HOW WE TEACH | Classroom and Laboratory Research Projects

A day of immersive physiology experiments increases knowledge and excitement towards physiology and scientific careers in Native American students

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Becker BK, Schiller AM, Zucker IH, Eager EA, Bronner LP, Godfrey M. A day of immersive physiology experiments increases knowledge and excitement towards physiology and scientific careers in Native American students. Adv Physiol Educ 41: 137–144, 2017; doi:10.1152/advan.00165.2016.—Underserved minority groups are disproportionately absent from the pursuit of careers in science, technology, engineering, and mathematics (STEM) fields. One such underserved population, Native Americans, are particularly underrepresented in STEM fields. Although recent advocacy and outreach designed toward increasing minority involvement in health care-related occupations have been mostly successful, little is known about the efficacy of outreach programs in increasing minority enthusiasm toward careers in traditional scientific professions. Furthermore, very little is known about outreach among Native American schools toward increasing involvement in STEM. We collaborated with tribal middle and high schools in South Dakota and Nebraska through a National Institutes of Health Science Education Partnership Award to hold a day-long physiology, activity-based event to increase both understanding of physiology and enthusiasm to scientific careers. We recruited volunteer biomedical scientists and trainees from the University of Nebraska Medical Center, Nebraska Wesleyan University, and University of South Dakota. To evaluate the effectiveness of the day of activities, 224 of the ~275–300 participating students completed both a pre- and postevent evaluation assessment. We observed increases in both students self-perceived knowledge of physiology and enthusiasm toward scientific career opportunities after the day of outreach activities. We conclude that activity-based learning opportunities in underserved populations are effective in increasing both knowledge of science and interest in scientific careers.

Recent attention has focused on improving the recruitment and retention of underrepresented minority groups into science, technology, engineering, and mathematics (STEM) fields (8, 9, 15). Although indications of improving inclusion of minority groups in STEM fields have been observed, significant discrepancies continue to exist. Many scientific societies have designated outreach programs and goals focused on increasing exposure to science and scientific careers to the general population, often with a particular focus on serving underrepresented populations.

Native Americans are particularly poorly represented in STEM fields. According to data from 2014, only 0.3% of doctoral degrees awarded in life science fields were conferred upon Native Americans in the United States, although they represent a 2% share of the total population (6, 11). The geographical location of the University of Nebraska Medical Center (UNMC) within close proximity to numerous Native American reservations allows for an excellent opportunity for collaboration with tribal middle and high school educators to supplement current classroom endeavors with scientist-facilitated activities and exposure to scientific careers. To that end, UNMC holds a Science Education Partnership Award (SEPA) from the National Institutes of Health entitled “Building Bridges: Health Science Education in Native American Communities.” This SEPA brings together UNMC and the Great Plains Area Tribal Chairmen’s Health Board for the expressed purpose of supporting partnerships to improve K–12 understanding of science and science/health-related career opportunities. The current and prior SEPA-sponsored activities have been previously used with a large effect toward increasing exposure of Native American school students to aspects of scientific inquiry and health care (22).

Although nontraditional and active learning strategies have been demonstrated effective in secondary and medical education (12, 18, 19), there have been few published evaluations of the effectiveness of hands-on physiological activities in middle and high school student populations. We therefore sought to evaluate the effectiveness of active learning strategies in increasing understanding of physiology in this age group. Additionally, very little is known about the efficacy of these activities among underserved minority groups in increasing knowledge of science and exposure to scientific career opportunities.

Through the resources afforded by SEPA and the American Physiological Society, we partnered with local area tribal middle and high schools to provide a day of hands-on activity-based learning of various physiological concepts. Our primary goals of the day were to increase understanding and exposure to physiology along with increasing familiarity with and interest in scientific careers. To accomplish these aims, we recruited

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biomedical scientists and trainees from various scientific or health care-related programs from UNMC and the University of South Dakota and developed a printed resource to guide students and volunteers through the activities. We assessed the efficacy of the day through assessments completed before and after the day of activities. Overall, we found that the activities and interactions with scientists increased students’ understanding of physiology and interest in scientific career opportunities.

MATERIALS AND METHODS

Institutional Review Board

All protocols for collecting metrics during the day of activities were approved by the Institutional Review Board of the UNMC (Omaha, NE). Students assented to completing a survey before beginning the day of activities and afterward. All materials were collected anonymously and devoid of any identifying information (name, school, tribe, etc.) and were later transferred to a digital format.

Educational Problem

Although studies have examined the effect of outreach events to underserved populations in increasing participation and interest in health care-related occupations (17), relatively little is known about the effectiveness of short-term outreach experiences in improving knowledge of physiology and creating interest in scientific careers, and even less is known about these efficacies in underserved minority populations. Here, we designed an assessment during a day of hands-on physiology experiments intended to evaluate the effectiveness of the activities toward these ends.

Preparation of a Day’s Activities

We selected a number of areas of general physiology in which we and others had previously designed and administered related activities (14, 20, 21). These areas included cardiovascular, respiratory, digestive, sensory, musculoskeletal, vision, and neuronal physiology. We developed a resource booklet with general background information suitable for middle and high school comprehension levels. The booklet also contained instructions for the activities and an experimental logbook to document the experimental findings. Student participants were encouraged to use the resources provided in the booklet and a brief introduction by the volunteers to formulate hypotheses, test those hypotheses through the activity, and then record their results in the logbook (4). Creation of this comprehensive resource allowed us to recruit and use volunteers with little teaching and outreach experience and interactions with scientists increased students’ understanding of physiology and interest in scientific career opportunities.

Details of Activities

Indepth details of each activity along with background information and worksheet/logs can be found in the aforementioned booklet. The following are brief details of the methods and structure of each activity and specific details not mentioned in the booklet.

Heart rate and heart sounds. Students were given a brief cardiovascular physiology lesson and taught how to palpitate carotid pulse for measurements of heart rate. They then recorded their heart rate before and after various activities, such as running, lying down, standing after lying down, and jumping jacks. Colored duct tape was used to make running “lanes” or “boxes” to perform jumping jacks in. Eager competition and participation among students was greatly encouraged. Some volunteers had their blood pressures measured using Vernier LabQuest devices. Two preserved sheep hearts (one sectioned heart and one intact heart) were provided for students to observe and handle.

Lung capacity and respiration. In this activity, we provided two sets of preserved sheep lungs with intact bronchioles and trachea. Students inflated the lungs with a bike pump to observe the expansion and elasticity of the lungs. Students also examined the concepts of tidal volume, expiratory reserve, and vital capacity by inflating and measuring the volume of balloons.

Digestion. We used digestion as an avenue for describing aspects of comparative physiology by having students match various “fecal” samples with a picture of the appropriate animal. Fecal material was created using different candies that resembled the appropriate animal. For instance, rabbit feces were chocolate-covered raisins, deer droppings were malted milk balls, mouse droppings were chocolate sprinkles, and bat dung was represented by raisins that had been rolled in glitter to mimic the insect exoskeletons that appear shiny. Students also examined the concept of emulsification by adding 1 ml of water to 1 ml of vegetable oil in a conical tube and observing how difficult it was to get into solution. They then added a small amount of “bile salts,” which was powdered dish detergent, into the tube of oil and water and observing how they mixed well after the addition of an emulsifying agent.

Temperature sensing/muscles. Students learned about temperature sensing by placing one hand in a container of cold water and the other in a container of warm water. After 2 min, they moved both hands into a container of room temperature water and described the sensation. Students also demonstrated muscle action and fatigue by counting the number of times they could squeeze a stress ball in 20 s. They then immediately repeated the squeezing action for nine additional trials and recorded the number of squeezes they were able to make in the final trial.

Eye dissection. Only high school students participated in the eye dissection. After a brief introduction to vision, students worked in pairs to dissect a preserved sheep eye and were instructed to attempt to identify and describe the function of as many structures as they could.

Diving reflex. We used a Vernier LabQuest heart rate monitor system for this activity. The video output of the LabQuest was projected to demonstrate the changes in heart rate to the whole group gathered at this station. Baseline heart rate was determined via the LabQuest, the participating student then placed his/her forehead into
a container of ice cold water, and the ensuing change in heart rate was observed and recorded. Responses were also taken with repeating the experiment in warm water or with the student submerging his/her elbow in the water instead of forehead as control experiments.

Owl pellet dissection. Only middle school students participated in this activity. Fumigated/sterilized owl pellets were given to students to dissect, and students were instructed to identify the species of any discovered bones referencing a provided chart. Students were also asked what the owl pellet taught them about the digestive systems of owls.

Nerves and reflexes. Students arranged themselves into two groups of different sizes (one group had 3 or 4 more people), lined up, and held hands. A volunteer gave the students at the end of the two lines a signal and they squeezed the hand of the person next to them. The hand squeezing was propagated down the line. Students then discussed the concept of synapses and why one line propagated the signal faster than the other line. Students also tested patellar, iris, and nystagmus reflexes and measured reaction times to the dropping of a ruler.

Special senses/dermatome mapping. Students mapped dermatomes on their palms or forearm by working in pairs and stimulating two points with dull tacks. If the partner identified two separate points of contact, then separate dermatomes were marked. Students evaluated vision using Ishihara tests and found their blind spots using a test in the printed booklet. We provided different fruit chews for students to attempt to correctly identify taste while deprived of the sense of smell. Students also tested hearing of various pitches using tuning forks.

What does a scientist look like? Meet a scientist. This booth enabled students to converse with scientific trainees and faculty members in a nontraditional way by encouraging them to use various scientific props, costume items, and clothes to dress a plastic skeleton while allowing time for casual conversation. Students were encouraged to ask questions about the typical day of a scientist, the different specialties of the scientists, and other aspects of science careers with the faculty members and volunteers in the booth. Students could take photo booth pictures with the dressed plastic skeleton and were encouraged to post them to social media. A photo release was also obtained for this event so that images of the students could be taken and used by public relations at UNMC.

Assessment Design

The assessment was intended to evaluate the self-perception of participating students in two separate areas of interest. The first area was students’ knowledge and perception of science and particularly knowledge of physiology. The second area was to evaluate students’ familiarity with science careers and interest in the potential pursuit of science careers. The assessment consisted of a set of multiple-choice and Likert scale questions.

We developed a two-part assessment; the first part was taken as students arrived at the event in the morning before the commencement of any activities or interactions with scientists. The second part was administered at the end of the day after participation in all activities. Students were randomly assigned a number on their personal workbook that was used to pair pre- and postassessments to evaluate within-subject comparisons. Numbers were assigned in no particular order and devoid of any association with personal information. These assessments may be viewed online at http://www.unmc.edu/mmi/education/sepa/physiology-resources.html

Data Analysis

We were able to successfully collect 246 preassessments from the ~275–300 students participating in the event. At the end of the day, we successfully obtained 224 postassessments that were anonymously paired matched with preassessments, allowing us to evaluate within-subject changes from the pre-to postevent evaluations. We evaluated the weight of responses to each portion of the assessment as a percent of total respondents. Response data were analyzed using a $\chi^2$ goodness of fit test, where $P$ values of $<0.05$ signaled statistically significantly different responses from the pre- to postassessment.

RESULTS

Perceptions Toward and Knowledge of Physiology and Science

At the beginning of the day, 79% of students correctly identified physiology as “the study of how the body works,” although 18% incorrectly identified physiology as “physics” (Fig. 1). This was improved at the end of the day as more students correctly defined physiology, although there remained 8% of students who continued in the error of viewing physiology as synonymous with physics.

When students were asked about their self-perception of their baseline knowledge of physiology, 64% responded that they knew “a little bit” about physiology, whereas 35% re-
responded that they did not know anything about physiology. The percentage responding that they knew “a little bit” increased to 69%. However, there was a robust increase from students’ self-perception of “knowing a lot” about physiology from 1% to 24% (Fig. 2).

Students began the day with a high perception of the utility of science. When asked how useful they thought science was, 28% and 64% responded somewhat or very useful, respectively. There was a small increase in responses of very useful after the day activities to 72% (Fig. 3). When asked how students felt about science, nearly all replied that they felt “OK” toward science (18%) and that science was a little (47%) or very interesting and fun (33%). At the end of the day, there was an increase in responses indicating that students felt science was very interesting and fun to 42% (Fig. 4).

In the postassessment, we inquired how effective the activities were. The vast majority designated that they had either learned something or enjoyed the activity (Fig. 5). The assessment was designed to allow students to respond with multiple answers, but this appears to have been poorly communicated as no student selected more than one choice. If we combined the responses indicating students learned or enjoyed the activity, the effectiveness of each activity reached over 80% positive responses.

Attitudes Toward Scientific Careers

At the beginning of the day, there was relatively high confidence among students in knowing what a scientific career entailed, as the vast majority (87%) responded as knowing what scientists do. This was improved slightly to 97% after the day of activities (Fig. 6). This finding was contrasted, however, with a nearly equal percentage of 83% claiming to not personally know a scientist at the start of the day (Fig. 7A). This was dramatically improved after the day of activities to 44% responding that they now knew a scientist personally.

As it relates to an interest in careers in science, 50% of students indicated that they were either not interested in a scientific career or did not know their level of interest. The other half of students responded as being a little or very interested in a career in science. The category that saw the greatest change from pre- to postassessment was the category of respondents indicating that they did not know if they were interested in a career in science, as this decreased to 12% in the postassessment. This was associated with an increase in both slightly and very interested students to 45% and 19%, respectively (Fig. 7B). If we combined responses indicating being “a little” and “very” interested in scientific careers, we achieved
an increase of interest in scientific careers from 50.4% (95% confidence interval: 44.2–56.6%) before the event to 63.8% (95% confidence interval: 57.4–69.8%) after the activities. When evaluating changes within individuals between the beginning of the day and end of the day, we observed the most dramatic shift within the category who designated that they did not know if they were interested in science careers. Half of the respondents who selected this category at the beginning of the day increased their interest in scientific careers to a little or very interested. There was little impact of the day with regard to those who initially designated that they were not interested in scientific careers as nearly two-thirds of these remained not interested or changed to not knowing their interest at the end of the day. Similarly, those who began the day a little or very interested in scientific careers generally did not alter their perspective over the course of the day’s activities (Fig. 8).

As a control question, we also evaluated students’ personal acquaintance with health care providers and interest in health care-related careers. Responses to both of these questions were mostly unaffected by the day of activities (Fig. 9).

DISCUSSION

The major conclusions from our day of immersive physiology demonstrations are that the activities and interactions provided were able to increase students’ knowledge of and interest in science. Furthermore, within the minority group of Native American students who participated in our event, we increased familiarity of students with scientists and increased students’ interest in scientific careers.

The first goal of our event was to increase students’ knowledge of physiology. Previous studies have observed changes to student behavior after high school and university partnerships in teaching anatomy and physiology (16) and increased test performance after student-centered experiments in high school students (1). Upon evaluating the impact of our activities on student understanding of physiology, we observed an increase in students correctly identifying what the subject of physiology is and an increase in students’ self-perception of their knowledge of physiology. Before the day of activities, more than one-third of participants designated that they did not know anything about physiology. This was also evident by nearly 20% of respondents incorrectly selecting physics as the definition of physiology, and very few designating that they knew a lot about physiology. However, at the end of the day of activities, there was a drastic reduction in students’ self-perception of not knowing anything about physiology. This was also evident by nearly 20% of respondents incorrectly selecting physics as the definition of physiology, and very few designating that they knew a lot about physiology. However, at the end of the day of activities, there was a drastic reduction in students’ self-perception of not knowing anything about physiology coupled with a dramatic increase in the self-perception of knowing a lot about physiology. These data indicate that the day of activities

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Fig. 7. Students’ response to the questions “Do you know anyone who is a scientist?” (A) and “How interested are you in being a scientist when you grow up?” (B) compared before and after the day of physiology activities. Data are presented as percentages of total respondents ± 95% confidence intervals. A: P < 0.001; preassessment: n = 242 and postassessment: n = 222. B: P < 0.001; preassessment: n = 246 and postassessment: n = 224.

Final Category

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Fig. 8. Representation of the change in attitude about scientific careers between pre- and postassessments. Each column represents the category selected during the preassessment, and shading represents the category selected during the postevent assessment. We were able to pair match a total of 177 surveys for this assessment. There were 45 initial respondents designating “I do not know;” 40 initial respondents designating “I am not interested;” 76 initial respondents designating “I am a little bit interested;” and 16 initial respondents designating “I am very interested.”
was effective in communicating knowledge to students in a way that increased their understanding of physiology in a way in which they were confident to answer that they understood the concepts presented. A potential weakness in this approach is that we only evaluated students’ self-perception and did not evaluate any objective measure of their comprehension. The assessment was designed to be unobtrusive and of short duration; thus, we were limited in our ability to evaluate the knowledge level of students before and after the activities in an objective manner. We are confident in our approach and conclusions because of the large percentage of students who initially designated that they did not know anything about physiology, indicating that the students had no hesitation in being honest with the assessment. The significant change from pre- to postassessment in the self-perception of physiological knowledge indicates to us that the day was effective in communicating at least some principles of the discipline. We are, however, unable to assess whether this increase in knowledge persisted over time, as we were limited in our period of interaction.

Events such as ours and others have focused endeavors in middle and high school populations and have been used with the goal of increasing student awareness of and interest in scientific careers (3, 10, 16). Increasing the involvement of underrepresented minority groups in STEM fields has also been an area of increased focus in recent years (2, 8, 9, 15). Furthermore, sex disparities in STEM representation are well documented, with a substantially lower number of women involved in STEM careers (7, 13). A recent finding has suggested that an increased variety of STEM experiences and a variety in presentation of material have beneficial effects in increasing ethnic and sex interest in STEM majors in college (5). Our results support the suggestion that an increase in the variety and types of exposure to STEM concepts can be beneficial in increasing interest in STEM fields in underrepresented groups. These types of events are likely to be highly beneficial in supporting and strengthening the type of science and mathematical instruction occurring routinely in middle and high school settings. Unfortunately, we did not collect data on the increase in knowledge and interest in physiology between male and female participants in our data and, as such, cannot comment directly on differences in responses. However, as we mostly increased interest in scientific careers, we can assume many of those responses included female participants. Our volunteer force also consisted of nearly twice as many female volunteers as male volunteers, which hopefully conveyed the message that not only men are scientists and which allowed many female participants to interact with female scientists throughout the day and during the “Meet a scientist” booth.

Through our day of physiology activities, we were able to increase interest in scientific careers among our student participants. One aspect of barriers to interest in scientific careers we hoped to address was the misunderstanding of what a career in science entails. We made use of a “Meet a scientist” booth as one of the activity stations to allow students to interact with science faculty members and trainees to demystify the process of becoming and the stereotypes associated with scientists. Students were encouraged to ask many questions of the scientists during this booth and throughout the various activities, and many of the volunteers reported very positive interactions with students.

One of the more interesting increases in students’ perceptions toward scientific careers came in the category who initially expressed uncertainty about their interest in the career path. Of those with initial uncertainty, half increased their interest, indicating that exposure to both scientists and scientific activities was able to increase their openness and interest in exploring scientific careers. We appear to have had little influence on students whose minds were already decided as being not interested in scientific careers or on those who were already interested in scientific careers. Although it is worth mentioning that even in the category initially not interested in scientific careers, there was a nearly 30% improvement in interest (Fig. 8).

To evaluate the effectiveness of our activities in increasing exposure to scientists and interest in scientific careers, we included a control question in our assessment. There were no changes between the pre- and postassessments in the knowledge of and interest in health care providers or health care careers (Fig. 9), as this was not one of our goals to communicate at this outreach event; however, both the students’ perceptions that they knew a scientist and were interested in scientific careers increased in the postassessment relative to the preassessment (Fig. 7). This indicates to us that the increases in...
this particular set of questions were not due to excitement from the event naturally leading to increased positivity in completing the evaluation but was selective for the specific type of activities completed. However, it is also interesting that we had no significant effect on interest in medical careers as many of our activities and concepts had direct medical correlations. Another possibility in explaining these data apart from it not being the focus of our event could be in the relatively high baseline interest in medicine at the beginning of the day.

Before the event, three-quarters of participants indicated knowing a health care worker (Fig. 9A) as opposed to less than one-fifth indicating they knew a scientist (Fig. 7A). There was also a substantially larger preexisting interest in health care careers among our participants, with 62% indicating that they were a little or very interested in health care and only 16% indicated uncertainty (Fig. 9B). Contrast this with the 50% indicating a little or great interest in scientific careers and 24% uncertainty (Fig. 7B). It is possible that the prior exposure to the medical field in this cohort was high enough to cause an effectively established personal interest in medical careers; however, the relative lack of experience with scientific careers and uncertainty allowed for the opportunity to increase interest by exposure to scientists and science-related activities.

One weakness in interpreting the results from our event was in the nature of the assessment design. We were only able to take two evaluations, one evaluation immediately before and one evaluation immediately after the day of activities. It is possible that the postassessment was influenced by the immediate conclusion to the day of activities in that students may have been feeling a level of excitement related to the event rather than the activities themselves; however, as already mentioned, health care-related control questions failed to demonstrate this postevent, excitement-driven increase. It would have been interesting to provide a third assessment for students to complete weeks after they returned to their home schools. This third assessment would have been able to evaluate whether or not the improved attitude towards science and science careers had persisted in students, which is the ultimate goal of activities such as these. As this was logistically difficult to accomplish for the current event, we were unable to collect such data, and evaluation of future events may provide an opportunity for such a perspective.

In summary, we can conclude from our day of activities that we were able to both increase students’ understanding of physiology and increased students’ attitudes toward careers in science. These data provide evidence in favor of the effectiveness of activities that are PhUn week compatible in meeting the stated goals of the American Physiological Society. We encourage the use of immersive, activity-based outreach among our colleagues to promote understanding of physiology and increasing awareness of the opportunities for careers in science.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

DISCLAIMERS

The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

AUTHOR CONTRIBUTIONS

B.K.B., A.M.S., L.P.B., and M.G. conceived and designed research; B.K.B., A.M.S., L.P.B., and M.G. performed experiments; B.K.B., A.M.S., and E.A.E. analyzed data; B.K.B., A.M.S., I.H.Z., E.A.E., L.P.B., and M.G. interpreted results of experiments; B.K.B. prepared figures; B.K.B. and A.M.S. drafted manuscript; B.K.B., A.M.S., I.H.Z., E.A.E., L.P.B., and M.G. edited and revised manuscript; B.K.B., A.M.S., I.H.Z., E.A.E., L.P.B., and M.G. approved final version of manuscript.

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