ITEAMS: An Out-Of-School Time Project to Promote Gain in Fundamental Science Content and Enhance Interest in STEM Careers for Middle School Students

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ABSTRACT

We report preliminarily on the efficacy of an innovative, STEM education project for middle-school youth participating in out-of-school-time programs, targeting girls and students from underrepresented communities. Participating students attend urban schools in Eastern Massachusetts. The two main goals for the technology-based project are to inspire the participants to consider STEM careers and increase the student mastery of fundamental STEM subject matter. The students control robotic telescopes – either from school or home – to acquire and then process images of solar system and deep space objects. Project teachers attend workshops to become adept at using the robotic telescopes, meet weekly with the students, pilot project curricula, collaborate with staff to plan and supervise field trips and star parties, and assist in all project evaluation. There are both academic and non-academic partners; the latter include amateur astronomers and retired engineers. We use an online system to evaluate teacher and student subject matter knowledge and survey students and parents about STEM careers.

Keywords
STEM Careers, Technology Education, Middle School, Out-of-School-Time, Robotic Telescopes, Online Assessment.

BACKGROUND

The number of American college students showing interest in a STEM (Science, Technology, Engineering and/or Math) career is low, in comparison with the total number of students attending two and four year colleges. The challenge of producing a sufficiently large, qualified work force for a world that is daily becoming more dependent on technology, requires inspiring all students – particularly students of underrepresented communities as well as females – to pursue and persist in STEM. Students' probability of persisting in STEM is greatest if they choose a STEM career and/or show significant interest in STEM by the eighth grade. ITEAMS[1] (Innovative Technology-Enabled Astronomy for Middle Schools) is an out-of-school-time (OST) program that captures middle school students' interest in STEM content and in STEM careers using technology-based astronomy investigations. ITEAMS targets students in underserved communities, who are, according to the literature and current research, less likely to enter into STEM careers. The participating students use online robotic telescopes to conduct original research. Additionally, they process their images, produce original Wiki sites, and communicate their findings to other students and teachers. Early findings suggest this project has produced significant interest among students in STEM careers and some enhancement of fundamental science content knowledge. There is need to increase both interest in STEM fields and mastery of science and mathematics content if we are to bring more students into STEM career pathways. Upon the completion of the pilot study, project materials will be made available via the internet to any interested class, and thereby extend the possibilities of increasing student interest in STEM within underserved communities.

Recent reports paint a stark picture for America's STEM education and resulting workforce. They provide ample evidence that a decreasing number of students major in STEM during their university career. They also confirm a vast under-enrollment and under-representation of women and minority students in the field [1]. The problem may begin early in one's schooling for one study has shown that persistence in STEM is twice as likely for students who express an interest in STEM during middle school [2].

At the graduate level, the overall statistics for underrepresented groups are equally disturbing—of all STEM doctorates earned in 2008, White students earned 75% and, women only earned 36% [4]. America's STEM workforce, which depends on advanced technology geared toward accelerating research and techniques for future

[1] ITEAMS is funded by the National Science Foundation (NSF 08-33378) with support from Harvard University and the Smithsonian Institution.

technologies, is waning in both quality and quantity. If there are no dramatic increases in the quality and quantity of this workforce, the damage to the country's economy will be deep and long lasting [3]. The question of how to interest students at younger ages and sustain their interest throughout school and into their careers is a recurring problem. Finding a solution has become essential. While many different kinds of reform curricula and programs have been proposed to address this crisis, no definitive answers have emerged.

ITEAMS seeks to interest students in STEM during their middle school years, and measures the efficacy of the program in relation to both content knowledge and career intention. The National Science Foundation funded our project on 1 October 2008. It is a three-year project managed by science educators from the Science Education Department (SED) at the Harvard-Smithsonian Center for Astrophysics (CfA). We target underserved and minority students in grades 5-8 who are enrolled in out-of-school-time (OST) enrichment extended-day programs. There are five eastern Massachusetts schools involved, one each in Lynn and Fall River, and three in Cambridge. Our goal is to provide sustained, innovative experiences emphasizing the centrality of Information and Communication Technology (ICT) for the growing STEM workforce. Extensive student activities – all with intercurricular extensions and career correlations – are built around the CFA's MicroObservatory robotic telescopes. Working from school, home, or libraries, the students directly control one of the telescopes (located in MA and AZ) to acquire images, primarily of galactic and extra-galactic objects. The next morning the images are delivered to the students by email for processing (colorizing, enhancing, altering the dynamic range, creating simulations and visualizations, and more).

We have both academic and non-academic partners, including: Harvard University's (HU's) Earth and Planetary Sciences Department and the Initiative for Innovative Computing; the Amateur Telescope Makers of Boston (one of the oldest and largest amateur astronomy clubs in the nation); and the Retirees' School Volunteers Association (supported by Raytheon Corporation, and whose retired engineer members contribute 5000 hours of volunteer service to area schools.) Students come to the CFA each summer for institutes, which include programs with the HU partners and at other campus locations. The non-academic partners volunteer at the schools, working with the students during the OST sessions. Participating students take field trips to high technology and robotic firms. There is also programming for the students' families, both at CFA and in their communities.

Project leaders have designed a content assessment, given to both students and teachers, based on previously designed distractor-driven multiple choice (DDMC) concept inventories produced by the SED. A significant portion of the students will be involved for two or three years, providing an excellent base for longitudinal study. There is much evidence from the literature for the validity and utility of DDMC items of the type we use [5]. The intervention strategy is to first use the inventories diagnostically, and then longitudinally with the deliveries of comparable assessments twice a year for both students and teachers. Teachers predict the strongest distractors for the DDMC items, and these predictions are compared with the actual frequencies of incorrect answers chosen by students, as proxy measures of teacher pedagogical content knowledge. In addition, an affective assessment is administered to the students twice a year to determine both STEM interest, and implicitly, confidence in one's abilities, and STEM career intention. These data are then analyzed to determine significant change over the course of a year.

METHOD

In the pilot phase of this project, we recruited 84 students and 9 teachers from 5 schools. Almost every student involved in the project was from an underserved population. This included females, minorities and those from low Socio-Economic Status (SES) settings. All students were enrolled in grades 5 through 8, and were between the ages of 10 and 14. During professional development workshops, we taught the teachers how to request and process images obtained with the MicroObservatory robotic telescopes. We also provided pilot curricula modules and materials. Teachers piloted the new curricular materials, helped in further development, and then again piloted the revamped materials with their students. The teachers taught their students how to use MicroObservatory and helped them establish their own accounts for requesting and saving images. Teachers then guided students through image processing, including stacking filtered images and re-defining image parameters. We asked the teachers to proceed at their own pace through the semester.

The students had their own accounts on MicroObservatory. They used these accounts to request and receive images. They processed their images using two different kinds of software. By processing the images the students were able to draw out from their original images characteristics not originally discernable. The students also developed wikis for their OST group at their school, and used their wikis to post the images they had acquired and processed. Students used additional forums, such as science night or science fairs, to disseminate their findings and display their work. Volunteers from the amateur astronomy and retired engineer groups worked with the students during the OST sessions. We include these interactions as a means to inspire students to learn more about the possibilities of a STEM career, and to have the students develop relationships with scientists and engineers largely outside of their normal educational experience.

The concept inventory was administered to all students via an online system now being implemented by the SED to deliver all of our DDMC tests. Teachers brought students to their school computer laboratories and guided them through the pretest, helping them to sign onto the testing site their first time as well as submit their answers properly. We had the students take the posttest while attending their two-day summer institute at Harvard University. We calculated preliminary results using a paired-samples t-test and a repeated-measure ANOVA. This version of the concept inventory included items aligned to six different standards: three from the National Science Education Standards and three from the AAAS Benchmarks. All standards aligned with the content and intention of the ITEAMS project; specifically, all items directly tested concepts addressed either in ITEAMS curricula or direct use of the MicroObservatory robotic telescopes. Teachers were given a similar assessment: the teachers' assessment consisted of all the questions on the student test as well as eleven more questions in order to lessen the probable ceiling effect that frequently occurs when teachers take tests designed for students.

We also had students take an affective survey, which tested attitudinal hypotheses, and asked about frequency of technology use and career intentions. This survey delved into issues of self-efficacy, confidence, hobbies and approach to problem solving. We asked students about their computer and software experience in order to gain insight into which of those programs the students would need introduction and training. We tracked students anonymously using the same demographic questions on every assessment and survey. In order to maintain anonymity while still tracking students longitudinally, we use their birth date, gender, school and race as identifiers. At the end of the assessment, we asked students if they were considering a career in STEM and, if so, what career they were considering. Students typed in answers to this question, which we then coded into five categories: Science/Math, Engineering, Computer Science, Medicine/Health, Other Applied Science and Other. As before, students completed this survey via the online testing site from school-based computer laboratories. We analyzed these data using a one-way ANOVA and Chi Square test, in which Likert-scaled data were tested for main effects and interactions between gender, race, and attitude/frequency of technology use. In an effort to measure gain and/or change in attitude, both the content and affective assessments are administered twice per school year.

RESULTS

The students clearly enjoyed working with MicroObservatory, and produced work of which they were very proud. They excelled at requesting and processing images of deep space objects as well as requesting and processing images of the Moon and some solar system objects (Figure 1). The students posted their processed images on their wikis and displayed them during Science Day at their schools. Their facility with the robotic telescopes and image processing technologies was impressive and permitted the students to pursue their own research interests.

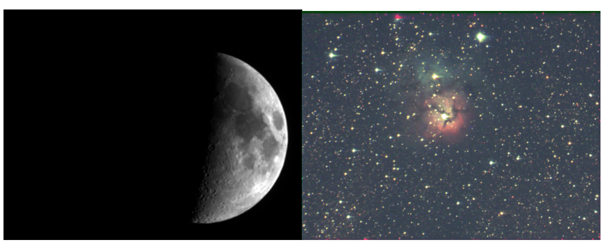

Figure 1. Student processed images: Students acquired images from MicroObservatory and processed them. On the left is an enhanced image of the Moon; on the right, an image of the Trifid Nebula created by combing red, green, and blue images.

With minimal guidance, students used the Internet to begin preliminary data research on deep space objects and engaged in astronomical research. In short, the students' use of MicroObservatory served its purpose and continues to do so: it enhanced their mastery of STEM content and made them more aware of possible STEM careers.

For the content test, preliminary diagnostic data showed some parallels between teachers and students in both knowledge gaps and expertise before they began ITEAMS. Teachers performed significantly better than students on nearly all the test items, although some items proved far more difficult than others for teachers. We also found that teachers hold some of the space science misconceptions reported in the literature and known to us from our department's work. Misconceptions can be obstacles to their own learning and to that of their students. We grouped the questions according to their alignment with either the National Science Education Standards (NSES) or the AAAS Benchmarks (B)[2], and then analyzed them by standard (Figure 2). For example, teachers excelled on the standard concerning the purpose and use of telescopes, but need more work on the solar system standard. As this is an OST course, we do not want to overemphasize content gain or alignment with standards at the expense of inspiration. Nonetheless, it is important for the overall aims of the project that both students and teachers have the basic knowledge needed to enjoy using the MicroObservatory telescopes. Based on these diagnostic data, we began to approach professional development differently, placing more emphasis on the areas in which the teachers need more work.

The student pretest results showed a similar pattern; that is, the students scored higher on the same standards as did the teachers. But, compared to the teachers, the students scored lower in each standard and particularly so for the standard concerning energy. This was likely the first space science test taken since primary school by the majority of the students involved in the program. They may have had some experience with related topics (such as distance and scale) in the interim, and scored well relative to the long gap in time since their last exposure to the topic.

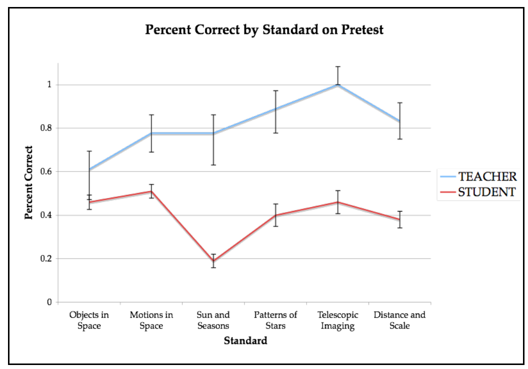

Figure 2. Pretest Results by Standard: Teachers score significantly higher than students for each standard. As a diagnostic tool, the pretest shows areas where teachers and students excel and/or need further instruction.

During their summer workshop we had students take the correlated posttest to measure any content gain after one semester of instruction. We found a significant drop in scores, which may be related to either instruction or poor timing. In terms of instruction, studies have shown that students' subject matter knowledge (SMK) may initially drop after the students are faced with their misconception about a topic. Upon their primary encounter with a moderate to difficult DDMC item, students generally guess at the answer, resulting in a statistical profile in which all possible answers have equal numbers of students choosing them; each of 5 possible answers will be chosen with equal frequency (20%). After some exposure to the topic, but before true conceptual understanding occurs, students will begin to choose the answer that represents their misconception with greater frequency than other answers, shifting the statistics so that the item profile no longer represents guessing, but definitive choosing (of the misconception). It is only after much more instruction and the students' replacement of their misconceptions with the scientific understanding that they begin to choose the correct answer. This again shifts the item profile, but so that the majority of test takers

[2] Please see Appendix 1 for a list of the standards used on the content test.

now choose the correct response. This last step is often accomplished only after a struggle to reconstruct one's thinking; robust misconceptions are extremely difficult to replace with scientific ways of thinking, and this takes time to accomplish. After this period, studies show that students' gains in SMK often move beyond the trajectory of a student in a more traditional learning environment [6]. The students' lower test scores could also have been partially a product of timing. We had students take the assessment almost immediately after school had ended while they were visiting Harvard University for their summer workshop. Excited to be at Harvard, they were, at least in part, already on summer vacation and less focused on testing than other pursuits.

During the second semester of the first year of this project, we asked teachers to administer the pilot affective assessment to the students[3]. We used the data collected as diagnostic data and analyzed it accordingly. At this time, gender did not have any significant impact on how the students felt about science in general (Figure 3). The students answered positively on all of the Likert-scaled questions, except when asked if they'd like to receive science books or equipment as a gift.

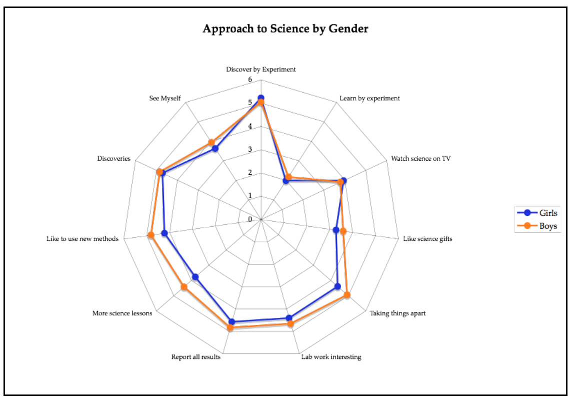

Figure 3. Approach to Science by Gender: Student responses to Likert-scaled questions concerning their approach to science, their feelings about science, and whether they see themselves as scientists. Average student response is more positive toward the outermost circle.

When asked if they could see themselves as scientists, girls and boys answered virtually the same. This reinforced the notion that gender differences appear later in their academic careers, and served to underscore the opportunity that middle school educators have at this time to interest students in STEM related careers. We have every confidence that the students took these surveys seriously and thought about each question before answering it. The teachers reported student comments on this assessment, noting that the students found it to be fun and almost like playing a trivia game, even though they knew it to be an assessment. It was encouraging to see the students so excited about incorporating technology into their everyday lives, using high-tech substitutions for what they normally do, but even more so to see the girls and students of color taking a particular interest in these technologies.

[3] Please see Appendix 2 for a text version of the Affective Assessment

The questions concerning the use of computers showed significant differences in gender (Figure 4). This series of questions was of particular concern to us for several reasons. The answers to these questions gave us an understanding of the baseline technical knowledge with which the students were coming into the ITEAMS program. They also provided an indication of how quickly we could increase the students' use of more advanced technologies, and served to guide us in the development of our curriculum. In the use of online communication, word processing programs, and graphics software, the girls' use was significantly more frequent than the boys' use if the same applied technologies.

Overall, these data show that there is equal interest by boys and girls in STEM at this point in their lives, and that girls actually surpassed boys in frequency of use (this may imply greater interest in these technologies). Again, the age-old adage that boys excel at math and science while girls do well in the humanities is not supported by our findings. Girls not only have equal interest in STEM, they also avail themselves of the many conveniences of technology more often.

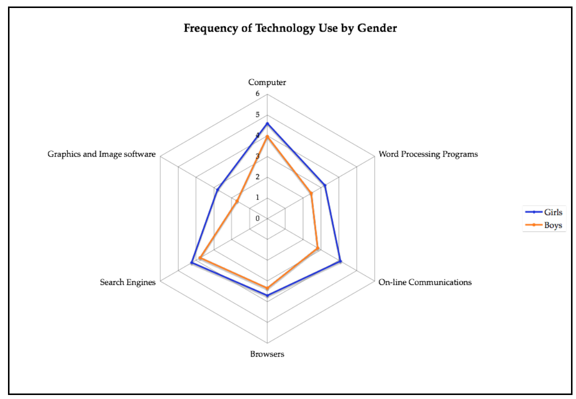

Figure 4. Frequency of Technology Use by Gender: There is a significant increase in regular use of particular technologies for girls in this sample.

Finally, we analyzed the statistics for the probability that students of a particular gender or race would show a preferential interest in a STEM career. Using Chi-Square analysis, we found a higher probability of Black or Hispanic females choosing a career in medicine or health than students of other races/ethnicities, or boys (2-sided Asymp. Sig. = 0.04 for both groups). All of the other categories of career were non-significant for both gender and race and there were no main effects. While statistics show the dominance of white males earning degrees in STEM and pursuing STEM careers, our data show that girls of color have a significantly higher interest in applied STEM (that is, medicine and health) than their white counterparts.

CONCLUSIONS

In its pilot phase, ITEAMS has been shown effective in several ways, including amplifying student interest in STEM content and providing quantitative data on the use of technology. We find that there is no significant difference between the genders in terms of interest in STEM and in STEM careers. Instead, it is the girls in our sample who embrace technology more extensively. The distinction between genders presuming that boys will surpass girls in their science and math skills is not present at this age within our population. Although there are data that show that the majority of students receiving higher degrees in STEM subjects are white and male, we find in our sample that applied STEM appeals far more to girls of color than to white girls or males of any race or ethnicity. These findings offer some promise: the face of the STEM work force in America can potentially undergo significant change if we can help students persist in STEM throughout their academic careers. The ITEAMS project is still in its pilot phase. By the end of the project, we hope to demonstrate that a blend of advanced online technology and age-appropriate classroom materials increases the interest of students in STEM careers.

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APPENDICES

Standards Used for The Content Assessment

Objects in Space—The earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects, such as asteroids and comets. The sun, an average star, is the central and largest body in the solar system.

Motions in Space—Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.

Sun and Seasons—The sun is the major sources of energy for phenomena on the earth's surface, such as growth of plants, winds, ocean currents, and the water cycle. Seasons result from variations in the amount of the sun's energy hitting the surface, due to the tilt of the earth's rotation on its axis and the length of the day.

Patterns of Stars—The patterns of stars in the sky stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons.

Telescopic Imaging—Telescopes magnify the appearance of some distant objects in the sky, including the moon and the planets. The number of stars that can be seen through telescopes is dramatically greater than can be seen by the unaided eye.

Distance and Scale—The sun is many thousands of times closer to the earth than any other star. Light from the sun takes a few minutes to reach the earth, but light from the next nearest star takes a few years to arrive. The trip to that star would take the fastest rocket thousands of years. Some distant galaxies are so far away that their light takes several billion years to reach the earth. People on earth, therefore, see them as they were long ago in the past.

Affective Assessment for ITEAMS/Fall 2009

Answer the following according to this scale:

Strongly Agree / Agree Slightly / Agree / Slightly Disagree / Strongly Disagree

1. I would rather discover why something happens by doing an experiment than by being told how it works.
2. Doing experiments does not help me learn as much as finding out information from teachers.
3. I like watching science programs on TV.
4. I would like to be given a science book or a piece of scientific equipment as a present.
5. I like taking things apart to see how they work.
6. Working in a laboratory would be an interesting way to earn a living.
7. In science experiments, I report unexpected results as well as expected ones.
8. School should have more science lessons each week.
9. In science experiments, I like to use methods which I have not tried before.
10. I would like to work with people who make discoveries in science.
11. I could see myself being a scientist or engineer.

Please describe how much experience you have had with the following:

I use it:

Every day / A lot / Quite a bit / Only a little / Not very much / None

12. A computer
13. Word processing programs
14. On-line communications (like IM or email)
15. Web browsing and information searches
16. Yahoo, Google or other search engines
17. Creating graphics, photos, graphs or tables on a computer
18. Are you male or female?
19. How old are you?
20. Which of the following best describes your race/ethnicity?
    White / Black / Hispanic / Asian / Native American / Other
21. Please enter your birthdate: (MM/DD/YY)
22. How interested are you in science, technology or engineering as a career?
    Completely / Quite a bit / A little bit / Somewhat / Not very much / Not at all
23. How often have you given serious thought to your future career?
    Every day / Frequently / Often / Occasionally / Infrequently/ Never
24. If you already know what you might like to be when you're older, please write it here: ___________________