visits, while also making them available to other teachers in their classes.

The Summer Research Program participants must provide weekly progress report presentations as they receive nurturing feedback to foster continuous improvement in effective scientific communication skills. As part of the evaluation strategy, oral communication is evaluated individually using a presentation rubric to assess each participant's enthusiasm, eye contact, preparedness, clarity of speech, content organization, use of visual elements, writing, comprehension, knowledge, timing, and results (i.e. objectives, findings and research progress). After each presentation, the results are discussed with the participants focusing on strengths and areas for improvement.

At the end of the Summer Research Program, the participants deliver a final oral and poster presentation on their respective research accomplishments in a summative symposium. A panel of experts evaluate the student posters and presentations and the top three poster presenters are recognized at the program's closing ceremony. The presentations by students and teachers support continuing research efforts under the various interdisciplinary research groups of the Center, as some of the results could turn into preliminary data to support the development of future research proposals.

The summer program evaluation includes participant assessment of the initial briefing meeting, workshops, closing activity, and overall program organization. In addition, a self-reflection with open and closed questions is required as part of the program assessment. As part of the formative process, the program evaluator summarizes evaluation results, student progress, observations, and participation data to build an assessment report of the summer activity. Accordingly, the next section describes the assessment instruments and results for the various pre-college program components.

Evaluation Strategies

An integral part of the pre-college program is the documentation and tracking of student participants. As outlined in Figure 1, information from schools and participants is stored in the Center's management system, designed to record the participant's involvement, including visits to schools and summer program participation, which facilitates reporting to the funding agency, i.e. the US National Science Foundation. The system, called Sysdat, includes a tablet app for portability, as most activities take place off-site. Sysdat is a web-based application with a PHP database developed by the project team, used to store participants' demographic information (Figure 3), track participation in the Center's activities (Figure 4) and manage events.

Participant demographic information includes personal information (i.e. name, birthdate, last 4 digits of social security number, phone, email, address, and gender), verification of parental consent forms (for pre-college students), school information (i.e. school name, GPA, study year), and future academic interests on where and what they want to study (Figure 3). The participants' academic interests are recorded at the beginning of the year and again later, upon student graduation and/or before admission to college. As part of the Center's outreach coordination, each student is assigned a member code that identifies the student's school and member number. The member code is provided in a personalized identification card during the second school visit and it helps track student participation during visits and facilitates data entry.

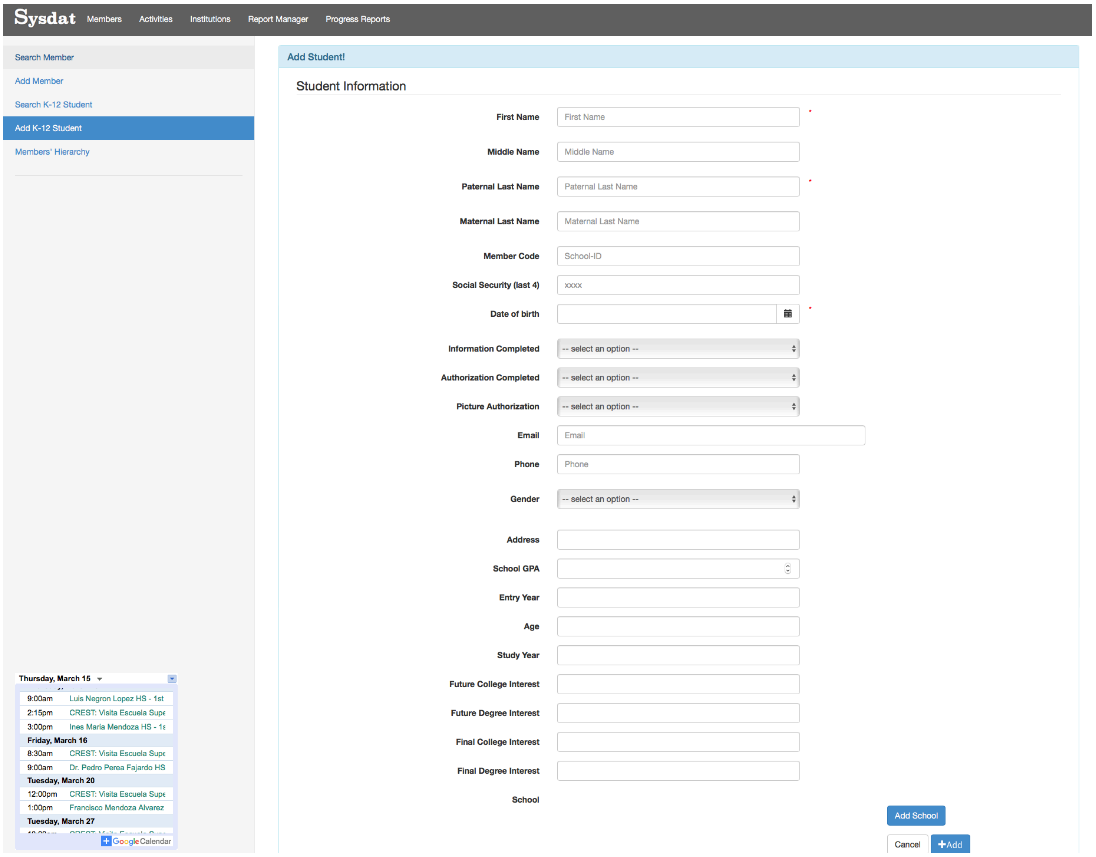

Figure 3. Fields completed to document participant information in Sysdat.

As part of the assessment and evaluation process, Sysdat records the impact of the Center's activities. As shown in Figure 4, each activity is identified with its corresponding thrust area within the Center, its target (i.e. research, education, knowledge transfer, safety, and working with K-12 students, among others), participating institutions or schools, and key participants from the Center. After the activity is created and the event takes place, the web-based system allows documenting the activity attendance, highlights, impact and contributions. The summary of the number of participants that attended the activity, as well as relevant gender and geographical information helps weigh the impact of the endeavor. For the federal reporting process, the computer program downloads the data from all activities as an Excel report that facilitates data entry into the federal data collection system.

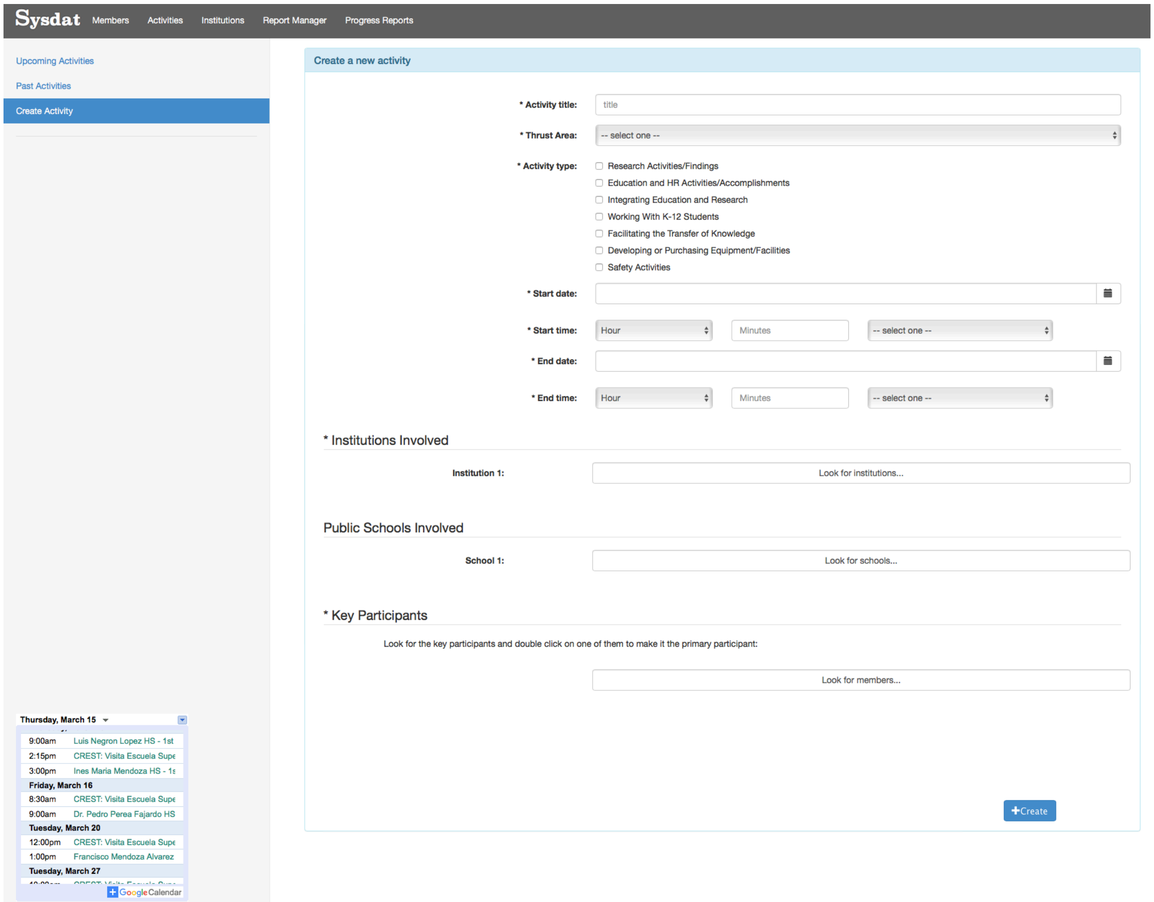

Figure 4. Process to create a new activity and document results.

As part of the pre-college program, annual club meetings, workshops, seminars, and meetings during the summer research program are evaluated using a straightforward questionnaire with 9 statements (described in Table 1) and three open questions. For each statement, participants identify their level of agreement using a Likert scale (1=Strongly Disagree, 5=Strongly Agree). In the evaluation report, a summary table by activity shows the date, number of participants, evaluation items and average scores for each item with participant's comments for each activity, along with areas for improvement. The open questions prompt the participants to: (1) mention what they would do differently given what they learned in the activity; (2) reflect upon situations in which they could apply the skills learned and the information provided; and (3) share suggestions to improve the activity in the future. The questionnaire is also used during all educational activities of the Center.

Table 1. Criteria used to evaluate Center activities

	Evaluation Item
1.	Objectives for the activity were discussed and achieved.
2.	The speaker was knowledgeable in the topic presented.
3.	The speaker presented the ideas clearly and effectively.
4.	The speaker provided adequate time for questions and answered them satisfactorily.
5.	The activity was informative and easy to understand.
6.	The activity improved my knowledge in the topic presented.
7.	I will be able to apply the skills learned and the information presented in my academic or personal life.
8.	The activity had a good organization.
9.	In general, how did you evaluate the activity?

In the last three years, activity evaluation results for the annual club meetings show that on average, over 85% of the participants either strongly agree or agree with all evaluation items, supporting that the activities were successful. Some relevant ideas shared by participants after the 2014 meeting highlight that they learned (1) how to build a polymer and (2) teamwork skills. Assertions from 2014 participants include "*learning about nanotechnology, polymers, engineering, and how engineering relates to the environment… Having a demonstration, building a polymer membrane to create a material based on the workshop... Working in groups and sharing with other schools*." In 2015, the participants shared that in the future they will "*preserve water (recycle water) and avoid its contamination, as well as reduce waste by choosing products that do not contaminate*." Other common responses suggested that participants became aware of contamination and they *"would like to learn more about food and contaminants in everyday products and be careful with consumption, share with others what they learned, use water filters, keep learning and experimenting in this topic, and follow recommendations provided in the lecture in their daily lives."* In the 2016 activity, participants were inspired to *"study more about bacteria, apply the concept learned in school, learn more about nanotechnology and avoid contamination."*

Assertions shared by undergraduate and graduate students in the annual program evaluation show that they also benefited from engaging with middle and high school students in the pre-college program. For example: *"I believe the Center has transformed the way I see things. I have learned a whole new range of things that I think I could have never done outside of the project. I have become a better mentor and researcher. Also, I have learned to communicate difficult topics to the general public and other students."; "One of the greatest opportunities that I've ever had to give back to our society the knowledge, experiences and help that I've acquired for the next generation of professionals. It is, without any doubt, a great satisfaction!"; "Outreach activities have helped me discover many opportunities available within the engineering branches and further aided me be a sensible guide and mentor to others. As a professional, I feel the* *obligation to help students discover their own goals in the same way my mentors have helped me."*

Table 2 describes the 16 criteria used to evaluate the Summer Research Program with percent agreement in participant responses. For each statement, participants identify their level of agreement using a Likert scale (1=Strongly Disagree, 5=Strongly Agree). The overall program evaluation is sent to the participants after the summer program, via an online survey system. Since 2015, 16 high school students and 8 teachers have participated in the Summer Research Program. As shown in Table 2, evaluation results from 6 teachers (75% response rate) show that, after the Summer Research Program, 83% of teachers felt motivated to integrate nanotechnology and science concepts in their courses (T1). They indicated to be comfortable to implement the modules they developed during the summer (T2), as well as to create new ones based on the training provided by the program (T3). Responses from 9 high school students (56% response rate) show that 66% were motivated to participate in scientific fairs during the following academic year (S1), whereas 77% confirmed that the summer program motivated them to pursue a college degree in STEM fields (S3).

With respect to open questions (O1-O3) in the program evaluation, teachers shared: *"Learned to prepare an effective presentation, for research purposes. Also, preparing an adapted educational module to the (Department of Education) standards and research, was one of the most important phases so that I can translate what I learned to my classroom"* (O1); *"I will modify my classes towards research"* (O2); *"It helped me to have first-hand experience and direct my students towards studying engineering"* (O3). Students shared: *"I learn how to develop effectively in an oral presentation, as well as improve my English"* (O1); *"I was helped to give presentations more fluidly and I know that in school I'll be more professional in my presentations"* (O2); *"I was interested in Engineering…now I am decided; I saw it was fun, interesting and very important"* (O3).

Institutional records show that of the students who participated in the summer program, 75% (N=12) have enrolled in our institution, and 92% (N=11) in STEM fields. With respect to retention in STEM fields, in a two-year period, all students are active with only one student transferring from an Engineering program to Arts. Even though other students have also transferred, they have stayed within STEM fields. Evaluation data from the Center shows that after participating in the MSE club, 73% of students maintained their interests for future degree fields (37% in STEM and 36% outside of STEM), 7% reported increased interest in STEM, and 20% lost their initial interest in STEM fields. This suggests that the club provides students with insights about STEM, helping students to choose their careers.

Table 2. Criteria used to evaluate the Summer Research Program, classified as general statements (G1-G8), specific statements for teachers (T1-T3) or students (S1-S3), and open questions (O1-O5) with preliminary results.

Type	Evaluation Item	Percent Agreement
G1	The summer program successfully provided opportunities to learn about nanotechnology and its applications.	100%
G2	The summer program helped me develop effective communication skills.	100%
G3	The summer program helped me develop new technical skills.	100%
G4	The program provided a space to share my ideas and collaborate with others.	100%
G5	The workshops and activities increased my knowledge in the topics presented.	100%
G6	I will be able to apply the skills learned in the program to my academic or personal life.	100%
G7	Overall, the program activities were well organized.	100%
G8	Overall how will you rate this summer program?	Excellent
O1	Describe at least two professional, technical or academic lessons, learned as part of your participation in the summer program.	N/A
O2	Based on what you learned during your summer experience, what would you differently as student or teacher in the future?	N/A
O3	What was the impact of the Summer Research program in your academic and professional life?	N/A
O4	What do you believe will be the impact of the Summer Research program in your future goals?	N/A
O5	As a student please describe your future academic plans (University and Program).	N/A
T1	The summer program motivated me to integrate nanotechnology and science concepts in my courses.	83%
T2	I feel comfortable implementing the educational module that I developed as part of the summer program.	83%
T3	I feel comfortable developing new educational modules after the training provided during the summer program.	83%
S1	I feel motivated to participate in the science fair during the next academic year.	66%
S2	I would like to develop a science fair project aligned with the summer program project.	44%
S3	The Materials Science and Engineering Summer Program motivated me to pursue an undergraduate degree in Science, Engineering or Technology.	77%

In the first two years of the pre-college program, institutional admission records show that 107 MSE Club students (over 60% females) enrolled in college programs at UPRM, amongst all disciplines, with 94% retention rate in the second year, in comparison to a five-year campus retention rate of 90% between 2010 and 2014. These students represent a 42% of all students admitted from schools with active MSE Clubs in 2015 and 2016. As shown in Figure 5, for those schools with MSE Clubs, between 49% and 75% of students who selected science, engineering or technology programs were active club members. Common STEM fields chosen by the students include Surveying, Agricultural Sciences, Biology, Computer Science, Mathematics, Nursing, Geology, Engineering (i.e. Civil, Computer, Electrical, Mechanical, Chemical, and Industrial), Chemistry, and Microbiology.

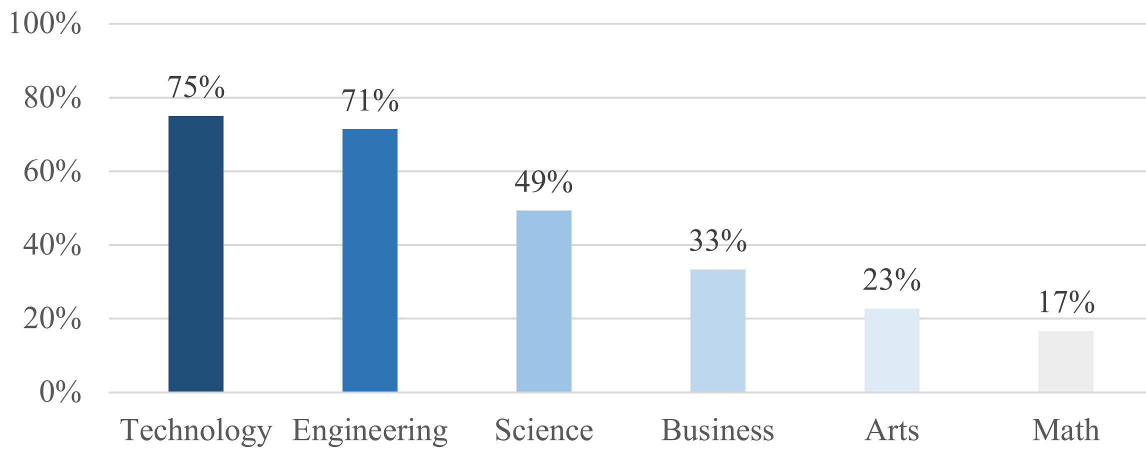

Figure 5. Percentage of MSE Club members enrolled at UPRM by field.

Conclusions

The outcomes of the described endeavor provide evidence about an effective pre-college intervention in public schools serving underprivileged Hispanic communities. Without major monetary investment from the hosting academic institution, this endeavor required the involvement of dedicated faculty members with the collaboration of undergraduate and graduate student volunteers. As indicated, while Nanotechnology was the cornerstone of the intervention, similar projects could be successfully developed in other STEM areas.

Also, the intervention has been successful in recruiting and retaining high school students from clubs and summer programs in our institution, evidencing the impact of the program and the achievement of the Center's goal to increase the number of minority students entering engineering fields. As part of the Center's evaluation and assessment activities, student progress at our institution is continually tracked. By 2021, the Center should be able to evaluate the number of students who completed their college degrees successfully. Future work could integrate surveys to understand if the club participation had an impact on students' decisions to choose and complete a college degree in our institution.

The present manuscript evidences the sustainability, portability, and scalability of the effort seeking to reach out to underprivileged sectors of the society. In effect, because the overall activities require mostly a team of engaged scholars, similar projects can be designed with more broadening scopes. Furthermore, large segments of the community do not possess access to information on ever expanding fields of STEM, limiting their children's awareness on the benefits of a higher education in competitive fields. As long as this social landscape threatens the upward mobility of the less fortunate, pre-college programs like the ones described hereby can be effective strategies to reengage those members of society.

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