An outreach program with hands-on, physiology-based exercises generates questions about STEM career expectations

Clarke MA, Sharma NM, Schiller AM. An outreach program with hands-on, physiology-based exercises generates questions about STEM career expectations. Adv Physiol Educ 43: 175–179, 2019; doi:10.1152/advan.00013.2019.—Scientific advocacy and outreach programs are encouraged to increase public understanding of scientific knowledge and generate interest in science, technology, engineering, and mathematics (STEM) careers. However, evaluation of these events’ effectiveness is difficult and somewhat rare. This study’s purpose was to better understand how effective an established physiology-based outreach program was in generating interest in STEM careers, while simultaneously providing information that can be used to increase the effectiveness of future events. We partnered with a private school located in Omaha, Nebraska, where 64–80 students participated in 3 h of physiology-based activities presented by volunteers from the University of Nebraska Medical Center. The event included a brief presentation of the eye, sensory, heart, and lung systems, followed by hands-on demonstrations and activities. Each session concluded with 15 min of questions and answers (Q&A), where students were encouraged to engage the volunteers in inquiries about what they just learned, career-related questions, or any topic of their choosing. Each Q&A session was audio recorded and evaluated using thematic analysis to identify patterns in the Q&A data. Two major themes of questions were identified: 1) scientific content (animal circulatory systems and how organs are affected by disease or stimulus); and 2) career-related content, including typical day-to-day activities of a scientist and the volunteers’ satisfaction with a scientific career. We conclude that hands-on physiology-based learning opportunities are effective in generating short-term interest in STEM content and careers. The results of this study will also facilitate informed modification of event content to better suit student’s interests.

education; outreach; physiology; STEM

INTRODUCTION

The Evaluation of STEM Outreach

Despite high concern over the current interest in science, technology, engineering, and mathematics (STEM) careers and encouragement from professional societies, universities, industry, and government laboratories for scientists to participate in scientific outreach events (13), there is minimal evidence of a large-scale change in the interest in STEM careers. For example, the results of the American College Testing (ACT) annual “Condition of STEM” report indicates that interest in STEM education for high school graduates within the United States has not increased in the past 5 yr. In 2012, 48% of ACT-tested high school graduates had an expressed and measured interest in STEM education, and this percentage was the same in 2017 (1). Funding for STEM education has remained stable during this time, with $3.1 billion spent in 2010, compared with $2.9 billion in 2016 (20). This information highlights the importance of effective evaluation of outreach programs in meeting their desired goals; for both financial (20) and social reasons (16). Hands-on and active learning approaches, typical of many outreach events (11, 17), show an increase in cognitive retention of learned concepts (8, 12, 15). However, this does not necessarily translate into long-term interest and pursuit of STEM careers. Event assessment, although rare and with many challenges (13, 20), can serve to improve the effectiveness and better achieve the goals of STEM outreach.

The objective of our study was to understand better how effective an established physiology-based outreach program was in generating short-term STEM career interest, while simultaneously providing information that could be used to increase the effectiveness of future outreach events. We evaluated our objective using a qualitative research methodology, as opposed to a quantitative research methodology, to understand the best approaches to tailor our future physiology-based outreach events to most effectively meet our outreach goal.

METHODS

Research Approval

The University of Nebraska Medical Center (UNMC) Institutional Review Board (IRB) determined that the evaluation of our outreach event was considered a program evaluation and did not constitute human subject research, as defined by 45CFR46.102, subpart A: basic U.S. Department of Health and Human Services Policy for Protection of Human Research Subjects. IRB approval was unnecessary.

Student Safety

The activities included in the outreach event were discussed with the students’ teachers before the event, during the planning stage. The teachers’ provided permission for students to participate in the suggested physical activities. Additionally, students were invited to participate in the activities on a volunteer basis; participation was not mandatory.

Volunteer Instructors

Volunteers from the Cellular and Integrative Physiology, Anesthesiology Departments and Division of Cardiovascular Medicine at UNMC served as volunteer instructors. Recruitment e-mails were...
circulated within each department requesting their involvement in the outreach event. Volunteers included three faculty members, five postdoctoral research associates, three graduate students, and one research technologist. Materials (PowerPoint presentations, activity equipment, supplies, specimens) and curriculum were provided to the volunteers for the event. Before the event, two volunteer meetings were held to plan and familiarize the volunteers with the material and event sequence. Volunteers had various levels of previous outreach experience. A seasoned volunteer served as a “float” and monitored each of the four classrooms to ensure each was running as planned and assisted with the event on an as-needed basis.

Outreach Participants

We partnered with a private K–8 institution located in the greater Omaha, NE area. Between 16 and 20 students from four classrooms (grades 6–8) participated in 2.5 h of physiology-based activities. There was one teacher for each of the four classrooms present.

Event Schedule

The outreach event took place on a single day, 8:15 AM to 10:45 AM, during regular school hours with the student’s regular teacher present. Four classrooms participated in the event concurrently: two rooms focused on heart and lung activities, whereas the other two rooms focused on eye and sensory activities. Each classroom had two stations with hands-on activities in which all students participated. After 1 h and 10 min, the student groups that participated in eye and sensory activities rotated to another classroom that focused on heart and lung activities, enabling each student to participate in all of the activities offered.

Each session began with a brief introduction from the student’s teacher informing them that “special guests” from UNMC would be teaching and presenting hands-on activities. The volunteers then introduced themselves by name, gave a brief description of what type of research field they worked in, and their role in the research. Next, a short (10–15 min) PowerPoint presentation was given by the volunteers introducing the students to basic physiology and anatomy concepts of either the heart and lungs or eyes and sensory system, depending on which classroom the students were in at the time. The PowerPoint presentations were a mixture of didactic physiology-based content and question and answer. A set script was not provided for the instructors. Instead, material previously created with the help of an educational professional and used in past outreach events was used (3). PowerPoint slides were used to outline the select elements of each organ system to be presented to the students and as a guide to keep instructors on track during the presentation. The instructors were provided with material and “coached” during the planning sessions on how to interact with students during the hands-on activities. Next, the students rotated within their classroom to two stations related to the lecture material. Students spent ~15 min at each station. Finally, the students were invited to participate in a recorded question-and-answer (Q&A) session.

Event Content

The PowerPoint presentations and hands-on booth activities used were created for a similar event and are freely available for download (3). The activities, which utilized a previously established physiology-based curriculum and activities (3), are described in brief below.

Heart and lungs. The didactic material covered the basic anatomy and function of the heart, lungs, circulatory system, sounds of the heart, and a high-level overview of the nervous system that controls these systems. A preserved sheep heart was used to show the anatomy of the chambers of the heart. A bicycle pump was used to lightly inflate preserved sheep lungs and to discuss the importance of lung alveoli. Students wore gloves and were invited to touch the preserved specimens. Students volunteered to participate in an activity where they increased their heart rate with exercise (jumping jacks and running in place), with discussion about the underlying physiological mechanisms responsible for these changes. Students volunteered to participate in a diving reflex activity where a heart rate monitor was used to record students’ change in heart rate when their face or forehead was submerged in water.

Eye and sensory system. Didactic information on the anatomy of the eye, including the tapetum lucidum, cone and rod cells, mechanisms of eye fatigue, the somatosensory cortex, and broad function of the brain was presented. To demonstrate the effect of negative afterimage, students were shown an image of an American flag with contrasting colors. After fixing their gaze on the image for 30 s, they were directed to change their view to a blank, white wall where the negative afterimage of an American flag with its traditional colors was visible. Students were then able to view an eye dissection and touch the dissected specimen with a gloved hand. To participate in the sensory perception activity, students were paired with another student and conducted a guided two-point discrimination test using a paperclip on areas of different sensory perception, such as the hand and arm.

After the hands-on activities, the students returned to their assigned classroom seats and participated in a Q&A session.

Q&A Session and Data Collection

Each classroom session ended with 15 min of Q&A that allowed students to engage the volunteers in inquiries about what they just learned, science as a career, or any topic of their choosing. All students were encouraged to ask and answer questions. Each Q&A session was audio recorded with permission from the classroom.

Fig. 1. Final thematic map, representing the strong themes identified through thematic analysis.
Table 1. Representative quotes of experiment-based themes identified from thematic analysis

| Supporting Quotes |
|-------------------|
| Experiment-based theme: Animal circulatory systems |
| “Do bugs have the same heart as we have?” |
| “What animal has the biggest heart?” |
| Experiment-based theme: Conditions affecting various organs |
| “When you exercise, why does a heart beat faster?” |
| “Does your heart rate depend on what altitude, like higher or lower or at sea level?” |
| “When you are snorkeling, with the tube above the water, will your heart rate still slow down even though you can breathe?” |
| Lungs |
| “What exactly does bronchitis do to the lung?” |
| “When we pumped the air into the lung, why did it start turning white when you did that?” |
| “If a person’s lungs collapsed, does half of their lungs still expand like that?” |
| Eyes |
| “If you have one eye one color and the other a different color, like I do, does that affect the way you see?” |
| “Depending on your eye color, can certain eye colors see better than others?” |
| “When people are color blind to specific colors, how does that work inside the eye?” |
| “Can animals, like humans, have one eye different in color than the other?” |

RESULTS

General

When prompted during the Q&A sessions, students were able to correctly identify the different parts of the eye, anatomic features of the heart and lungs, and the sensory system. Sixty-six percent of the questions (60 questions) were based on the experiments conducted, and 24% (19 questions) were career-based questions. Fifty-four percent of students’ questions were about the heart, 24% were about the eyes, and 11% were about the lungs.

Experiment-based Themes

Animal circulatory systems. The hands-on activities and experiments generated more student questions compared with the didactic information presented. In other words, students asked more questions that were related to the activities and experiments than the lecture material. Students’ were interested in heart, lung, and eye sizes, and the types of heart in other living things (Table 1).

Conditions affecting various organs. There was also interest in scenarios that affected heart rate and the effects of infection and respiratory conditions on the lungs. They also were interested in the expansion of the lungs after injury. Concerning the eye, students were interested in how eye color and color blindness affects vision. Students were also interested in the eye color of other species.

Career-based Themes

Scientist job functions. Career questions accounted for 35% of students’ questions (Table 2). Students asked multiple questions related the typical day-to-day activities of a scientist.

Job satisfaction. Volunteers were asked multiple questions about their satisfaction working in the science field.

DISCUSSION

STEM outreach programs, when assessed (16), are commonly done so by examining the comprehension of presented scientific content and short-term interest in STEM careers, as measured in terms of enthusiasm or excitement generated the day of the event (6, 7, 18, 21). Understandably, long-term interest in STEM careers is much more difficult to assess methodologically and has changed little, despite increased awareness nationally (1).

Our results show that our outreach event was effective in generating questions about physiology-related content and the daily activities of scientists. We interpret this as the generation of short-term interest in STEM careers among the students.

Table 2. Representative quotes of career-based themes identified from thematic analysis

| Supporting Quotes |
|-------------------|
| Career-based theme: Scientist job functions |
| “What exactly do you guys do every day?” |
| “Are you guys still in school or do you do teaching?” |
| Career-based theme: Job satisfaction |
| “What is your favorite part about working in the science field?” |
| “Are there any days that you just wish you could have a different job?” |
Evaluating the Effectiveness of Outreach Activities

Both qualitative and quantitative methods play essential roles in evaluating outreach activities. Traditionally, quantitative measurements are the standard used to evaluate content comprehension and enthusiasm for events largely because they are simpler to obtain, interpret, and disseminate (13). However, quantitative research methods are inadequate at capturing students’ thoughts about what activities they liked, did not like, or had an interest that was not addressed. Quantitative methodology can provide evidence for the occurrence of an event, but is not an appropriate mechanism to provide context and answer the “why” of an occurrence. For example, by choosing only to provide a quantitative evaluation of the comprehension of didactic material, we would have been unable to identify gaps in student understanding, such as the students’ ability to translate the knowledge of physiology concepts and related hands-on activities into an interest or understanding of STEM careers.

Qualitative Data: Current Event Evaluation

The hands-on activities at our event generated more student questions compared with the didactic scientific material. The majority of students’ questions centered on the heart and lungs and how different scenarios, including ones not presented or discussed, would affect heart and lung function. The data collected gave us the ability to recognize gaps or curiosities in the students’ understanding, based on the question content. We were also able to see where the outreach activities generated an increased number of questions, indicating increased interest. Students had many questions about the day-to-day activities of a scientist, highly suggesting that the outreach event did not adequately address this knowledge gap.

Future Hypothesis Generation from Gathered Qualitative Data

One of the goals of using a qualitative research approach was to gain an enhanced understanding of our established outreach program and generate a testable, high-quality, relevant hypothesis for future research. Based on the results of this study, future outreach events where generating interest in STEM careers is a goal should consider the importance of translating the hands-on activities of an outreach event to the job experiences of a scientist. Outreach events should not solely focus on comprehension of educational material that likely generates only short-term interest in STEM careers.

Scientific Outreach Goals

Clearly defined goals and measurable objectives are necessary for program evaluation to determine a program’s success. A program evaluation also provides insight on what metrics could be improved (4). If the program goal is to generate interest in science as a career, then our data suggest that activities should provide students with an inside look into what it means to be a scientist. A common outreach event model is to focus heavily on the presentation of educational and scientific content through short-term, hands-on, “scientist in the classroom” type experiences (13), with an events’ success evaluated on the comprehension scientific content-based material (9, 22). Students enthusiastically enjoy these experiences (7, 19), and there are significant benefits for the presenters, including increases in professional, communication, and teaching skills (5, 14). However, there may be no benefit to students in terms of long-term interest in STEM careers (1), a difficult-to-assess parameter, given the scope of many outreach programs.

Furthermore, our data suggest that students are not naturally able to translate how learning the anatomy of the heart, even with interactive and hands-on approaches, would apply to a career as a scientist. Duplicating information taught in school or that is available online at an outreach event is not necessarily an effective way to generate interest in STEM or in future STEM careers (10). Filling this gap could be a unique role for professional societies by being more cognizant of the way outreach is conducted, with a defined and measurable goal in mind. As an example, an event with a goal of increasing scientific knowledge would appropriate the use of very different curriculum and evaluation metrics in comparison to an event designed around a goal of increasing long-term STEM career interest.

Conclusion

We conclude that physiology-based outreach events are effective in generating questions about didactic physiology-based content presented and the daily activities of those involved in STEM careers. Future physiology-based outreach events designed to increase interest in physiology-based careers should include a more significant focus on the interaction of STEM career professionals, to satisfy student interest.

ACKNOWLEDGMENTS

We acknowledge Ryan J. Adam, Juliana Bezerra, Juan Hong, Sharon Morais, Kristina Pravoverova, Tara L. Rudebush, Julia A. Shanks, Bangchen Wang, Lu Qin, and Zhijiu Xia for volunteering time and participating in the outreach event.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

M.A.C. and A.S. conceived and designed research; M.A.C. and A.S. performed experiments; M.A.C. and A.S. analyzed data; M.A.C. and A.S. interpreted results of experiments; M.A.C. and A.S. drafted manuscript; M.A.C., N.M.S., and A.S. edited and revised manuscript; M.A.C. and A.S. approved final version of manuscript; A.S. prepared figures.

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