Evaluation of a non-formal science education program for high-school students from a low-income underserved area

**Abstract**

The Princeton University Materials Academy (PUMA) is a 16-year-old summer academy by the Princeton Center for Complex Material (an NSF supported center) in materials science for 14 to 16 high-school students from Trenton, New Jersey, a low-income underserved area. Through a mixed-methods approach including qualitative observations and interviews of all stakeholders involved in the academy (students, teachers and administrators), as well as a small quantitative portion of attitude and content pre- and post-tests, we evaluate the academy’s outcome by examining its impact on these students, the change in their attitudes towards science and their decisions in their future careers. We hope this study will yield positive results regarding the impact of the academy, including that its goals are being met, and that it will provide an outline of successful strategies to develop a summer program guideline to be applied in the future in other educational institutions, such as schools, universities and science centers. Qualitative data will be analyzed through the comparison of transcribed interviews and observations (data triangulation) by multiple analysts; the quantitative portion will be analyzed by comparing the two means of the test scores using a *t*-test for correlated means.

**Keywords: non-formal education, materials science, science summer academy, low-income high-school, underserved area**

1. **Introduction**

Motivating high school students to learn science and engineering is an abiding concern in American education, even more so to pursue science careers. In comparison to other industrialized countries, American students are doing less well in mathematics and science and even their scores are falling in standardized tests (Bhattacharyya, 2011). In a world where economies and societies are rapidly being ruled by science and technology, fewer students are pursuing science majors and fewer engineers are graduating in the United States (Duncan, 2007).

In addition to this, not everybody has (or feels of having) the same access to education, the view that they too could pursue higher education and/or become a scientist. As informal science specialists, we have seen middle and high school students change their opinions and values on science, as well as change perspectives on their future careers through our scientific programs outside of the classroom. When students are directly in contact with academic environments and with science and engineering experts (such as graduate students, professors, etc.), they are able to gain deeper understandings of science and engineering (Duncan, 2007), and with student access to modern scientific equipment such as academic research laboratories, will provide them with an authentic experience in data collection and analysis (Markowitz, 2004). There are also numerous research studies that indicate positive relationships between students’ achievement in science knowledge, process skills and attitudes toward science with laboratory instruction. (Markowitz, 2004). In addition to this, there have been many reports regarding the importance of the “summer learning loss issue”, as well as declarations that the current school time schedule has several important design flaws and that summer should be a time for enrichment (Borman, 2004). Summer academies could be a solution to this issue. Studies have been developed about the enhancement of student’s achievements in science and attitudes towards science through science-enrichment programs (both formal and informal), for students in the general population and gifted students (Markowitz, 2004), but there is no research about what these kinds of programs can do for underrepresented minority students or from underserved areas.

The purpose of this proposal is to assess the Princeton University Materials Academy program, a 3-week science summer program for underrepresented minority students, through an outcome evaluation to assess the impact of the academy through the analysis of its stakeholders’ experiences (students, teachers, administrators), to determine if the academy’s goals are being met and ultimately to develop a model to be applied in other (similar) locations nation-(or world-)wide.

*Program Description*

* 1. **Princeton Center for Complex Materials**

The Princeton Center for Complex Materials (PCCM) is an NSF-funded Materials Science Research Center (MRSEC) at Princeton University. PCCM currently has three Interdisciplinary Research Groups (IRGs) and several seed projects. PCCM Education Outreach department runs a variety of programs that include Research Experiences for Undergraduates (REUs), public science days and shows (some bilingual), science communication training for graduate students and faculty, as well as summer schools for graduate students and postdocs, among others. In this article we will focus on PCCM’s Princeton University Materials Academy (PUMA), created in 2002.

* 1. **Princeton University Materials Academy**

The Princeton University Materials Academy (PUMA) is a summer enrichment program designed to introduce middle and high school students from minority and underserved communities, more specifically Trenton, New Jersey, to materials science and engineering topics. Since its inception, the materials academy has covered several topics regarding energy, climate change, water filtration, batteries, several takes on polymers (both biological and artificial), as well as coding and wearable technology. PUMA applies a project-based learning approach in science and inquiry learning (Steinberg, 2009), in accordance with Next Generation Science Standards (NGSS). Students are taught materials science from a multi-disciplinary standpoint and are able to experience this multi-disciplinarity through the projects, lectures and laboratory experience, as well as through their immersion in the truly academic environment that Princeton University has to offer.

Students have traditionally been selected via an application portal and from the student pool of the center’s two partners in New Jersey: Upward Bound and Gear Up (Gear Up’s last year of participation was 2017, as the program closed due to lack of federal funds). Both are educational programs offered throughout the year for middle- and high-school students (most self-identified as underrepresented minorities) from low-income families, with the goal to increase the participant’s completion of secondary school and to develop academic and personal skills students will need to successfully complete college. Among others, they offer: supplemental academic instruction, after school tutoring, SAT prep, college visits and college application and financial aid instruction.

PUMA involves many stakeholders (teachers that are selected via a job application process, educators, professors, technicians, administrators and students) and many parts: from daily lectures by the resident teacher and our center’s professors, to tours, activities. The goals of the academy are to supplement high-school science courses, expose students to current scientific researched at the university/academic level and inspire them to pursue science in their college careers and beyond.

*The current study*

The current study is designed to review the aforementioned goals of PUMA and assess the academy’s impact, if these goals are being met from the stakeholder’s point of view and the changes in the student’s relationship towards science and (possibly) their careers. In order to do so, we will employ qualitative research techniques through multiple methods (observations and interviews) and data source triangulation. Potentially, this study will also use analyst triangulation.

The following research questions will guide this study:

* What impact did this summer experience have on the students?
* What were their learning achievements?
* Did it change their attitudes towards science?
* Did it change their career goals?
* Did it create any impact on their communities/families/friends?

1. **Method**

The data for this research project will originate from the experiences of a selected group that will include all stakeholders involved in the summer academy, from students to administrators. Our primary data source will be verbatim transcripts generated from in-depth, individual interviews with the selected group of participants, as well as from observations of administrators and teachers. This study will also potentially include a mixed-methods approach with the inclusion of content and attitude pre- and post-tests from the 2018 PUMA edition (16 participants). This is still potential because we will need to consider deeply if and in which ways this dataset collected from the past summer is relevant to the purpose of the study, as well as the role it will play in its validity. In the following sections we describe participants, as well as our data collection and analysis procedures:

*Participants*

Participants (Total N=TBD; tentatively 3 administrators of the program, 2 partner administrators (Upward Bound and Gear Up), 3 teachers, N (~20) students) will be recruited in Spring 2019 from all stakeholder groups: academy teachers, academy administrators, partner administrators and students that have participated in the summer academy. These students come primarily from Trenton High School (THS). Nevertheless, students from this school have been temporarily split up into four other locations (called small learning communities), given that in 2014 THS was closed for renovation after 82 years due to over a hundred of health and safety violations, such as no drinkable water, asbestos, leaky roofs and no lights in the hallways (Pizzi, 2014). The renewed Trenton High School is expected to open its doors Summer 2019.

*Data Collection & Analysis*

Based on considerations of the coordinators of the program, as well as the teachers involved in the academy, we will conduct interviews to the selected student participants from the pool of over 300 students that PUMA has received since 2002, through homogeneous sampling, by selecting similar participants to decrease the variation within the sample (Martella et al., 2013), in our case students that showed a similar level in their science courses from grades 10th to 12th and that were part of the same school (THS). We hope to achieve this by partnering with Upward Bound and tentatively with THS, who hold the students’ academic records.

To acquire data as up-to-date and relevant as possible, we will interview only the latest three (out of the five) PUMA teachers. Administrators (6) have more or less remained the same since 2002 and all will be interviewed (see **Table** **1**).

A naturalistic observation approach will be used to collect data from observations, unobtrusively observing the students in their natural setting (Martella et al., 2013), in this case the academy.

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| **Month** | **February** | **Early March** | **Late June** |
| Method | **Observations**  and thoughts about the students participating in previous editions (starting by 2018 PUMA) will be collected from administrators and teachers | **Face to face semi-structured individual interviews**  with students (potentially 20) | **Face to face (or phone) semi-structured individual interviews**  with teachers and administrators |

Table 1: Expected temporal phases of data collection during 2019

A standardized open-ended interview approach will be used to collect data from interviews; each participant will be exposed to the same topics and questions in the same order, with the purpose to be more effective and reduce interviewer effects (Martella et al., 2013). Two sets of interview questions will be developed: one for administrators and teachers, which will include opinion/values questions, sensory questions and feeling questions, and one for students, which will include experience/behavior questions, knowledge questions and feeling questions, and potentially background/demographic questions as well (see **Questionnaire 1** and **2** in the Appendix for current tentative questions). These questions will include key components and educational experiences such as their perceived impact of the summer academy during their high school years and beyond, the specific aspects or topics they recall from those summers, as well as a recollection on the interactions between stakeholders (both student-student and student-administrator/teacher).

To strengthen our themes, we have chosen to collect the data from multiple sources (data triangulation) in the form of observations and interviews, in order to compare and look for correspondence between the data gathered from teachers, from administrators and from students. We also hope to use analyst triangulation by using multiple analysts and interviewers during the gathering of the data. So far 2 interviewers (the researchers) have been selected and we hope to include up to two more, with the hopes to reduce bias as much as possible and check the accuracy of the data we record.

Observations and interviews will be recorded and transcribed (when necessary, as we may receive observations written already) word-by-word. Then we will focus our analysis by looking at how individuals responded to each question or topic. We hope to code the data by identifying themes or patterns into concepts, behaviors and interactions, and incidents (more categories or subcategories may be added, we expect them to emerge from the data itself). We will then identify similarities and differences between the responses that belong to each category. We also hope to be able to identify if there are any categories that appear to be more important than others (for example, by how many times the same topic comes up). We then hope to develop a list of key points and to develop an outline of our results that will include quotes and descriptive examples.

The quantitative portion will include existing data from PUMA 2018, when two one-group pretest-posttest designs were used studying attitudes and content knowledge of students; one wave was applied to the academy participants on the first day of class (July 5, 2018) and the other on the last day (July 26, 2018). The **content** pre- and posttest were designed by PUMA. 2018 lead teacher through the selection of similar questions from other tests used at her school (pilot-tested) about mathematics, science and technology content knowledge (such as coding experience, computer use, composite materials knowledge, among others), that ensured question reliability (that all students were answering questions in the same way) through closed-ended questions using the Likert scale. The **attitude** pre- and posttest was designed by William Friday, former president of the University of North Carolina, which include attitude questions on science, engineering and technology, 21st Century skills, science and engineering careers, social and academic identity, also ensuring question reliability through closed-ended questions using the Likert scale.

These tests will be analyzed though a *t*-test for correlated means, a robust parametric test of statistical significance that compares the means of two sets of scores to determine whether the difference is statistically significant (Martella, et al., 2013). The *t*-test for correlated means is specifically useful to study the same group of participants across two different points in time (such as the PUMA students at the beginning and end of the program). That being said, if we see any violation in the three assumptions described in Martella, et al. (2013, p. 118) about the obtained scores, or consider the score sample to be too small for a *t-*test, we will alternatively use the Wilcoxon signed rank test, a nonparametric test of statistical significance, an alternative to the *t*-test, especially appropriate to study the same group of participants across two different contexts or points in time (PUMA rationale also applies to this analysis), and that ranks the differences in the scores (from the first test to the second) to indicate the direction of the differences (Martella et al., 2013), without including the assumptions of the *t*-test (although the latter would be more robust).

1. **Results**

The academy personnel involved every year has assessed the program by, outlining the succeses, recognizing the failures and adjusting for the following year. Unfortunately, this was always done through face-to-face interactions, at most with notes from meetings, but mainly through spoken word. This will be the first attempt to pursue this assessment through truly studying the academies achievements and shortfalls with the gathering of (hopefully) all or most experiences and points of view. As such, we expect to find similar results to what has been found informally in the past. A description of some expected findings follows:

*From observations*

We expect PUMA personnel (administrators and teachers) to report positive outcomes from the school, such as positive change in student engagement (from more disengaged in the beginning to more engaged by the end). We also hope to receive observations about specific events where students were exposed to the scientific method, for example through a failing experience that made them understand how these can also be rewarding in their own way. Additionally, we also hope to receive observations on negative changes in students that didn’t make the most out of the academy or didn’t enjoy their spending a big chunk of their summer doing research, so we may have a glimpse at what went wrong and address it in the future. On a more positive side, we also expect personnel to report some positive moments the students experienced, such as successfully completing an experiment. Furthermore, program administrators from Upward Bound and Gear Up will also be able to provide stories and anecdotes about past students, as these programs follow up with PUMA students throughout the years.

*From Interviews*

Students have consistently been happy by the end of the program, showing PUMA personnel how appreciative of their time at Princeton they are, most also requesting recommendation letters for their future career efforts. Through our interview questions to students (please see **Questionnaire 1** in the Appendix), we hope to answer the questions posed in this research proposal and, given the aforementioned enthusiasm, to receive mostly positive recalls from the students about their time at Princeton, although we also expect a number of students recalling little to nothing, especially from students that were part of the academy 16 years ago.

Through our interview questions to teachers and administrators (please see **Questionnaire 2** in the Appendix), we hope to build on the response of our research questions and receive similarly positive responses about student engagement, classroom functionality (if students were more active in the morning vs. afternoon; if they seemed to enjoy one type of activity over others, etc.), as well as challenges that arose during their time at Princeton.

*From one-group attitude and content pretest-posttests*

We hope these tests will provide a **glimpse** into the experiences of participants in PUMA 2018 that will let us measure, albeit at a minuscule scale, if there were any improvements (or declines) in their attitudes towards science and their scientific content knowledge, while also adding on to our developed responses (through the qualitative methods) for questions 1 through 3 in this research proposal. We expect these tests to show that students feel comfortable when using computers (especially for tasks that they are accustomed to in school, such as presentation making or document creation), to have some knowledge on creating computer code/programs, and to be able to successfully respond to some scientific terms such as knowing what a polymer, a molecule, the different states of matter or basic scales are, among others.

1. **Discussion**

One of the main focuses of this study is to elucidate the usefulness and impact of science academies during the summer. Through the support of existing literature on the importance of science programs outside of school, especially to develop an interest for science that will be put to use at school and the importance of summer programs to fight the summer learning loss issue, as well as the qualitative and quantitative study of all stakeholders involved in PUMA, we expect the results of our investigation to elucidate ways to help students make the most out of PUMA, improve the program in itself and hopefully develop a set of guidelines that could be use in any educational environment (meaning other schools, universities, science centers, etc.). Being mindful that qualitative data analysis is not a straightforward path, we will consider the three main areas to evaluate our qualitative investigations (reliability, validity and credibility of the data; adequacy of research process, and its empirical grounding) as described in Martella, et al. (2013). We will also use data source triangulation comparing observational data with interview data, to validate information obtained from each source (administrators and teachers), as well as analyst triangulation, as several observers will be involved in the study (at least 7) and interviews will be attended by at least 3 interviewers, to reduce bias.

As described above, the quantitative portion of the study will be analyzed through the comparison of pretest and posttest scores with a correlated *t*-test, to see how they differ, or alternatively with a Wilcoxon signed rank test if the there’s a concern that the assumptions in the t-test are being violated.

*Study Limitations*

A portion of our study will include observations from personnel part of the program (both teachers and administrators). With such method, observer bias and the inaccurate report of what was seen is of great concern to us; given the subjective nature of qualitative observations, we will be very aware of such biases. Thus, data source triangulation will be used for the qualitative analysis, as described above.

Another method used in this study will be that of standardized open-ended interviews which have several weaknesses such as questions not being tailored to each participant and the loss of free-flow from informal conversations, which may weaken the participants’ responses.

We acknowledge the sample size in the quantitative portion of the study to be too limited to get truly relevant results or provide statistical significance. Therefore, for findings from the attitude and content pre- and posttest it will be very clearly stated that they belong only to the PUMA student group of 2018 and results will be taken with a grain of salt and only to point out interesting achievements or positive/negative positions of students to contribute and supplement to the qualitative portion and research questions of this study.

The one-group pretest-posttest designs specifically also raises concerns regarding internal validity, as it doesn’t provide much experimental control, by being unable to control six of its threats (history, maturation, instrumentation, statistical regression, testing and selection by maturation interaction) as described in Martella, et al. (2013, p. 159). This research design also raises concerns regarding external validity, as it does not control any of its threats such as generalization, verification of independent variable and Hawthorne effect, among others.

*Future directions*

After the 20 years of the existence of PUMA, there have been many reflection sessions, personal evaluations and review discussions about the program. We hope this study will be a first step towards the formalization of this process. As we have acknowledged many times throughout this proposal, the quantitative portion that this project can actually study at the moment is very small (only one year so far). This also brings us an opportunity, and something that we have already declared as an intention for our future efforts, to continue to conduct these attitude and concept pre- and post-tests in coming years, and conduct truly quantitative research with robust results.

1. **Research Ethics**

The ethical implications of the study will be carefully considered prior to interviews and observation submission. The necessary reviews by an Institutional Review Board (IRB) will be obtained. All subjects will have to provide written consent of participation in the study. Participants will be met at all times with respect and study methods will be adapted, if needed, to different age groups. Participating students will also be encouraged to ask questions and be explained that during interviews there will be no “right” or “wrong” answers, but that we are interested in their points of view.

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**Appendix**

1. **Interview Questionnaire 1: Tentative Questions for Students**

* What 3 words would best characterize the Princeton University Materials Academy for you?
* Did you enjoy PUMA? Could you explain why/why not?
* Had you ever taken a science course before being part of PUMA? Which ones? How about after PUMA?
* In how many editions did you participate?
* If you participated in more than one edition, can you recall which topic you liked best?
* Did you feel that you cared more about science after participating in the academy?
* Describe a particular memory you have from the academy
* What was the best thing about PUMA for you?
* How did it feel using a real laboratory or science workstation?
* What was your favorite activity during PUMA?
* Do you feel like you have changed a bit yourself?
* Did you enjoy speaking with and meeting university professors and scientists?
* Can you remember some of the facts that you learnt during PUMA?
* Do you think PUMA was an important part of your high school experience? Why/Why not?
* What is your involvement with science now?
* Did any of your siblings participate in PUMA also?

1. **Interview Questionnaire 2: Tentative Questions for Teachers/Administrators**

* Tell me about your work at PUMA. What did your position involve?
* How many years have you been involved with PUMA?
* What do you think the students enjoyed the most about PUMA?
* How did the 9 to 3pm schedule impact the classroom?
* What activities do you think were better received by students?
* Did you notice an increase of excitement and interest from the participants towards science by the end of the program?
* What were some of the challenges while being involved with PUMA?
* Could you see any major themes or branches in the organization of PUMA that could be applied in other locations/to develop a general curriculum?
* What was one of the most meaningful experiences you had while at PUMA?