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Teaching Fundamentals in Lasers and Light Technology to Advanced Applied Optics in Biology and Biomedical Research: Analyzing the Team-teaching Influence on High School Students' Perception of and Confidence in STEM

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I am a PhD student in Electrical and Computer Engineering Department of Drexel University. I finished my undergraduate and graduate studies in physics. My studies in bachelor was mainly focused on soft condensed matter and complex systems. I worked on a neural network to simulate and model the patterns of spikes in a two and three coupled neural network. In 2012, I joined the Physics program of Stuttgart University joint with Max Planck Institute for Solid State Research and earned my master degree in Germany. My master researched was based on the fabrication and characterization of magnetic metamaterials useful for building up quantum computer devices. I moved to the US in 2016 to study my PhD in electrical engineering. My current research is focused on optoelectronics, fabrication and dynamic analysis of micro-scale light-actuator made of Liquid Crystal Elastomers. I am a fellow of the ExPERT program at Drexel and cooperate with the team as the engineer PhD student.

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Jared Ruddick has been teaching high school science At Girard Academic Music Program in South Philadelphia since 2008. During his tenure, he has made strides to better student's interest in science through educational opportunities provided by partnerships with the Gift of Life Donor Program, Dow Chemical, the University of Pennsylvania, the Wistar Institute, and Drexel University's GK-12 Program. During the 2015-2016 school year, Jared won the Lindback Distinguished Teaching Award and the Harold W. Pote "Behind Every Graduate" Award from Drexel University.

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Jessica S. Ward serves as the Director of Operations for DragonsTeach and the Program Manager for the Experiential Practices in Education Research and Teaching in STEM (ExPERTS) program. During her tenure at Drexel University, Ms. Ward has successfully coordinated with multiple faculty members in the submission of approximately 600 grant proposals, including co-writing, editing and serving as the Program Manager for 8 awarded STEM education grants totaling more than $13M. She has collaborated with University offices, faculty and staff in the facilitation of recruitment strategies to increase the quality and quantity of undergraduate and graduate enrollment in STEM programs. Ms. Ward now manages the day-to-day operations of the DragonsTeach and ExPERTS programs, including supporting the development of programs of study, student and teacher recruitment, fundraising and grant-writing, hiring and supervising staff and student workers as well as coordinating program evaluation.

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Teaching Fundamentals in Lasers and Light Technology to Advanced Applied Optics in Biology and Biomedical Research, Analyzing the Team Teaching Influence on High School Student' Perception of and Confidence in STEM (Work in Progress)

Vahideh Abdolazimi, Jared Andrew Ruddick, Jessica S. Ward, Richard Edward Giduck, Adam K. Fontecchio

Abstract

Laser and light technology has the potential to be the science milestone of the century. The essential use of light and laser technology in designing revolutionary devices such as quantum computers, optogenetic tools, and biomimicking light-actuator microrobots represent the inspiration behind this vision. Therefore, running classroom activities followed by advanced lectures around multidisciplinary research and innovation in optics could serve as an excellent contextual vehicle for increasing K-12 student perception of and confidence in some areas of Science, Technology, Engineering and Mathematics (STEM). In this work, we present a project facilitated in a high school biology classroom during the academic year by a team of ExPERTS (Experiential Practices in Education Research and Teaching in STEM) composed of an engineering Ph.D. student, a biology undergraduate student, and a high school Biology teacher. The team introduces laser and light technology topics related to biological and biomedical applications to high school students through inquiry-based Modules (including associated introductions, activities and assessments) with the goal of increasing student confidence in and understanding of the use of optics in STEM applications.

Results and connections of pre- and post-surveys for each module implemented will be presented.

Keywords: STEM, K-12, Laser and light technology, optics, biology and biomedical research, optogenetics

1. Introduction

Despite the needs and vacancies in STEM professions, universities around the world continue to have difficulties recruiting students interested in pursuing coursework and research in these areas. The number of STEM majors has stopped growing in some countries and in others it has begun to decline. Investigations revealed that science subjects are often viewed by students as too difficult and the presentation of STEM content as unattractive, almost always being delivered through lectures while experimental activities are neglected[1]. This creates a need for educators to pursue more effective and creative ways of teaching STEM. Undergraduate and graduate STEM student are at the forefront of cutting edge curricula and research and have the potential to be a major influence on secondary students' motivation to study STEM fields in and after high school.

This work explores a team of ExPERTS (Experiential Practices in Education Research and Teaching in STEM) composed of an engineering Ph.D. student, a biology undergraduate student pursuing secondary certification, and a high school biology teacher. There are two main reasons that identifies this work as unique; First, the teamwork that requires individuals to be responsible in lesson planning and performance based on their background an expertise; Second, the topic selection of the Module series which is around optics and its implementation in biology and biomedical research, that not only introduces different areas of STEM fields concerning its interdisciplinary nature, but also provides a huge flexibility for the team to introduce exciting biology and biomedical research topics to the students[2-5]. However, the topics are advanced, they are relatively comprehensive for high school levels, because they are based on very fundamental concepts in chemistry, physics, biology and optics that are taught to the students via the primary activities and class discussions. The Modules satisfy various teaching criteria defined by NGSS (Next Generation Science Standards), including but not limited to: structure and properties of matter, chemical reactions, energy, forces and interactions[6].

Modules were performed in a music-oriented urban high school of Philadelphia public district, having grade levels of 5 to 12 with special admissions and acceptance rate of 17.4%. The school has female dominant gender distribution and around 40 percent of the students participate in the National School Lunch Program (NSLP)[7].

Together the team introduced approximately sixty ninth-grade biology students to the fundamentals of optics and how these basics play a significant role in their daily-lives through modules comprised of an activity, lecture and discussion. The goals of this program structure and content are to: 1) improve the students' perception about concepts in STEM; 2) frame the importance and influence of STEM on human life; and 3) motivate secondary students to pursue higher education in STEM fields.

2. Methodology

Modules are planned in a six-step performance structure: including pre-survey, pre-activity, activity, post-activity, lecture, and post-survey. Each activity is performed during one- or two-day sessions lasting approximately forty minutes followed with thirty minutes of lecture and discussions, including displaying videos, student participation and questions. The modules utilize low cost materials and can be replicated in other schools.

Students are asked to complete surveys online prior to the activity session in each module. The activity day begins with a seven- to ten-minute pre-activity which includes brainstorming questions about the use of light and laser technology in everyday life and introductory questions that provide background before heading into the experiment part. Each activity is performed by groups of four to five and is on optics topics that are connected to the ninth-grade biology curriculum. Module topics include: optogenetics, microscopy imaging, bio-mimicking micro-robots, and quantum computer devices for fast biology simulation and modeling.

Following the activity, the graduate student presents their ExPERTise on research in light and laser technology. Through this lecture, they expand the activity that is based on fundamentals of optics to more advanced research discoveries related to both biology and optics and lead a brainstorming session asking student groups to relate their module observations and inferences to the advanced topic. The teacher helps to improve the activity/module plan and modifies it into a more comprehensive lesson based on the students' level of knowledge, as well as co-teaches the lecture. As part of their student teaching for secondary certification and role in the ExPERTS team, the undergraduate student helps run the activities in the classroom and interacts with the student groups during experiments, ensuring that no student is left behind.

Students take notes while doing the activities and listening to the lectures and use them as reminders when answering post-activity homework questions that assess learning and allow students to develop their comprehension of how progressive technology is founded on basic interactions of light. Post-survey questions are mostly a repeat of the pre-surveys, with minor variations and expansions tailored to the topic-specific concepts mentioned during the lecture and discussion to employ the analytical thinking abilities of the students.

3. Module Descriptions

3.1 Module One The first module focused on the basic interactions of white light with diffraction glasses, bulk/transparent objects (triangular and rectangular prisms), and dyed waters in comparison to the interaction of lasers with similar materials. The students were given flashlights, laser pointers of different colors, and various objects to perform the activity and report their observations (Figure 1).

The pre-activity was an introduction to several concepts including light as a wave, the four main interactions of light with materials (absorption, reflection, refraction, and transmission), chemical definition of dyes and pigments, and essential physical rules in laser and beam production. After experimenting with white light and lasers, the students received a lecture by the graduate student on optogenetics, which is about reaction of bacteria to specific light wavelengths and connects the principles that they learned about light to biology content. Videos were displayed during the lecture to allow the students to envision the experimental research environments being described. The lecture transitioned into a class discussion on how accomplishments in this field can improve human health and the new challenges in both optics and materials science that directly affect optogenetics, such as the need to design tunable laser filters that reduce brain damage during experiments.

Figure 1: The experiment materials and optical kit components (left); Students reactions to seeing glowing green water while shining a laser of the same color through it (right).

3.2 Module Two

The second module concentrated on the interaction of white light and laser beams with lenses and magnifiers. In the second part of the activity, students made a microscope using a syringe and a laser pointer. The piston-less syringe was steeped into aquarium water and a laser pointer was shone directly on the droplet stuck in the tip, magnifying the image of bacteria or dust in the water droplet on the screen (a sheet of paper or wall) (Figure 2).

During the pre-activity, students were familiarized with the essential optical principles in lenses and the various effects of different shapes of lenses on the trajectory of a laser beam. After the activity, the lecture began with a brief review on the cohesion and adhesion characteristics of water. Then the optical rules resulting in the magnification of bacteria was animated for the kids to help them visualize the connection between the optical principles in lenses and the water droplet shape that gave them the ability to make such a simple microscope. During discussion, challenges facing biologists when attempting to control light interaction with lenses in nano- or lower scale observations and the significant influence that the optical science can have on biology research and medical treatments was explored. The ExPERTS team used the example of the retina functioning as a lens and described sight disorders related to the deformation of the retina. Videos of how LASIK surgery corrects this issue were shown.

Figure 2: A magnified image of the bacteria and dust in the water droplet stuck in the tip of a syringe

4. Results

Answers given to the multiple-choice questions on the pre- and post-surveys reflect student perceptions about various topics relevant to the activities, lectures and discussions.

4.1 Comprehension and Confidence

Survey questions asked “How much of an expert do you think you are about:” and directed the students to select a response from a 5-point Likert scale based on their comprehension of and confidence in various topics. The 5-point Likert equivalent descriptions are:

1 = I know nothing about the topic
2 = I have heard about the topic
3 = I could describe the topic
4 = I could answer specific content questions about the topic
5 = I could teach someone else about the topic

The corresponding answers to each topic are reported in the Figures 3 and 4 based on the percentage of responders. The overall integration indicates shifting to higher levels of confidence in almost every topic. The data reflects our outstanding ExPERTS teamwork achievements in improving the students' cognition about some of the introduced interdisciplinary fields, namely optogenetics and biophysics, as well as other subjects in optics and laser science.

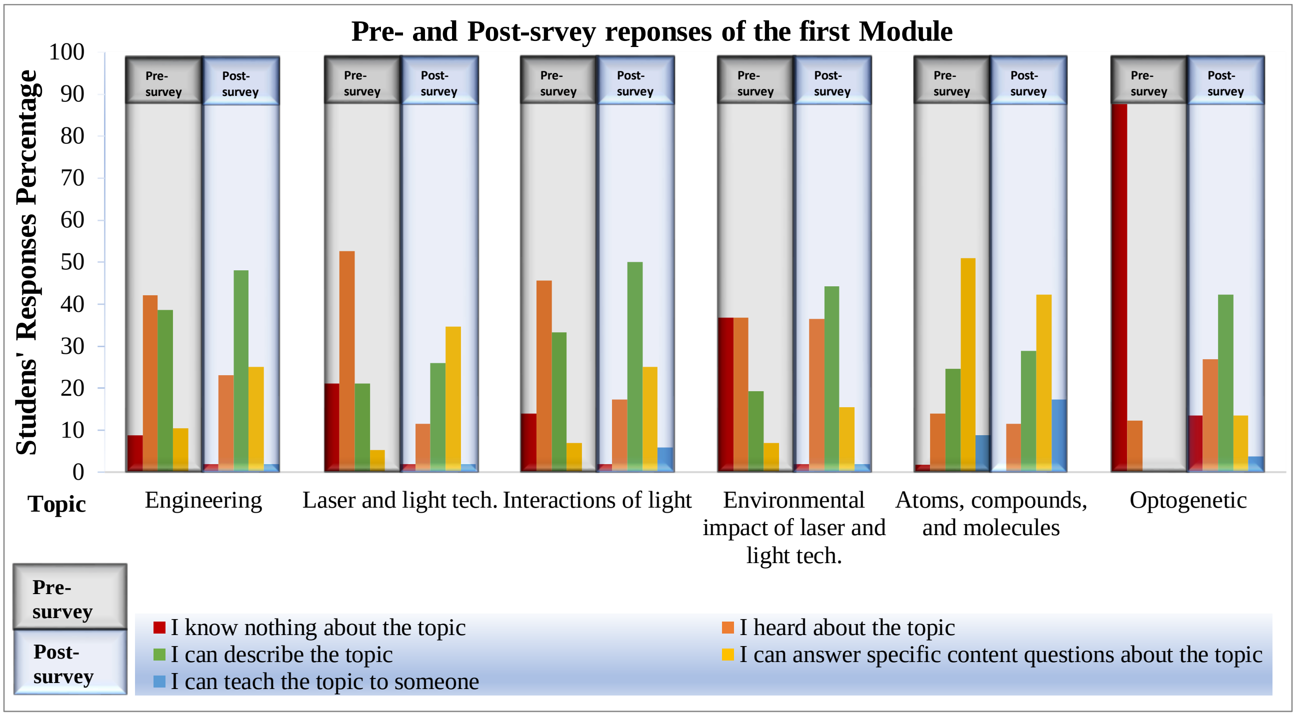

Figure 3: The percentage of the students' pre- and post-survey responses (on a 5-point Likert scale) to questions based on their comprehension about each topic explored in Module One (total responders in pre-survey: 57 and in post-survey: 52).

4.2 Uses of Laser and Light Technology

In a multiple-choice question, students were asked to identify as many of the National Academy of Engineering (NAE) Grand Challenges that they think are possible to be resolved or improved by scientists or engineers with the use of laser and light technology (Figure 5). The areas included: Making Solar Energy Economical, Providing Energy from Fusion, Developing Carbon Sequestration Methods, Managing the Nitrogen Cycle, Providing Access to Clean Water, Restoring and Improving Urban Infrastructure, Advancing Health Informatics, Engineering Better Medicine, Reverse Engineering the Brain, Preventing Nuclear Terror, Securing Cyberspace, Enhancing Virtual Reality, Advancing Personalized Learning, Engineering the Tools for Scientific Discovery.

The answers exhibit a gradual movement from the use of laser and light technology in "Solar Energy" and "Enhancing Virtual Reality" in the pre-survey to post-survey responses of "Engineering Better Medicine", "Reverse Engineering the Brain", and "Engineering the Tools for Scientific Discovery". This expresses the success the ExPERTS team had in introducing the use of laser and light technology to the students and the importance and advantages of optics in improving biological research, medical tools, and consequently the quality of life. The movement also showcases success in elevating the students' perception about engineering and their knowledge about the implementation of fundamental optics to advanced biological and biomedical related topics.

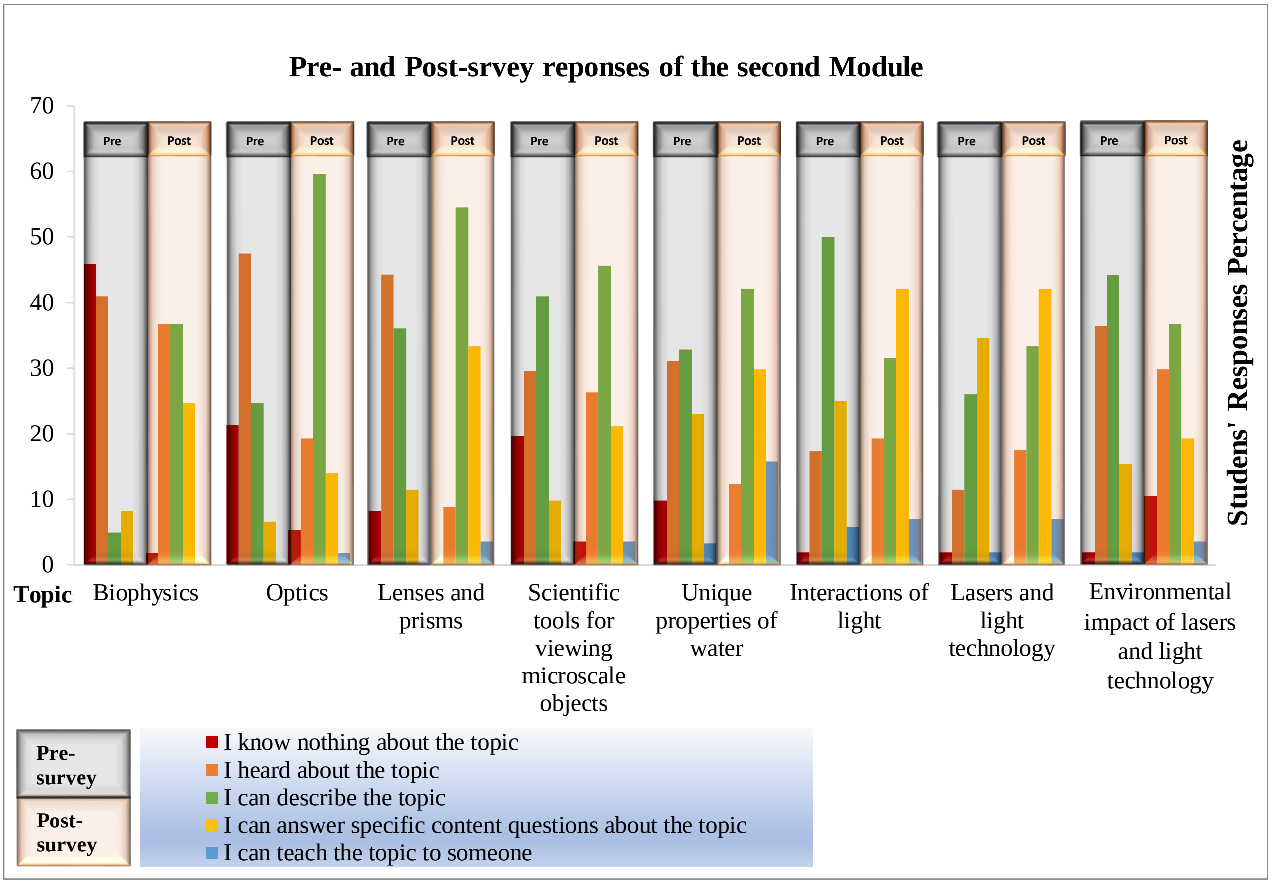

Figure 4: The percentage of the students' pre- and post-survey responses (on a 5-point Likert scale) to questions based on their comprehension about each topic explored in Module 2 (total attendees in pre-survey: 61 and in post-survey: 57).

4.3 Open-ended Questions

Students were requested to give evidence of how laser and light technology can improve the areas that they selected in the NAE Grand Challenges question. In the pre-surveys the answers described broad uses of lasers and light. Conversely, In the post-surveys the students frequently supported their choices by explaining the advantages of lasers as a tool in optogenetics discoveries and how it can resolve health problems. They also gave examples of improving surgical tools to do future operations with fewer side effects. These responses display their progress from conjecture to evidence-based understanding.

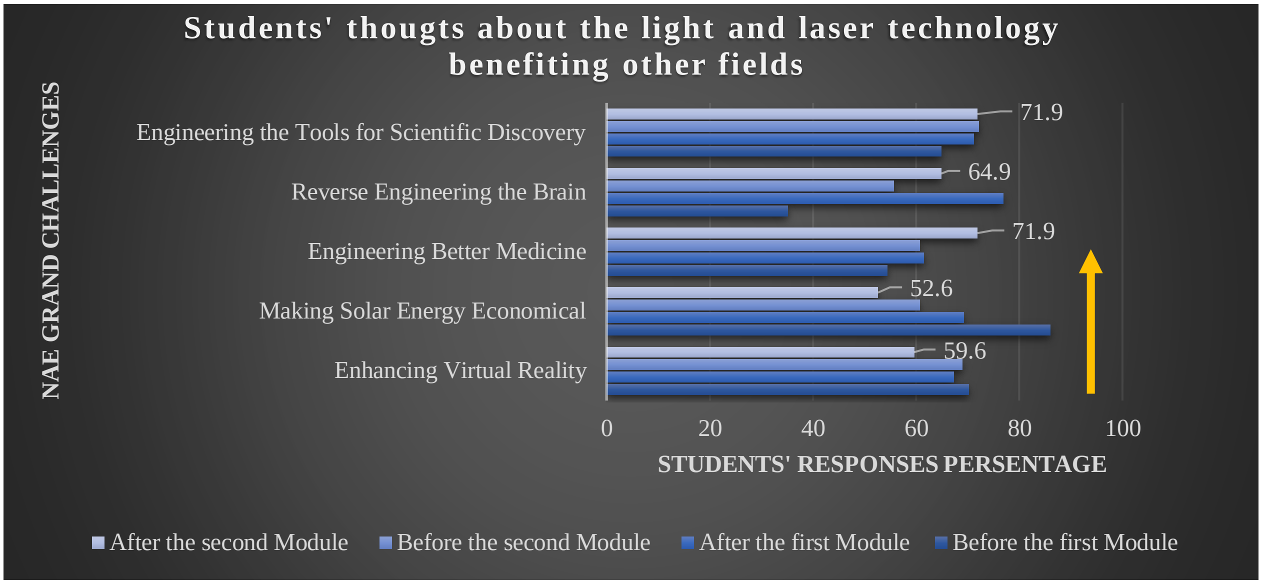

Figure 5: The results of students' thoughts about the fields that would benefit from the use of light and laser technology; the arrow shows the gradual trend toward the biology and biomedical advanced challenges.

In an open-ended question for surveys associated with Module One, students were asked about the roles of laser and light technology in everyday life. In the pre-survey, most responses were centralized around its use in phones and flashlights. Some students noted agriculture, food production or traffic lights. In the post-survey, students more frequently gave examples about the use of light and lasers in medical treatments. Some mentioned ultraviolet light and heat technology as well identified light as a wave. This suggests that they learned additional needs of light and lasers, such as in medical care, through Module One.

In the Module Two we asked some introductory questions about lenses, including the definition of a lens, describe shapes of lenses, and an example of a device which works with lenses. Collected responses confirmed that the students recognize lenses as glass shaped objects that are used in cameras and eye care. Some also noted their effect on the geometry of light rays and magnification capabilities. Based on the post-survey responses to the same questions, we discovered the students' scientific knowledge about lenses enhanced through participation in Module Two; for instance, some students described other characteristics of lenses, such as transparency, and named lens shapes as concave and convex. Moreover, they mentioned lens effects on laser beams, such as refraction or concentration when used in microscopes. This suggests increased understanding of lenses, their technical uses and other optical concepts.

In another question, we asked students to think about the future (year 2042) and wanted them to describe how they think lasers and light technology will evolve or be utilized in daily life. The pre-survey answers covered a wide range of areas such as expecting enormous changes in surgery, transportation, weapons, secured systems and identifying criminals. Furthermore, we noticed comments saying, "I do not know how to answer this question". In the post-survey, however, most of the responses were concentrated on the use of lasers in optogenetics such as helping people to stop smoking, resolving blindness/deafness, curing paralyzed patients, fixing nerve damage, helping disabled people to move, and redeeming mental illness. This shift in students' attention to the use of lasers in the future for research and discoveries in optogenetics and reveals our success in conveying this topic to them during the Modules.

These were some of the findings that we investigated through analyzing the pre- and post-surveys data. Further investigations and discussions to support our teamwork achievements requires performance of the next modules and applying statistical analysis on the recorded responses.

5. Conclusion

The ExPERTS team comprised of an engineering Ph.D. student, biology undergraduate student and biology high school teacher aims to provide students with a well-rounded understanding of geometrical, physical, and visual principles in optics and its practical applications in biology and biomedical science. This is mainly accomplished through well-structured Modules (pre-survey, pre-activity, activity, lecture, discussion, and post-survey) focused on telling a story that connects the fundamentals of optics, biology, and chemistry to advanced topics in STEM research areas. Pre- and post-survey results show increased knowledge of and confidence in laser and light technology as well as improved analytical and reasoning skills.

6. Future Work

According to the success of the initial work reported in this paper, several more Modules will be implemented in the 2017-2018 academic year and the ExPERTS team will apply statistical analysis of the recorded responses. We believe this success is mostly based on the lessons structure and teamwork performance as well as topic selection. Topics cover a wide area of science and technology related to advanced biology and biomedical research that not only motivates the students about biology and the introduced STEM fields but also helps them to achieve a better understanding of the biology fundamental lessons.

Additional surveys will be administered before the fourth Module and at the end of the seventh Module to gauge student interest in pursuing higher education in STEM fields due to their experiences working with the ExPERTS team which will help us to track more details about the advantages of this work and the areas of improvement to be considered in the next year of the program (2018-2019).

7. Acknowledgement

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