STEM Enrichment Program for High School Students:

Results and Lessons Learned

Abstract

While science, technology, engineering and mathematics (STEM) are crucial fields when it comes to driving innovation and competiveness in today's economy, there is a lack of interest for high school students in the United States in pursuing such degrees. This paper describes a two-week summer enrichment program that focuses on improving student preparedness for college, while promoting STEM education through active learning experiences and activities. The program, a partnership with industry, has a major goal of engaging under-represented students, including female students, in STEM. Students are introduced to various engineering disciplines through hands-on activities and participate in two field trips to facilities that employ engineers and scientists. This paper presents program data over two years and discusses results and lessons learned.

Introduction

The shortage of STEM graduates in the United States has been the focus of a number of recent studies[1-4]. A report by The 2012 President's Council of Advisors on Science and Technology (PCAST) states that the "*economic forecasts point to a need for producing, over the next decade, approximately 1 million more college graduates in STEM fields than expected under current assumptions. Fewer than 40% of students who enter college intending to major in a STEM field complete a STEM degree.*" In order to remain globally competitive, the U.S. must increase the quantity, quality, and diversity of the STEM workforce.

Studies have shown that students who participate in STEM programs before college increase their chances to succeed[5-13]. These programs provide them with important knowledge and skills to gain a better understanding of science and engineering careers. This paper describes a STEM Summer Enrichment Program (STEM-SEP) designed for high school students. STEM-SEP's goal is to improve the recruitment and preparation of students, particularly those from underrepresented groups, through participation in a two-week summer enrichment workshop that increases students' knowledge in a variety of areas. Students who had just completed either the 10^{th} or 11^{th} grade are recruited via a program web site or by contacting guidance counselors, STEM teachers, and principals. Social media was also used as a recruitment tool. Applicants are evaluated using selection criteria that include high school transcripts and an essay where students describe their reasons for wanting to attend.

STEM-SEP has been held on the campus of Penn State University-Harrisburg each June since 2016. The workshop sessions provide participants with active learning opportunities through participation in laboratory-style experiments and team activities. Such activities have shown to improve retention of women in engineering majors, a key feature since female students disproportionately change majors from engineering into other fields of study.

In 2016, 28 students successfully completed the workshop[14]. The group included 10 females and 15 minority (none-white, self-reported) students. Participants represented 12 high schools and one home-schooled student. In 2017, 33 students successfully completed the workshop. The group included 14 females and 16 minority (none-white, self-reported) students representing 19 high schools. The following sections describe the program activities and present evaluation results.

Student Recruitment

Recruitment for the STEM SEP program begins in December/January of each year. The program has a designated webpage located on the School of Science, Engineering and Technology's website (https://harrisburg.psu.edu/science-engineering-technology/STEM/summer-STEM-program). The webpage includes an overview of the program, activities, application, as well as, specific pages targeted towards parents and students. A flyer is sent electronically to high school guidance counselors, principals and STEM educators. The Office of Marketing and Communications at Penn State Harrisburg assists by distributing the program information via social media and relevant news outlets. The program has grown in popularity in the region and word-of-mouth has become a popular means of recruiting students.

Workshop Sessions

As mentioned in the Introduction, the pedagogical techniques employed in all of the workshops are active-learning student-centered methods. The instructors decided at the inception of the program to present material in ways that each instructor had found to be most effective in the university environment. All sessions used mini-lecture presentations followed by activities that teach the concepts through demonstration or experiment that the students perform themselves. From the first year to the second, the biology and chemistry sessions were revised based on feedback from students that indicated they had done the particular type of DNA analysis and polymer synthesis before. The session descriptions below are reflections of the 2017 workshops; all of which were well received and were new to the students. A particularly important component of the program that makes this possible is the inclusion of teaching assistants that are current undergraduate students at our university. They are trained to help the workshop participants right before the program begins. These teaching assistants, close in age to the participants, make it possible to hold large lab-based classes with new equipment and methods that a 1:30 student teacher ratio would make difficult. The STEM-SEP program has a 1:8 student teacher ratio. The undergraduate teaching assistants eat lunch and play games with the participants too so that there are opportunities for mentoring even during relaxation time.

The workshop starts with registration and a welcome session where parents and students meet the faculty and staff. Each student receives a welcome package that includes a free calculator. Pictures are taken with the University mascot. These pictures are mounted with a certificate of completion and presented to each student at the closing ceremony.

The first week of the workshop consists mainly of science sessions (mathematics, computer science, physics, biology, and chemistry) and includes a field trip. The second week is devoted to engineering sessions (civil, mechanical, and electrical) and includes a second field trip. One of the field trips is a tour of a local steel manufacturing facility that takes steel from raw material

to finished rail products. The second week concludes with brief student presentations and award of certificates. Students normally comment on their favorite learning experience during the workshop and how what they learned might impact their future career plans. Table 1 shows the 2017 workshop schedule.

The following paragraphs provide brief descriptions of the 2017workshop sessions.

Biology – The biology workshop included four topics crime scene investigation, food color, robotics and nanotechnology. During the crime scene investigation topic students learned how biology helps in solving crimes and identifying suspects using DNA and enzymes. The second topic discussed was food coloring and the advantages/disadvantages of naturally occurring versus artificially created. Students learned about the effect of pH on color pigments. Next the students explored anatomy by constructing a robotic hand that mimicked a human hand. Students learned how muscles, bones, ligaments and tendons all work together to perform a task such as grabbing a ball. The final topic discussed was nanotechnology and how it has revolutionized the field of medicine.

Table 1. Sample STEM-SEP Workshop Schedule

Lunch 12pm – 1pm

		9-12 noon	1-4 PM
Week 1	**M**	Registration, Welcome, Photo	Math Applications
	T	Math Applications	Physics Applications
	W	Chemistry Applications	Field trip 1: Diagnostic Lab
	R	Biology 1	Biology 2
	F	Computer Science 1	Computer Science 2
Week 2	**M**	Civil Engineering 1	Civil Engineering 2
	T	Electrical Engineering 1	Electrical Engineering 2
	W	Mechanical Engineering 1	Mechanical Engineering 2
	R	Field Trip 2: Steel Plant	Preparing for College Work on presentation
	F	Work on presentation	Presentations & Awards

Chemistry – The chemistry workshop was set up as a mission to cure a virus outbreak that was turning people into zombies. The goal of the session was to demonstrate qualitative analysis of substances and how similar looking substances are not actually similar. Students learned how to utilize paper chromatography to measure weight/volume of liquids and calculate density. In addition, students used gas chromatography to differentiate liquids using pH. Students also used gas chromatography to understand the differentiation of molecules inside a gas chamber. Finally, antibodies and antigens were discussed and students were given infected and fresh samples to separate.

Civil Engineering – The civil engineering workshop focused on the design and construction aspects of civil engineering with emphasis on the difference between and importance of a design engineer and construction engineer. Topics related to environmental engineering were presented and the importance of protecting the environment before, during and after construction. Students were given hands-on aspects of civil engineering such as bridge construction, use of alternative materials to form concrete and their associated weights/strengths. Different types of material testing procedures were conducted. The students were then presented with a challenge to build a sustainable bridge and concrete canoe.

Computer Science – The computer science workshop focused on weak points in a software platform using HMTL, SQL and command. The discussion highlighted the topic of hacking and included a demonstration on vulnerabilities that hackers exploit. Students engaged in a conversation about how to keep critical information safe on the internet, including developing a secure password. The session concluded with information on the search function of a website, how it works and how it can be exploited by hackers.

Electrical Engineering – The electrical engineering workshop taught the basic elements and components like resistors, transistors, potentiometers and the soldering process. An hour glass example was utilized to demonstrate the basic functionality of a resistor. The volume of a music player was used to demonstrate the potentiometer and students were asked to construct photophilic robots that followed light. As part of these exercises, students learned to trace a circuit in a printed circuit board, how to recognize different components like LDRs, LEDs, transistors and potentiometers by appearance. All students successfully designed the robots and tested them in the classroom.

Mathematics – The mathematics workshop focused on coordinates and dimensionality. A video was utilized to visualize how mathematics demonstrates the possibility of higher dimensions which was further reinforced by using a hypercube. The concept of dimensionality was demonstrated by using 3D and 4D tic-tac-toe games that students played during the session. The idea of encryption and decryption, the process of creating, sending and understanding a secret message was discussed. The session instilled the idea that mathematics is interesting and integrates into many fields.

Mechanical Engineering-1—The mechanical engineering 1 session focused on aerodynamics and different aerodynamically stable designs. Students learned about the forces responsible for objects to remain in flight. Bernoulli's famous equation regarding the pressure above and below an object was taught then students were asked to design a paper airplane. The planes were flown three times and each time the students were asked to improve the design so their plane flew for a longer duration. The students analyzed the efficiency of the aerodynamic designs. In addition, students learned about wind tunnels and utilized a design analysis software.

Mechanical Engineering-2 – The second mechanical engineering workshop focused on 3D design and printing tools. Students participated in a discussion on how 3D technology is revolutionizing our world. Subtractive and additive manufacturing technology was taught, along with engineering and reverse engineering. Students learned about 3D design tools using

SOLIDWORKS and designed a cell phone cover then printed their design using a 3D printer available in the laboratory.

Physics – The physics workshop focused on optics and different phenomena like reflection, retraction, and diffraction were demonstrated. The nature and property of LASER were discussed. The process of the formation of a rainbow was explained and small beads of glass were used to demonstrate magnification showing the simplicity of physics. A discussion was had surrounding how helium was discovered. A demonstration using LASER showed that optical fiber carries data without comprising it and Snell's law was explained. The phenomena of total internal reflection was demonstrated.

2017 Field Trip-1: Clinical Simulation Center at Penn State College of Medicine: The Clinical Simulation Center at Penn State College of Medicine is one of the largest medical research facilities on the east coast. The field trip included four main focuses; CPR, Anesthesiology, and virtual and artificial organs. The medical practitioner demonstrated how CPR saves lives and students had the opportunity to learn the process and techniques. The purpose of anesthesia in certain procedures was discussed. In addition, students learned the necessity to de-nitrate patients before surgery. A demonstration of the of procedure and equipment used to oxygenate the patient during the procedure. The simulation of human heart, lung and artificial organs was demonstrated followed by case studies of patients who received artificial organs.

2017 Field Trip-2: ArcellorMittal Plant in Steelton, Pennsylvania: ArcellorMittal is one of the oldest multinational companies in the world and also serves as the sponsor for STEM SEP. Students observed the process of steel production and how raw material is transformed into a commercial product. The automation of the steel making process was shown using PLCs and sensors were used to obtain live feedback required to maintain quality of the final product. The field trip also demonstrated the amount of electricity required to produce steel.

Preparing for College

The workshop Preparing for College was presented by staff from the Office of Multiculturall Affairs and discussed the college admissions process and financial assistance. Following the workshop, a closing ceremony was help in which students received a framed certificate of completion and photos with the University mascot from the first day of the program. A group picture of workshop participants is shown in Fig. 1.

(a) 2016 Participants

(b) 2017 Participants

Figure 1. Group picture of STEM_SEP workshop participants

Program staff included 11 faculty members and three student assistants: two undergraduates and one graduate student. Each session instructor met with the student assistants for two-four hours prior to the workshop to train the assistants to ensure adequate was available.

Pre- and Post- Assessment

After reviewing the participant evaluations and discussions from the first year's workshop, we decided to administer a pre- and post-program learning assessment. Several factors went into the design of this tool. It needed to be "short and sweet" since we did not want it to feel like a test to the participants. The assessment had to cover all workshops. The questions and answers were submitted by each instructor to assess topic knowledge on entry and knowledge retention on the last day of the program. Note that these assessments were not administered before and after each session but rather on the first and last day of the program.

Fig. 2 is a histogram showing the percentage gain by participant as an overall percentage that reflects the post score – pre score as a percentage of increase in knowledge.

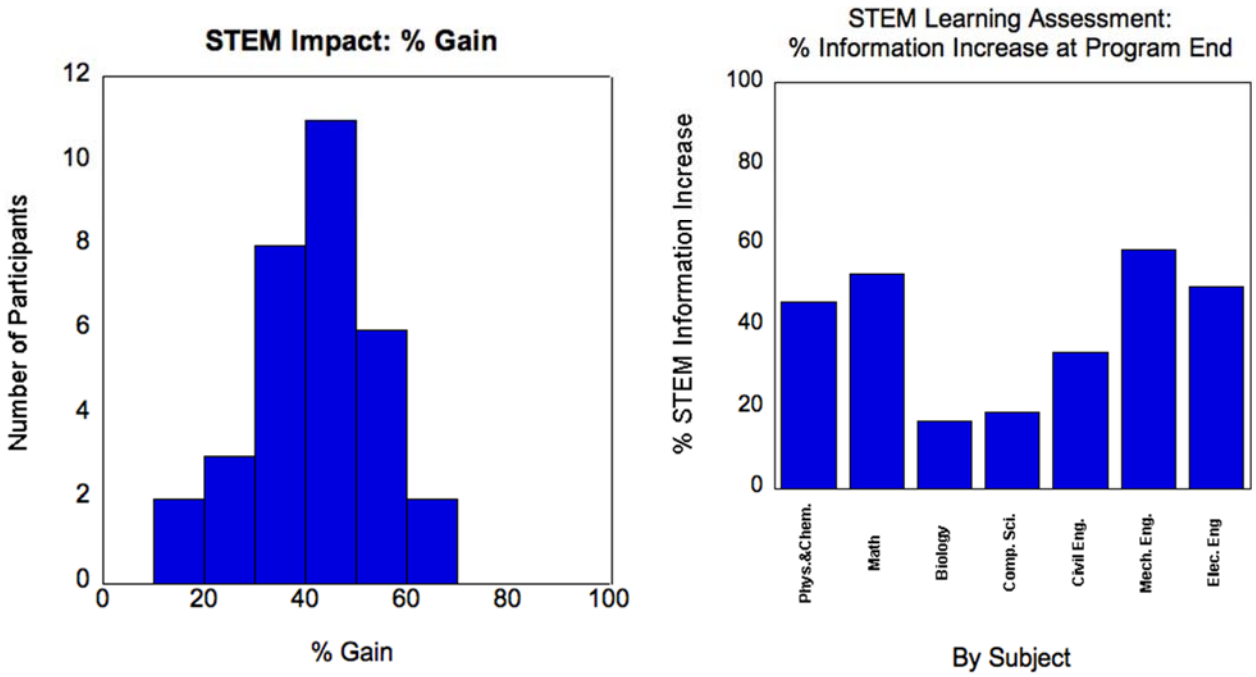


Figure 2. Pre- and Post- Assessment Results

The results by subject indicate confirmed statements made by the previous year's participants that the engineering week was the most educational because they had, as a group, little or no previous exposure to the fields although many were planning to enter engineering as a major as indicated by their essays and statements to program faculty and staff.

Another planned major of many of this group was medicine. They had already taken AP biology so those participants did very well even on the pre-assessment. The lower gains in computer science appeared to be attributable to previous misconceptions.

Session Evaluation by Participants

All workshop sessions, including the field trip, were evaluated at the conclusion of the session. The evaluation forms are shown in Appendices A and B. The corresponding results are summarized below. The highest score of 100% would indicate that all the students had "Strongly Agreed" or "Agreed" with all questions. The results from the five questions asked at the end of each session are presented in Table 2 and Figure 3.

Overall, the sessions achieved their goals and were well received by the students. As shown in Table 2 and Figure 3, the students expressed that they learned a lot, had fun, understood STEM topics better, and were more interested in STEM as a result of the individual sessions. The materials and supplies were generally easy to use with the computer science and the mechanical engineering session on design (ME 2) needing some improvement.

An unexpected result was that the students bonded quickly. They created a group chat that they used during breaks and at home. Spontaneous frisbee and soccer games were organized by the

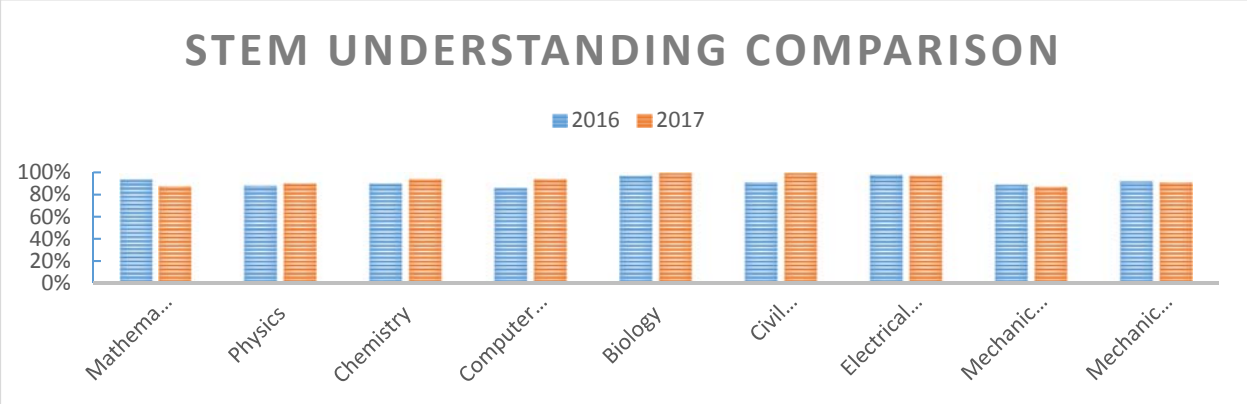
students during daily lunches. Contact from some students or parents in the weeks afterwards indicated that some of the friendships continued after the end of workshop.

Table 2 (a). 2016 Evaluation results from Appendix A for individual sessions

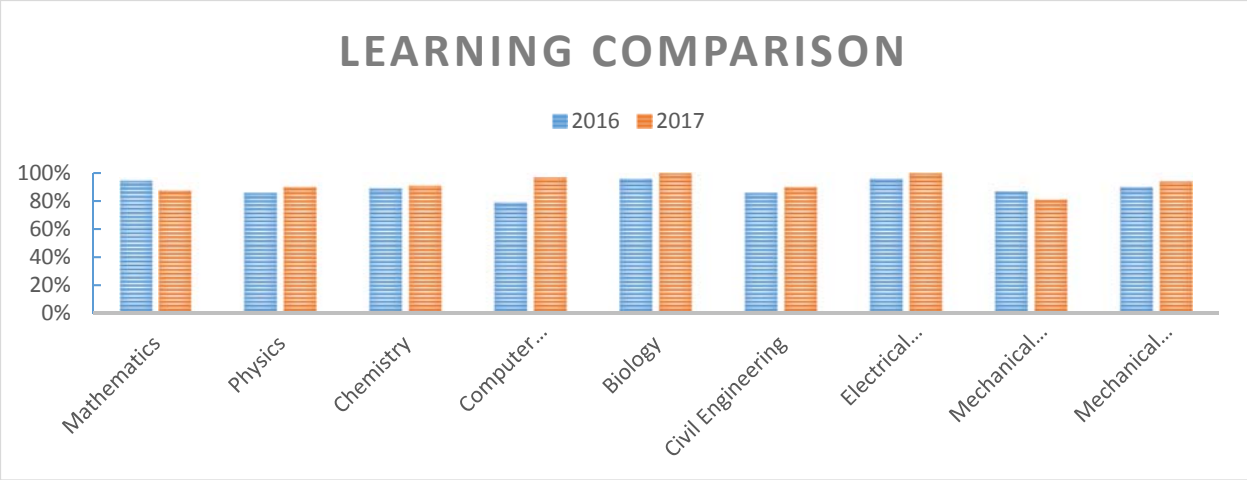
Session	STEM Understanding	Learning	Fun	Material Usability	STEM Interest
Mathematics	93%	94%	89%	92%	90%
Physics	88%	86%	97%	92%	91%
Chemistry	90%	89%	96%	96%	89%
Comp. Sci.	86%	79%	82%	60%	82%
Biology	97%	96%	96%	92%	94%
Civil Eng.	91%	86%	86%	92%	85%
Elect. Eng.	98%	96%	96%	85%	95%
Mech. Eng. 1	89%	87%	91%	96%	88%
Mech. Eng. 2	92%	90%	82%	66%	89%

Table 2 (b). 2017 Evaluation results from Appendix A for individual sessions

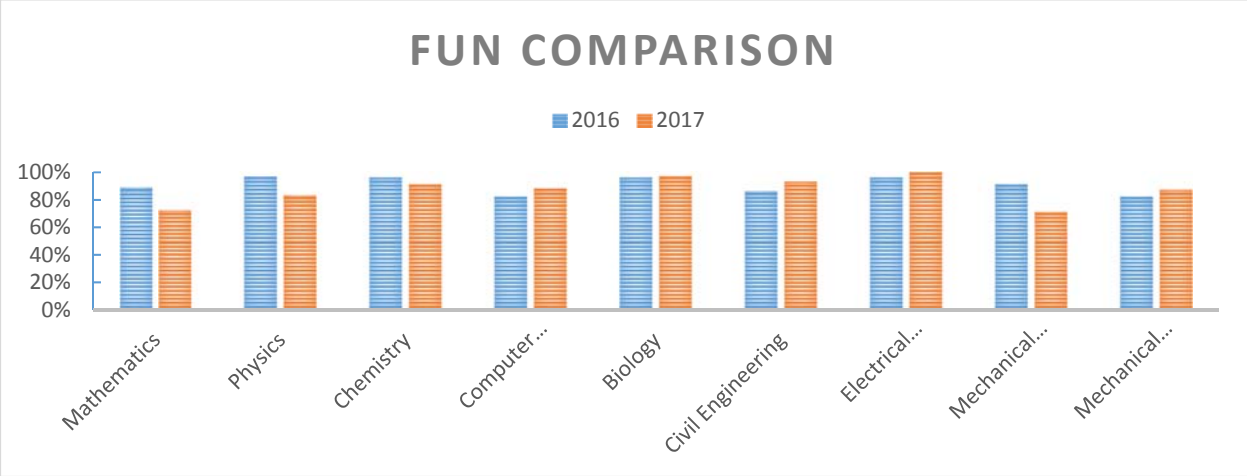
Session	STEM Understanding	Learning	Fun	Material Usability	STEM Interest
Mathematics	88%	88%	72%	91%	63%
Physics	90%	90%	83%	100%	93%
Chemistry	94%	91%	91%	94%	84%
Comp. Sci.	94%	97%	88%	69%	91%
Biology	100%	100%	97%	100%	94%
Civil Eng.	100%	90%	93%	97%	90%
Elect. Eng.	97%	100%	100%	87%	97%
Mech. Eng. 1	87%	81%	71%	97%	81%
Mech. Eng. 2	91%	94%	87%	75%	91%



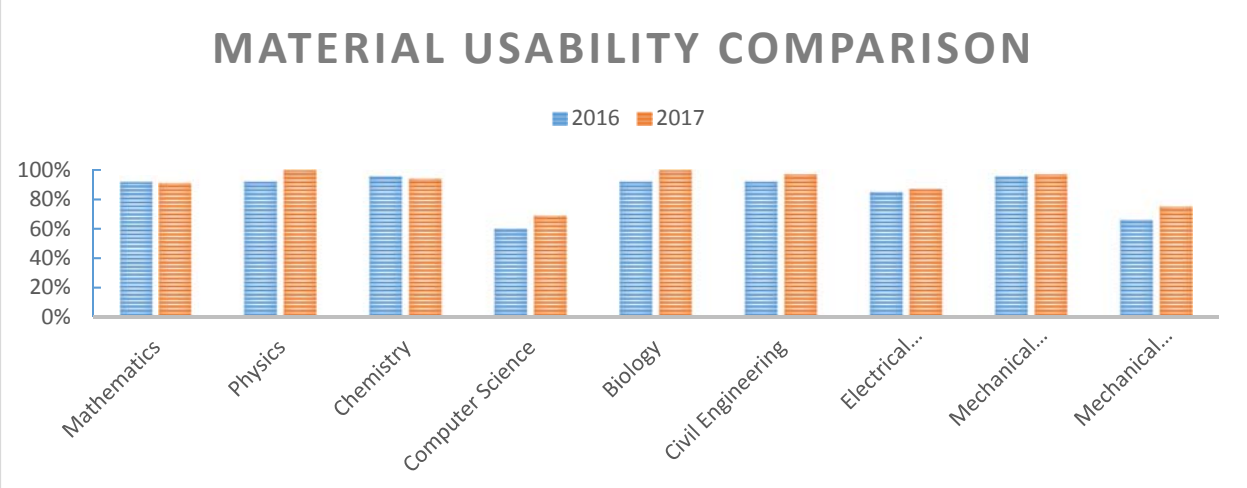
Comparison of 2016 and 2017 results to question #1 found in Appendix A.



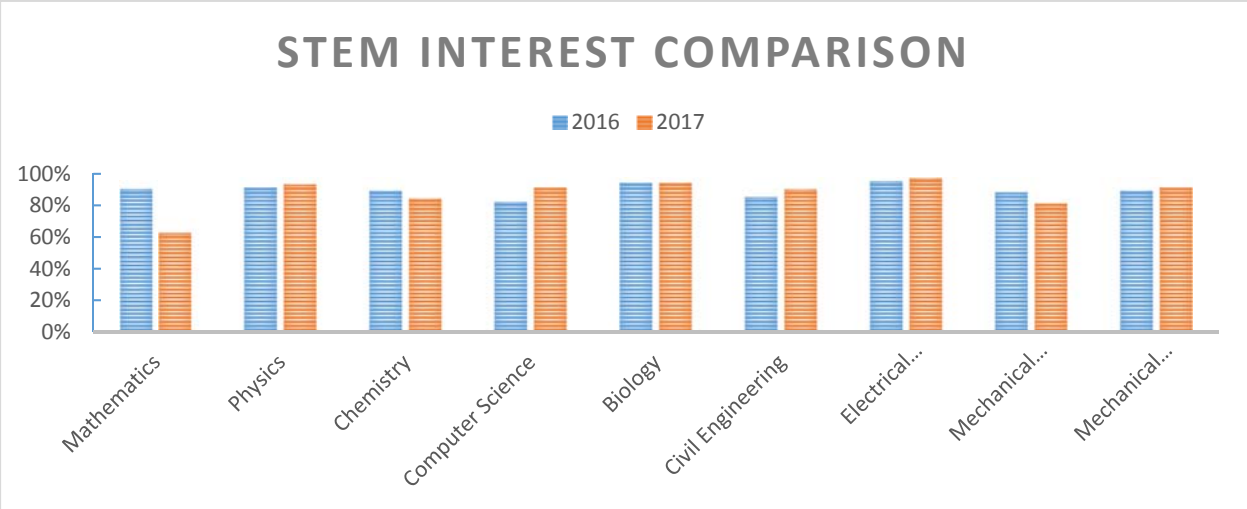
Comparison of 2016 and 2017 results to question #2 found in Appendix A.



Comparison of 2016 and 2017 results to question #3 found in Appendix A.



Comparison of 2016 and 2017 results to question #4 found in Appendix A.



Comparison of 2016 and 2017 results to question #5 found in Appendix A.

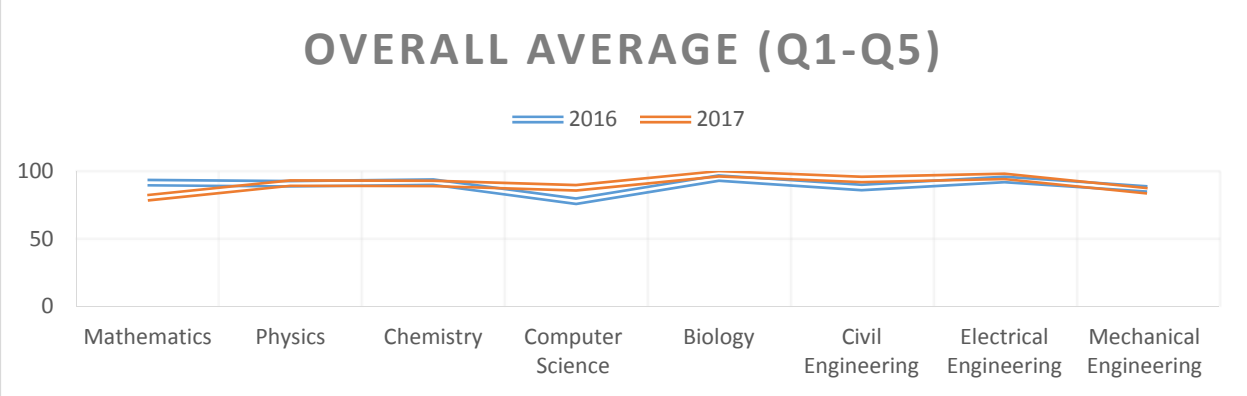
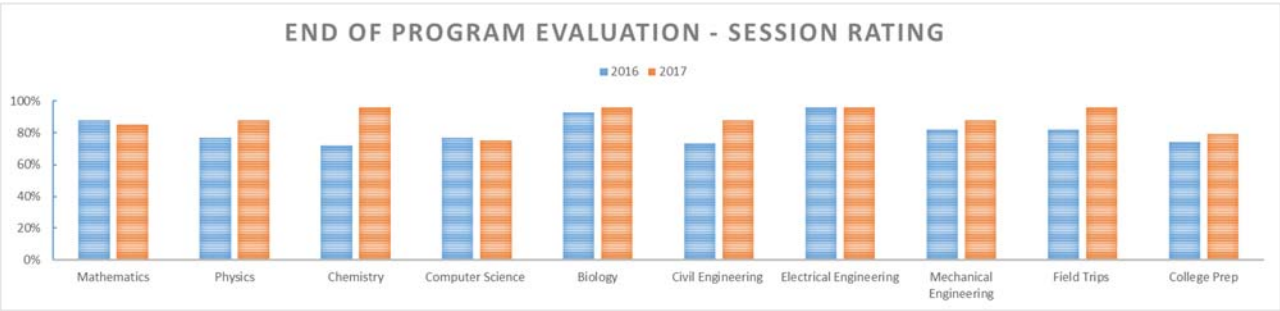
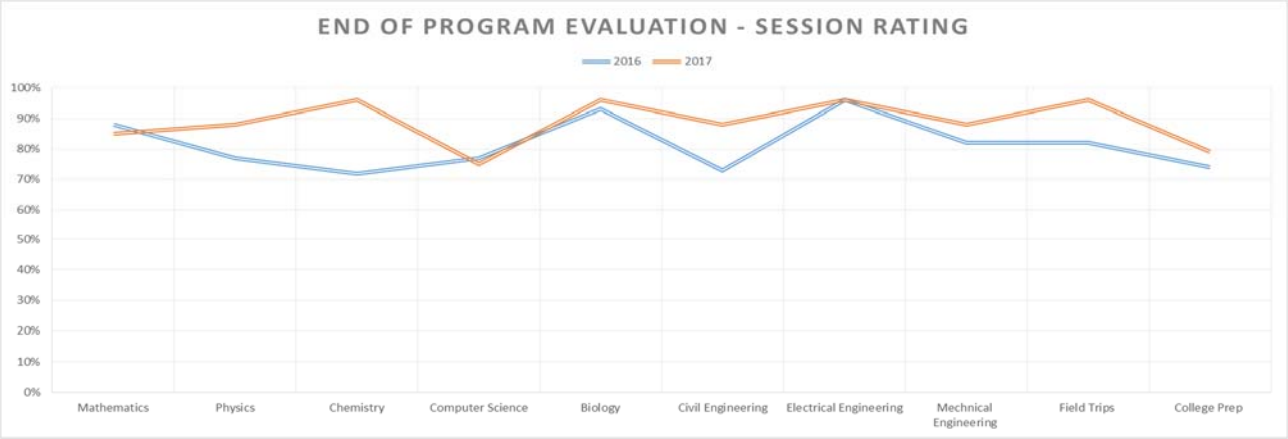


Figure 3. Comparison of 2016 and 2017 results based on averages from questions #1-5 in Appendix A.

Overall Workshop Evaluation

Students provided feedback on the last day of the workshop using the form shown in Appendix C. The results are shown in Fig. 4 below.





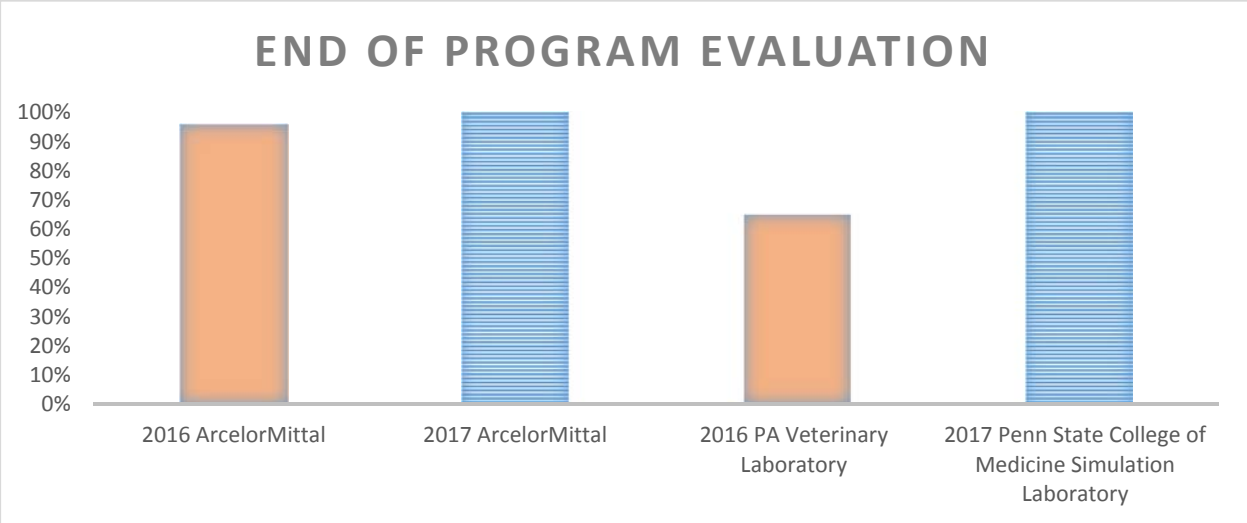


Figure 4. End of Workshop Evaluation

Workshop Evaluation by Faculty & Staff

All workshop sessions were discussed at the end of the day by the program faculty and staff with an eye toward quality improvement. Over the two weeks, daily contact throughout the sessions allowed the program staff to adjust student teams to keep academic and social activities running smoothly. Each instructor had the freedom to choose the material, within their area of expertise, they considered most advantageous to the students. Comments made to the staff and faculty by the students made clear that the topics and associated hands-on activities were pleasing to the students and augmented their previous high school studies or introduced new ideas to them.

These impressions were supported by the evaluation results. The students interacted extremely well together. Friendships blossomed and a “group chat” was started among the students in the first two days. To prevent social interaction from veering too far from the academic topics, purely social interactions were diverted to the short breaks during sessions and lunch; this worked well. These teenagers were so happy to meet a whole group of their peers who shared

their interests and aspirations. The program has been funded for another year. There will be small changes, but overall the program will retain the same structure and focus.

Other summer programs[7, 12-13] report similar enthusiasm from the participants. Those programs also reported that student evaluations of the sessions and experiences received high marks. During the last year, several parents of students communicated that their children are now actively planning on entering an engineering career when previously they had different plans. Data has not yet been collected to evaluate the long-term results for the whole group.

Conclusion

STEM-SEP was successful in achieving its major objectives. Feedback from students shows that the workshop activities were fun and effective in teaching participants about STEM disciplines and career opportunities. Due to the low response on one of the 2016 field trips, a new destination was selected in 2017, which received high reviews. Students mentioned the field trip to the sponsor's steel plant in their final presentation and thanked the company for sponsoring the workshop. Several parents talked to the program faculty and staff during the ice cream social after the closing ceremony on the last day of the workshop and thanked them for a well-organized and successful workshop.

A follow up survey was sent to students who participated in the 2016 STEM SEP cohort as these students have graduated high school. As part of the survey, three questions were asked; 1. Did you pursue post-secondary education?, 2. If you pursued post-secondary education, what did you study and 3. Did your participation in the Penn State Harrisburg STEM Summer Enrichment Program have any impact on your area of study in college or trade school? Of the students who responded, 88.9% pursued post-secondary education with all students choosing a STEM major. 87.5% of students indicated the STEM SEP program had an impact on choosing their field of study.

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Appendix A

STEM-Summer Enrichment Program (STEM-SEP)
June 12, 2017-June 23, 2017
Session Feedback Form

Session:_____

Date and Time:_____

Please complete the following questions:

1. This session added to my understanding of STEM
   __Strongly agree __Agree __Not sure __Disagree __Strongly disagree

2. I learned a lot from this session
   __Strongly agree __Agree __Not sure __Disagree __Strongly disagree

3. This session was fun
   __Strongly agree __Agree __Not sure __Disagree __Strongly disagree

4. Supplies and training materials were easy to use
   __Strongly agree __Agree __Not sure __Disagree __Strongly disagree

5. As a result of this session, I am more interested in STEM
   __Strongly agree __Agree __Not sure __Disagree __Strongly disagree

Please use the following space to write any additional information you would like to share with us regarding this session:

Appendix B

STEM-Summer Enrichment Program (STEM-SEP)
June 12, 2017-June 23, 2017

FIELD TRIP FEEDBACK FORM

Field Trip to:_____

Date: _____

1. This field trip increased my understanding of the operation of laboratory/industrial facilities?

   __Strongly agree __Agree __Not sure __Disagree __Strongly disagree

2. The most important thing I learned from participating in this field trip was:

3. This field trip can be improved if:

4. Overall, this field trip was:

   ___Excellent ___Good ___Fair ___Poor

5. Other comments. _____

Appendix C

STEM-Summer Enrichment Program (STEM-SEP)
June 12, 2017-June 23, 2017
Workshop Feedback Form

Please complete the following questions.

	Excellent	Good	Fair	Poor
6. Rating of individual workshop sessions:				
a) Math Activities	❒	❒	❒	❒
b) Physics Activities	❒	❒	❒	❒
c) Chemistry Activities	❒	❒	❒	❒
d) Biology Day (Biofuels Lab)	❒	❒	❒	❒
e) Computer Science Day	❒	❒	❒	❒
a) Civil Engineering Day	❒	❒	❒	❒
b) Electrical Engineering Day	❒	❒	❒	❒
c) Mechanical Engineering Day	❒	❒	❒	❒
d) Industry Visits/Field Trips	❒	❒	❒	❒
e) Preparing for College Session	❒	❒	❒	❒
f) Project presentations and awards (final session)	❒	❒	❒	❒
7. My overall rating of all workshop sessions is	❒	❒	❒	❒

8. My favorite workshop session was:

_____

Please complete the following questions.

9. I am pleased that I attended this workshop
__Strongly agree __Agree __Not sure __Disagree __Strongly disagree

10. I would recommend this workshop to a friend or sibling
__Strongly agree __Agree __Not sure __Disagree __Strongly disagree

11. Attending this workshop increased my confidence in my ability to succeed in college
__Strongly agree __Agree __Not sure __Disagree __Strongly disagree

12. How could the workshop experience be improved for future participants?

13. What was the best thing about this workshop?

14. What was the worst thing about this workshop?

15. Please provide any additional feedback that you wish to share with the workshop organizers.