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ARTICLE
An Effective Model for Engaging Faculty and Undergraduate Students in Neuroscience Outreach with Middle Schoolers

Peter J. Vollbrecht[1,2,a], Riley S. Frenette[2,4], & Andrew J. Gall[3,a]
[1]Department of Biomedical Sciences, Western Michigan University Homer Stryker M.D. School of Medicine, Kalamazoo, MI 49008. Departments of [2]Biology and [3]Psychology, Hope College, Holland, MI, 49423. [4]Department of Orthopaedic Surgery, University of Michigan, Ann Arbor, MI 48109. [a] Indicates co-corresponding authors.

Engaging undergraduate students in science outreach events is critical for improving future communication between scientists and community members. Outreach events are opportunities for faculty and undergraduates to utilize active learning strategies to engage non-scientists in scientific questions and principles. Through careful design of outreach events, undergraduate students can practice science communication skills while reaching populations of the public that remain underserved and underrepresented in scientific fields. Here we describe a classroom outreach event designed to give a broad overview of the field of neuroscience to middle school students of all backgrounds by delivering the content in school, during school hours. Through a variety of active learning strategies, middle school students learned about basic structures of the brain and their corresponding functions. Additionally, these students participated in demonstrations during which they generated and tested their own hypotheses and learned about sensory transmission and responses. We designed the lesson to meet the educational goals for middle school students, fulfilling the criteria for the Next Generation Science Standard MS-LS1-8 (NGSS Lead States, 2013). We evaluated the impact of the event on both undergraduate student instructors and middle school participants. Our results demonstrate that these outreach events effectively deliver new content to middle school students while also reinforcing the importance and value of outreach to undergraduate instructors.

Key words: outreach; neuroscience; assessment; nervous system; brain awareness week; communication

Scientists are becoming increasingly aware that it is not enough to perform research in isolation. As a result, a growing number of scientists are engaging in science communication and outreach (Haywood & Besley, 2014; Lopes et al., 2018). While the public may not be as knowledge deficient as many scientists believe (Simis et al., 2016), engaging the community in scientific discovery and dialogue is important, and is viewed positively by both scientists and the public (Varner, 2014; Lakeman-Fraser et al., 2016). Outreach events are well positioned to engage students and community members in science through active learning, broadly defined as "any instructional method that engages students in the learning process," which is accepted as a highly effective teaching and learning technique (Prince, 2004; Freeman et al., 2014). In addition, science outreach events provide an avenue for undergraduate and graduate students to act as instructors and improve their own science communication skills. Science communication and outreach face the common hurdle that these forums only reach members of the public who are actively seeking them out. Therefore, outreach events often fail to reach community members who are not already science enthusiasts, or those who are underrepresented in scientific fields (Bultitude, 2014; Jensen and Buckley, 2014; Kennedy et al., 2017, Payne, 2017). In addition, it is rarely clear whether outreach events are effective. Many outreach events overlook outcomes assessment and impact evaluations that are critical for measuring the success of an event (Laursen et al., 2007). However, with thoughtful design, implementation, and assessment, the impact of science outreach events can be significantly improved. Thus, science outreach is an artful combination of both science communication and science education (Baram-Tsabari & Osborne, 2015).

Brain Awareness Week (BAW) is a global campaign to promote understanding and public interest in neuroscience and the brain that was founded by the Dana Alliance for Brain Initiatives, and continues to be coordinated by The Dana Foundation. In 2018, more than 895 BAW events were held in 42 countries and 44 states. For the last three years, BAW activities at Hope College have included a neuroscience-themed community lecture on topics including Alzheimer's disease, neuroscience and law, and neuroscience and art. In addition, undergraduate students and faculty have led a "Brain Day" open house on campus to invite community members to learn about neuroscience through activities. Finally, we utilized BAW as an opportunity for outreach with K-12 teachers in their classrooms.

Here we provide details of a middle school classroom outreach program in which faculty and undergraduates worked in collaboration with area middle school teachers to introduce students in grades 6-8 to basic neuroscience concepts. Undergraduate student instructors led middle school students as they explored concepts including lobes of the brain and their functions, brain protection (skull and cerebrospinal fluid), central vs. peripheral nervous systems, and how the nervous system allows us to sense, process, and respond to external stimuli. Our learning objectives were designed to meet the Next Generation Science Standards middle school standard MS-LS1-8 (NGSS Lead States, 2013), which suggests that students should be able "to gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories."

These events fit our goals of 1) reaching students from all backgrounds and interest levels with regards to science and neuroscience by teaching them an important concept in neuroscience and assessing learning gains, and 2) providing an opportunity for undergraduates to practice and improve their own science communication. The lesson utilized active learning both through demonstrations and hands-on discovery. Our assessments provide a clear demonstration that this active learning approach led to significant learning gains by the middle school students. In addition, undergraduate students leading the outreach efforts in the classrooms exhibited significant positive impacts with respect to science communication and engagement with non-scientists. It is our hope that these positive results and the simplicity of the event and assessment will encourage other undergraduate institutions to utilize this event or to build similar outreach programs for their students, ultimately leading to an improved understanding and appreciation for science in the general public.

MATERIALS AND METHODS

Subjects

Twenty-two Hope College undergraduate students participated as instructors in this outreach event. Seventeen of those students responded to a post-event survey (77.3% response rate; see Outreach survey for undergraduate volunteers section below). Of the 17 responding undergraduate students, 2 were male and 15 were female. Six students were seniors, 6 were juniors, 3 were sophomores, and 2 were freshmen. Finally, 14 self-reported as White/Caucasian, 1 student reported as White/Caucasian and Hispanic, 1 student reported as White/Caucasian and Black/African American, and 1 preferred not to answer. The post-event survey was approved as an internal review board exemption from Hope College under the following section of the Federal Common Rule: 45 CFR 46.104(d)(2): Research involving the use of educational tests, survey procedures, interview procedures, or observation of public behavior (U.S. Department of Health and Human Services, 2018).

174 students in grades 6-8 participated in our outreach activities and took a pre-test to assess baseline neuroscience knowledge prior to our lesson (see Assessment section below). A total of 126 students took the post-test (72.4% retention) to assess neuroscience knowledge following our lesson. Students in grades 6-8 were selected by emailing teachers in the Holland, Michigan region. We targeted several teachers that have students who are members of underrepresented groups. Middle school students were selected from a total of 6 classes with 5 different teachers in the Holland area. All methods involving middle school students were approved as an internal review board exemption from Hope College under the following section of the Federal Common Rule: 45 CFR 46.104(d)(1) Research conducted in established or commonly accepted educational settings, involving normal educational practices (U.S. Department of Health and Human Services, 2018).

Event Organization

The described curriculum was developed by Hope College undergraduate students in collaboration with members of the faculty. This process was important in helping undergraduate students to understand the importance of proper planning and organization when communicating information to any audience, and particularly to non-scientists. It also helped to solidify concepts learned in class and build confidence in their knowledge.

The result of this collaboration was a BAW in-class event that consisted of two primary components: a presentation, and a set of hands-on learning activities. Many of these activities were modified from the BrainLink curriculum (Boyle, 1997a,b; MacNabb, 2006; Tharp et al., 2000; Moreno et al., 2001). Importantly, we modified these activities for ease of use in an outreach setting for middle schoolers. In addition, these activities were strategically placed in the same lesson in order to emphasize our primary objectives for students to understand the important role that sensory receptors play in our nervous system. For each event a minimum of 3 undergraduate volunteers and 1 faculty member were present in the classroom. When visiting a classroom, team preparation time was usually limited to the time reserved for class period change, often about 10 minutes. Thus, it was important to be well organized prior to entering the classroom. While two individuals began the presentation, the others ensured proper set-up of the activities.

Presentation and Group Demonstration

Our event started with a quick discussion of the first two aspects of a Know / Want to Know / Learned (KWL) discussion in which students were asked to form small groups and discuss what they knew about the brain, and what they wanted to know. Peer sharing was utilized to report back to the class, and the instructors wrote comments on the board under the two appropriate columns ("know" or "want to know"). This was followed by a short presentation focused on our primary learning objectives:

- Explain the anatomical basis for protection of the brain
- List the major lobes of the brain and their functions
- Gather and synthesize data in order to analyze how the body receives, processes, and responds to peripheral sensory information

We utilized a 5-slide PowerPoint presentation (Supplemental Materials) along with demonstrations to highlight these specific themes, but were deliberate in avoiding continued use of the PowerPoint. Our first demonstration examined the role of cerebrospinal fluid (CSF) in preventing mild injuries when we move our head. To demonstrate, we used two clear, closed jars. One jar contained an uncooked egg. The other jar contained an uncooked egg and was filled with water. The extent to which you fill the jar with water will determine how easy it is to break this "CSF protected" egg. To minimize classroom chaos the teacher was asked to shake each jar. The kids particularly enjoyed it when the teacher really got into trying to break the protected egg. After this demonstration, we emphasized the difference in the amount of water separating the egg from the jar and the volume of CSF separating the brain from the skull, and the importance of wearing helmets when involved in activities such as riding bikes or playing contact sports.

Our next demonstration utilized previously dissected sheep brains. We found that 4-8 students per brain was a functional number, with fewer students being better. Before allowing students to interact with the sheep brains, instructors showed the students the location of brain lobes, using a PowerPoint image and encouraged them to touch the roughly corresponding parts of their own head. The cerebellum and the brain stem were also introduced. After discussing the location and the rough functions of each of these areas, instructors took sheep brains to each group. Students were allowed to hold the brain, after putting on gloves, and instructors questioned them about the regions and functions that had previously been explained.

We next discussed the senses, including a brief overview of peripheral and central nervous systems, and discussed how information gets to our central nervous system (CNS) and how signals are sent out, resulting in a response. We used the basic withdrawal reflex as a simple example of these processes. We then talked about the need to have input, integration, and output. Once the walk-through was completed, students were divided into three groups to participate in group activities.

Group Activities

Three group activities including "blind-box", reaction time, and altered vision followed the class presentation. These activities are outlined in further detail below.

Blind-Box

A variation on a "blind-box" activity focused on the sensory inputs that allow us to discriminate between different tactile sensations. We also discussed how integration of these sensations with previous knowledge is necessary for us to identify objects solely by touch.

For this activity, brown paper lunch bags were rolled closed to prevent students from peeking inside of them. Each student selected a paper bag, reached into the bag without looking, and tried to decide what was in the bag. After a few seconds they passed the bag to a neighbor. This process was repeated until they ended up with their original bag. At this time, each person was asked to try to name what was in the bag, without looking. Often times this is done very easily, but it is fun to try to give students something that is very obvious when they see it, but is hard for them to identify simply by touch. We have found that dried rice can be difficult for some students. At this point, we review the portion of the brain that is the most important for our sense of touch, and we also discuss how one is able to identify the items in the bag. This allows us to discuss not only input via somatosensation, but also integration of current inputs with previous experiences to make an identification.

Reaction Time

The second activity was a reaction time activity in which students were asked to catch a yardstick, responding either visually, or to an auditory stimulus with their eyes closed. This activity allowed students to consider all aspects of a neural system including input, integration, and output.

The reaction time activity was the most involved activity. It was helpful to create a spreadsheet for data input before the event. We used yardsticks that already had mm and cm converted into ms (Carolina Biological Supply, Burlington, NC, USA). A number of resources can be found online to help with this conversion to make your own yardsticks, one of which is Neuroscience for Kids (2019), or an online calculator that has already been built (Reaction Time Calculator, 2019). Before beginning the reaction time experiment, we asked the students to hypothesize if their reaction time would be faster when their eyes were open or closed. This introduced the idea of generating and testing hypotheses in science.

In the reaction time activity there are a few important things to consider. As with all experimentation in which quantitative data are being collected and compared, consistency is important. Marking the edge of a table or desk with two pieces of tape as indicators for finger starting position, as well as an indicator for yardstick starting position greatly improved reliability (Figure 1). Students performed the reaction time with eyes open and no verbal cue for the drop, and a second time with their eyes closed and the person dropping the yardstick giving a verbal cue at the start of the drop. In this set-up, the biggest variable will be the experimenter's verbal command. Ultimately, this often determines the difference between the two reaction times. In reality, hearing should be the faster modality, as the amount of time it takes for the visual signal to reach the

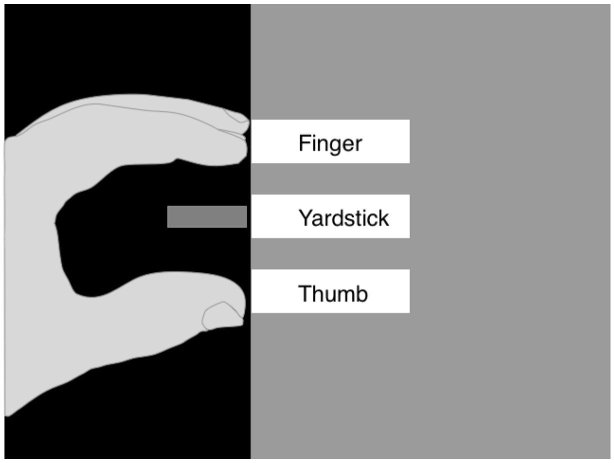

Figure 1. Visual representation of Reaction Time set-up. Light gray on the right represents a table or desk. Labeled tape on the table helps the researchers maintain a more consistent experimental environment by indicating the correct placement of the thumb, finger, and yardstick.

cortex once light reaches the eye is significantly longer than the time it takes for the auditory signal to reach the brain once sound waves hit the ear. Thus, despite the speed of light being much faster than the speed of sound this advantage is erased once our body begins to process the information (Pain and Hibbs, 2007; Shelton et al., 2010; Jain et al., 2015). However, variability of the instructor's command, may impact the outcome of each trial. This can actually make for interesting discussion about the limitations of scientific experimentation.

The discussion follow-up for the reaction time activity can include discussions as to why one input modality may be faster than the other. It also should include what brain regions are being utilized in processing the different signals. Finally, the discussion should include the output of the CNS, which is manifest in our closing thumb and finger to catch the ruler, all of which happens in milliseconds!

Altered Vision

In the third activity, students played catch while wearing goggles that alter vision by as little as 15 degrees to as much as 90 degrees. This activity allowed students to consider the critical role of integration of sensory systems and output, which allow them to appropriately respond to external stimuli. We asked students to generate hypotheses related to how their vision would adapt after wearing the goggles for a short time vs. a longer time frame. We then tested their hypotheses by allowing students to wear the goggles.

The altered vision activity is best performed with a reasonable amount of space, but can be adapted for most classrooms. Before students put on the vision shifting goggles they are asked to toss a ball back and forth with a partner 3 or 4 times. At this point students put on the goggles and then continue trying to play catch. This is where sufficient space is important, as the goggles are disorienting, and it will become difficult to throw and catch the ball. The purpose of this exercise is to emphasize the importance of integration of incoming signals with other information, such as body position, to create and execute an appropriate response (Pick et al., 1964). Depending on the grade level of the students, it is even possible to begin discussing proprioceptive and visual mapping, as well as adaptation and disorders that impair these abilities such as developmental coordination disorder (Mon-Williams et al., 1999) in the follow-up discussion for this activity. Once again, following this activity the instructor is able to discuss sensory input, sensory integration, and central nervous system output in the form of muscle movements to throw or catch the ball.

Materials

- 2 mason jars
- 2 uncooked eggs (per classroom)
- 3-5 sheep brains in various states of dissection
- Dissecting trays (1 for each brain)
- Gloves for students
- 8-10 paper bags containing one of a variety of materials representing different tactile experiences, (e.g., rice, cotton balls, crayons, feathers, etc.)
- Vision shifting goggles, or vision inverting goggles
- 2 soft balls that won't injure anyone they may hit
- A yardstick
- A computer with Microsoft Excel or other graphing software

Assessment

Prior to the event, teachers administered a 10-question multiple choice quiz based on the core concepts of our event (Table 1; Appendix 1). Following the event, students were asked to complete the same 10-question quiz a minimum of two days following the event and a maximum of 7 days following the event. All middle school student responses were collected via Qualtrics (2019 Qualtrics LLC, Provo, UT). Teachers were asked to have their students take the pre- and post-test on an assigned computer in the classroom. Pre and post-event assessments were matched to the computer each student used without any identifying information being collected.

Statistical Analyses of Middle School Student Assessment

Correct answers for a question were assigned a value of 100 and incorrect responses were assessed a value of 0. Thus, statistical analyses resulted in a percent correct vs percent incorrect for each question. A paired samples t-test (Figure 2) and a two-way Repeated Measures ANOVA with "Pre/Post" as the first variable and "Question" as the second variable (Figure 3) were performed. A significant interaction was followed by post hoc analysis using Sidak's multiple comparison tests to examine which questions resulted in significant learning gains. For all tests, comparisons were considered significant if $p < 0.05$.

Outreach Survey for Undergraduate Volunteers

A survey was distributed to the undergraduate students that volunteered to lead classroom visits following BAW 2018 (N = 22; Appendix 2). All undergraduate student responses were collected via Qualtrics. 17 of the 22 students completed the survey (77.3% response rate). The survey assessed the impact of outreach on: (1) teaching and science communication skills, (2) interest in science

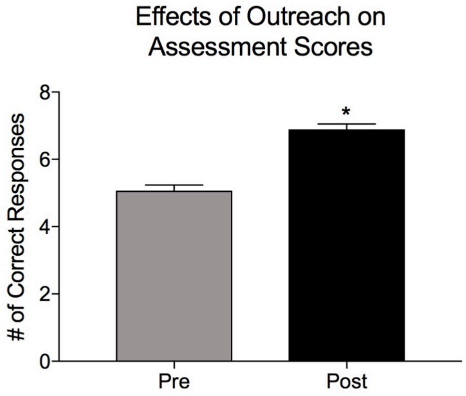

Figure 2. Classroom outreach event increases assessment scores. Two-tailed paired t-test $t_{125}=9.154$; $p<0.0001$. * indicates $p<0.0001$.

Question	Pre-Test Percent Correct	Post-Test Percent Correct	Percent Improvement	P- value
1. Without this, you could very easily get a concussion.	34.92	65.87	30.95	<0.0001
2. How does sound get to your brain?	59.52	69.05	9.52	0.2223
3. Imagine that you touch a hot iron. Ouch! Which of the following is NOT involved in feeling the hot iron, and pulling your hand away?	52.38	83.33	30.95	<0.0001
4. True or False: Nerves can carry sensory information into the central nervous system OR they can carry motor information out from the central nervous system.	84.92	83.33	-1.59	>0.9999
5. What allows you to properly identify an object without seeing it?	62.69	80.95	18.25	0.0001
6. What is the major function of the occipital lobe?	46.83	61.9	15.08	0.0039
7. What is the major function of the temporal lobe?	20.63	49.21	28.57	<0.0001
8. How much does a human brain weigh?	46.83	57.14	10.32	0.1409
9. Which of the following is part of the peripheral nervous system?	38.09	70.63	32.53	<0.0001
10. The brain is part of the ______________ nervous system.	60.32	67.46	7.14	0.6200

Table 1. Questions (without foils) and the percentage of students who correctly answered the question before and after the outreach event.

communication, (3) confidence in neuroscience concepts, and (4) overall perspectives.

The survey consisted of 10 questions dealing with how this outreach event has impacted the undergraduate student, ranging from -5 (a significant negative impact) to +5 (a significant positive impact). These 10 questions were based upon a survey that was administered to engineering students to assess the benefits of outreach and was modified to fit our needs (Pickering et al., 2004). The mean, standard error of the mean (SEM), and mode were calculated.

The survey also consisted of eight questions dealing with the extent to which undergraduate students agreed or disagreed with statements about how this outreach event affected interest in science outreach, communication skills, and confidence. The scale ranged from one (disagree strongly) to five (agree strongly). These eight questions were based upon a survey that was administered to K-12 students and graduate students to assess the effectiveness of science educational outreach programs and modified to fit our needs (Clark et al., 2016). The mean, standard error of the mean (SEM), and mode were calculated.

We also included 4 open-ended questions. We have included a subset of quotations of undergraduate student responses to demonstrate the impact of this outreach event on students.

Finally, demographic information was collected from the undergraduate students, including majors/minors, graduating class, gender, race/ethnicity, and level of involvement in the outreach event.

RESULTS

The pre- and post-event assessment allowed us to determine whether the outreach event successfully improved knowledge of neuroscience in our participants. Significant improvement was evident across all students when data were collapsed for all questions (Figure 2; two-tailed paired t-test, $t_{125} = 9.154$; $p<0.0001$).

When data were broken down by question, 6 of 10 questions showed significant improvement from pre to post assessment (Figure 3, Table 1 for p-values; Two-way RM ANOVA Main Effect Pre vs Post: $F_{(1,1250)} = 183.8$, $p<0.0001$; Main Effect of “Question”: $F_{(9,1250)} = 14.82$, $p<0.0001$; Significant Interaction: $F_{(9,1250)} = 8.035$, $p<0.0001$). When questions were evaluated using Sidak’s multiple comparison test significant improvements were observed for questions 1, 3, 5, 6, 7, and 9 (Sidak’s post hoc multiple comparison test: Question 1: $p<0.0001$, Question 3: $p<0.0001$, Question 5: $p=0.0001$, Question 6: $p=0.0039$, Question 7: $p<0.0001$, Question 9: $p<0.0001$).

No significant change was observed for questions 2, 4, 8, or 10 (Sidak’s post hoc multiple comparison test: Question 2: $p=0.22$, Question 4: $p>0.99$, Question 8: $p=0.14$, Question 10: $p=0.62$).

Knowledge gains exceeded 15% in 6 of the 10 questions and 3 questions demonstrated gains of greater than 30% (Table 1). Questions 1, 3, and 9 had improvements of over 30%, while questions 5, 6, 7, and 8 demonstrated gains of greater than 10%. Questions 2 and 10 showed learning

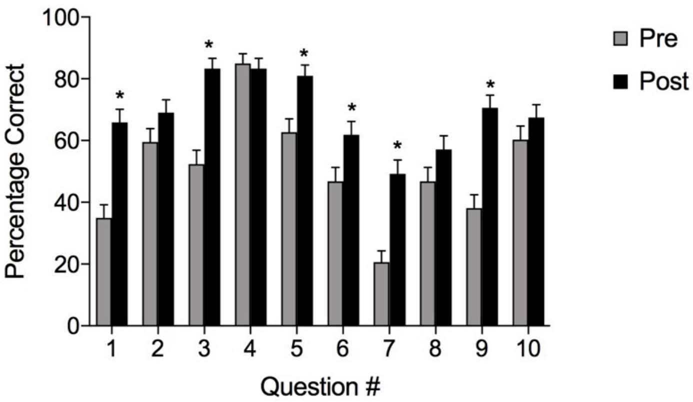

Figure 3. Post-event assessment revealed significant improvements in scores. All but four questions showed significant improvement in the post-event assessment. Two-way RM-ANOVA with Sidak's multiple comparisons test. * indicates p<0.05.

gains of between 7 and 10%. Only Question 4 demonstrated a negative change of -1.59% which was not statistically significant. Looking at student performance on an individual level, 68% of students demonstrated an improvement in their post-event assessment, and another 20% maintained the same score (Figure 4). Twelve percent of student scores decreased on the post-test. It is interesting to note that nearly half of the students whose scores decreased (7 of 15) were from the same class, suggesting that the presentation to this particular class may have been deficient in some way, or that sufficient time may not have been afforded to the post-event assessment in this class.

The outreach survey for undergraduate students allowed us to assess the impacts this outreach event had on communication skills, interest in science communication, confidence, and overall perspectives. As shown in Table 2, undergraduate students agreed most strongly with statements relating to improved science communication (mean: 4.65, frequency distribution graphed in Figure 5A) and increased interest in continuing outreach (mean: 4.41, frequency distribution graphed in Figure 5B). Improvement of communication skills and increases in overall confidence levels were not rated as highly, suggesting that students are performing the outreach for external reasons (e.g., to benefit society) rather than internal reasons (e.g., to benefit their skill sets or boost their curriculum vitae). This finding was even more evident in the responses undergraduates gave to the open-ended questions. In response to the question "Why did you choose to be involved in outreach?" 13 of 17 students gave an external reason for being involved.

> "*I chose to be involved in outreach because I enjoy serving the community and I think that it is important for children to become excited about learning about the brain."*
>
> *"I enjoy opportunities to engage with my community and working with children—so the opportunity to do so while combining my passion for neuroscience was ideal! I also found it a very important mechanism for instilling interest in neuroscience (and STEM in general) for girls and boys starting at a young age, hopefully creating memorable experiences that will stick with them as they continue their education."*

The outreach event also impacted the undergraduate students' excitement about science communication (mean: 4.12), along with having a positive impact on teaching skills (mean: 3.82), communication skills (mean: 3.76, frequency distribution graphed in Figure 5C), and leadership skills (mean: 3.53), as shown in Table 3. Responses were most positive for questions regarding science communication and outreach and lowest for management skills such as organization and time management, suggesting that the outreach event had the greatest impact on undergraduate students' excitement and ability for outreach and less impact on their own content knowledge or management skillset. This finding was evident in responses to open-ended question #3 ("Does outreach build any useful skills that aren't part of your neuroscience courses?"), where 16 of 17 students discussed the impact of building communication skills, whereas only 4 of 17 discussed time management or organizational skill development.

> "*I learned how to translate science speak into something most people can understand."*
>
> *"My communication skills with children and parents have definitely increased through my involvement in Brain Awareness Week."*

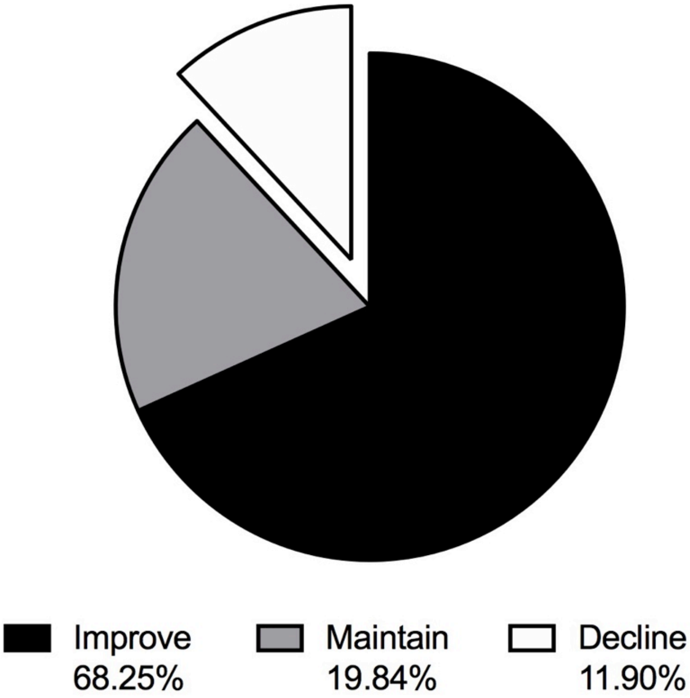

Figure 4. Percentage of students improving, maintaining or declining in assessment performance following event.

Question	Mean	SEM	Mode
Outreach helped me explain concepts to non-scientists.	4.65	0.15	5.00
Outreach was a valuable addition to my undergraduate training.	4.47	0.12	5.00
Outreach was an engaging process.	4.47	0.15	5.00
Outreach increased my interest in communicating with non-scientists.	4.41	0.17	5.00
Outreach increased my interest in conducting outreach.	4.41	0.19	5.00
Outreach sparked my interest in teaching others.	4.38	0.20	5.00
Outreach improved my communication skills.	4.24	0.14	4.00
Outreach made me more confident.	3.94	0.16	4.00

Table 2. Undergraduate survey assessing agreement (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4= agree, 5 = strongly agree) with the following statements ranked from highest to lowest mean.

> *"I think this opportunity allowed me to explain the concepts in a simple way and I was able to apply my knowledge to real-world scenarios."*
>
> *"…I believe teaching someone what you've learned is a great way to learn for yourself."*
>
> *"…the outreach event increased my communication skills. Teaching is a great way to learn the material, and the ability to articulate this knowledge in unique ways is an excellent exercise."*

The value of outreach shared by the undergraduate instructors was most evident in responses to the question "What responsibilities do you think scientists have for educating others?" where all 17 students discuss the positive impact of neuroscience outreach for teaching the next generation of scientists. It is clear that undergraduate students understand the value and importance of science outreach, and it should be encouraged as part of each student's educational experience.

> *"I believe it's very important for scientists to share their knowledge. The world around them offers unlimited opportunities, and when we learn new things, we should share them. After all, not everyone is a scientist."*
>
> *"I think scientists have the responsibility of teaching people the importance of their work, the application of their studies, and what their studies have demonstrated. It's important that scientists inform others in ways that are easy for their audience to understand and comprehend the problem and how the scientist's work contributes to the solution."*
>
> *"I strongly believe that scientists have a responsibility for educating others. We have the responsibility to bring awareness to others as well as help inspire future scientists."*

DISCUSSION

Here we have presented a lesson plan for a relatively simple and effective classroom outreach event that can be easily adapted to a variety of circumstances and classroom settings. In addition to laying out detailed descriptions of our activities, we have clearly shown, via our assessment quizzes, that this outreach event improved middle school student knowledge of basic neuroscience concepts, and that the information was retained beyond the day of the event. Not surprisingly, demonstrations that involved active learning resulted in the highest learning gains for students. Equally important, these events proved to be valuable to undergraduate students, allowing them to gain teaching experience, gain confidence, and improve communication between scientists and non-scientists.

The Role of Learning Gains Assessment

Post-event assessment of middle school students allowed us to critically evaluate our event and determine where improvements should be made. The question regarding the conduction of auditory signals to the brain (question 2) is one such example, where knowledge increased from 59.52% answering the question correctly before the intervention to 69.05% answering the question correctly

Question	Mean	SEM	Mode
Excitement about science communication	4.12	0.37	5.00
Teaching skills	3.82	0.31	5.00
Communication skills	3.76	0.28	4.00
Leadership skills	3.53	0.34	4.00
Presentation skills	3.47	0.33	4.00
Understanding of neuroscience concepts or skills	3.18	0.37	5.00
Confidence in neuroscience knowledge of concepts or skills	3.18	0.40	3.00
Self confidence	2.94	0.39	3.00, 4.00
Organizational skills	2.29	0.38	2.00
Time management skills	2.24	0.36	2.00

Table 3. Undergraduate survey assessing impact of outreach (-5 = a significant negative impact on life or skills, 0 = no impact, 5 = a significant positive impact on life or skills) ranked from highest to lowest mean.

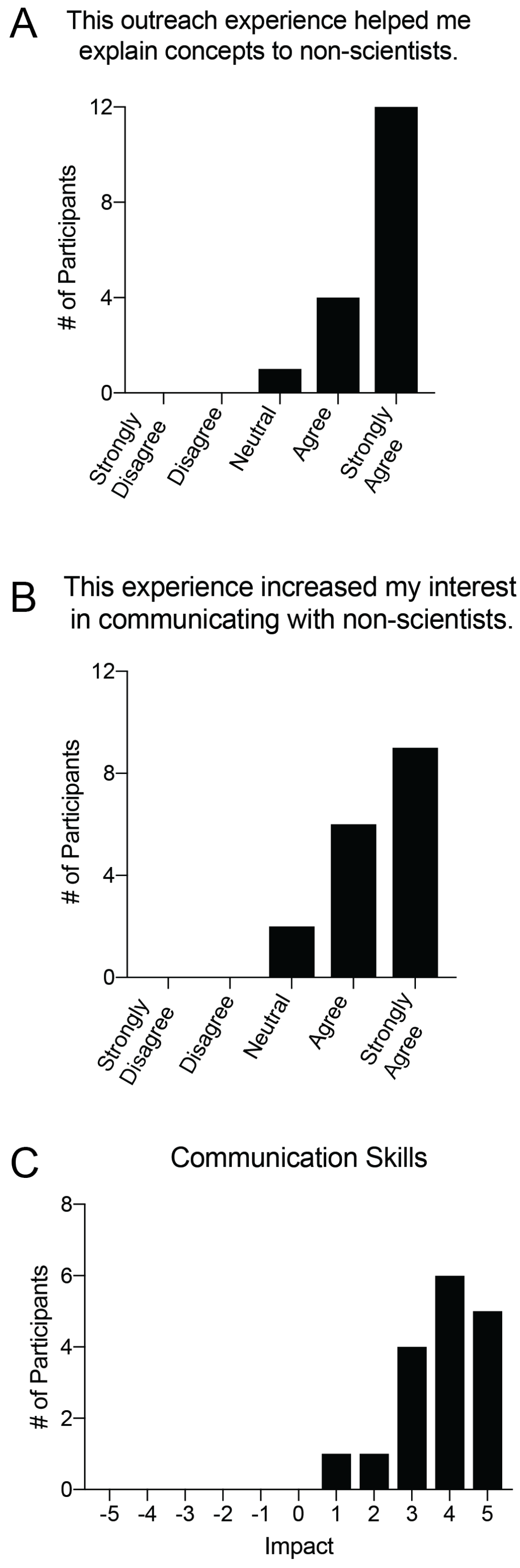

Figure 5. Frequency distributions of the extent to which undergraduate students agreed with the statement about *(A)* explaining concepts to non-scientists and *(B)* increasing interest in communicating with non-scientists. *(C)* Frequency distribution of the impact of outreach on communication skills in undergraduate students (-5 = strong negative impact, +5 = strong positive impact).

following the intervention. Based on a knowledge gain of only 9.52%, we conclude that this specific aspect of auditory signaling was, not covered in the classroom effectively. Similarly, responses to the question regarding location of the brain in the central nervous system (question 10) did not show the gains we would have hoped to see (increase of 7.94%; p =0.62) although this particular concept was not generally incorporated into the hands-on portion of the event.

In hindsight, questions 2 and 10, which focused on auditory signal conduction and central vs peripheral nervous system definition respectively, were not adequately addressed during the event, which has led to changes in how these topics will be addressed in future events. Question 4 was a True/False question with nearly 85% of participants answering the question correctly on the pre-event assessment, and only 83% of students answering correctly on the post-event assessment (Table 1; p>0.9999). The number of students getting this question right on the pre-event assessment was the highest achieved across the study and this high initial response rate likely prevented us from achieving significant learning gains for this question. In addition. It may also suggest that independent True/False questions may not be the best measure of knowledge (Frisbie, 1973). Finally, question 8 (average weight of a human brain) represented a somewhat trivial fact that was not a focus of any of our hands-on learning events and gains were not statistically significant (p = 0.14). Thus, when questions are examined on an individual basis, those questions in which we did not see gains either had a very high initial correct response rate, or were not a focus during the event. Thus, our assessments allowed us to not only measure the effectiveness of our event, but to make changes in an effort to increase the effectiveness of the event in the future.

Altogether, these data emphasize the importance of including engaging elements for each learning objective, without which learning gains are minimal (Freeman et al., 2014). We found that students exhibited the highest learning gains on questions that involved hands-on activities (e.g., concussions being demonstrated by trying to break an egg, peripheral nervous system being demonstrated using the reaction time demo, functions of the lobes being demonstrated with the sheep brain activity). Questions that assessed facts that were mentioned during the presentation that did not have a hands-on component (e.g., weight of the human brain, peripheral vs central nervous system) did not result in significant gains. From these findings, we confirm that (1) hands-on activities using active learning are critical for the highest learning gains and (2) assessments are important so that instructors can gauge and adjust future events to result in maximal learning gains from their students. In future outreach events, we intend to ensure that each learning objective is tied to active learning components using hands-on demonstrations.

Limitations of the Assessment

Although our outreach event was successful in engaging middle school students in neuroscience resulting in significant learning gains, there were several limitations.

First, we had a small number of questions on our assessment, and all of these questions were either multiple choice or true/false. We designed our assessment this way in order to reduce the time burden on the teachers and also to maximize attention span in the students. These types of assessments are also easy and objective to score, but do not assess the full learning gains of the students that open-ended or essay questions might. Another limitation of our assessment strategy was that the post-test occurred 2-7 days after we visited the classroom. This was by design in order to assess long-term retention rather than immediate recall. After leaving the classroom, we no longer controlled how the content was followed up on by the teachers adding the potential for variability to the student experience. However, we feel that having an assessment strategy in place is the most effective way to improve teaching strategies for future events. Future assessments should include open-ended questions, and should also evaluate changes in student attitudes towards science in response to the outreach event. Finally, about 27.6% of our students did not complete the post-test. This is likely because teachers either forgot or did not have time to give their students the post-test within the 2-7-day period. Although we provided reminders via email, this was not entirely effective at ensuring that all students completed the post-test. It is possible that providing an incentive for teachers would increase the post-test response rate.

Undergraduate Attitudes Towards Science Outreach

Our outreach event also fit our goal of engaging undergraduate students in teaching and outreach efforts. Students that engage in these teaching activities have been shown to become more confident, communicate more effectively, and learn new teaching skills (Carpenter, 2015). The results of our undergraduate survey indicate that in addition to improving students' ability to communicate with non-scientists the event had the greatest impact on students' interest in continuing to communicate with non-scientists. It is of utmost importance for undergraduate students to learn how to organize materials, speak effectively in public, and deliver a clear message by teaching others something new (Parvis, 2001). Undergraduate student instructors gained valuable teaching skills by participating in creating a lesson plan, delivering the lesson, and reflecting upon the learning gains made by the middle schoolers, they taught. Perhaps the most valuable effect of the outreach event for undergraduate students was increasing appreciation of the importance of building relationships with community members, which has been shown to be mutually beneficial to students and society (Webster & Hoover, 2006). Altogether, outreach experiences prepare undergraduate students for a culturally diverse workforce and instill an understanding of the importance of community engagement by scientists.

Importance of In-class Outreach

While departmental open houses and science festivals are important and should be encouraged, they rarely engage members of the public who are not already interested in science, and attendance is often skewed towards individuals and families with higher incomes and education levels (Bultitude, 2014; Jensen and Buckley, 2014; Kennedy et al., 2017; Payne, 2017). By partnering with local schools and taking our event to the classroom, we were able to reach underserved and underrepresented individuals who would not otherwise have experienced our activities through an open house event. The school district in which we primarily volunteered our time is composed of >47% Hispanic/Latino students, ~8% African American students, 2.5% Asian students and ~37% Caucasian students (Michigan's Center for Education and Performance Information, 2016-2017b). Greater than 63% of the district's students are considered economically disadvantaged (Michigan's Center for Education and Performance Information, 2016-2017a). Classroom events served as a marketing tool to encourage students to bring family members to our open house event at the end of the week, encouraging families to participate in an event that they might not have otherwise attended. Continuing to evaluate outreach efforts, including the population that is reached, as well as learning outcomes of the event is important if we are to improve our reach, and effectively illustrate the importance of science in our world (Jensen, 2015; Baram-Tsabari et al., 2017; Kennedy et al., 2017).

Increasing the Number of Scientists Involved in Outreach

In addition to increasing the quality and effectiveness of science outreach, it is also important to increase the number of scientists (e.g., faculty members and undergraduate students) participating in science outreach and communication. It is encouraging that interest in science communication and outreach continues to grow within the scientific community. Searches of the PubMed database for "Science Communication" or "Science Outreach" reveals increases of >70 fold and >200 fold respectively (Figure 6). Similar to our own undergraduate students, some of the primary reasons that scientists give for engaging in these

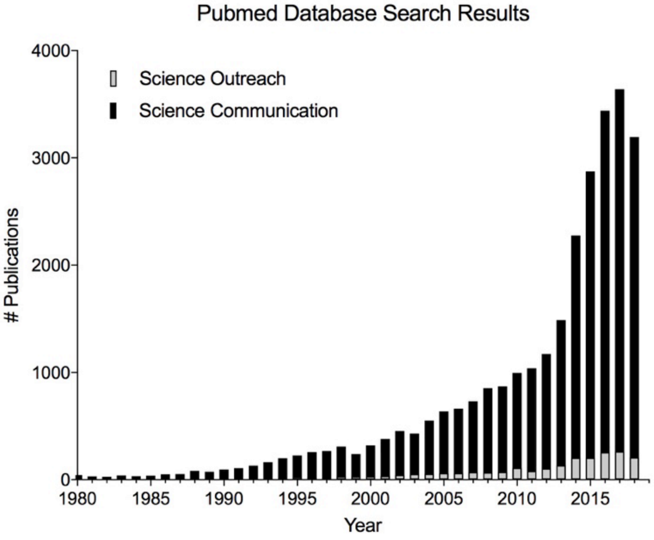

Figure 6. Number of publications found through a PubMed search for "Science Outreach" (gray) and "Science Communication" (black) clearly demonstrates a rise in the interest in science outreach among scientific scholars.

activities are 1) to inspire young students to think about careers in science fields and 2) to engage the public in understanding the importance of science in their lives (Leshner, 2003; Laursen et al., 2007; Brownell et al., 2013; Komoroske et al., 2015; Yawson et al., 2016). Despite the students, postdoctoral fellows and faculty members from physics, astronomy and biology fields were involved in some increase in outreach engagement, only 58% of graduate form of educational outreach in 2009 (Ecklund et al., 2012), leaving plenty of room for improvement.

Previous studies have explored the barriers that discourage and impede outreach participation by scientists (The Royal Society, 2006), which include fear that “dumbing down” their research will hurt their image among their peers (Hartz and Chappell, 1997), along with a lack of time, funds, or both (Devonshire et al., 2014). However, data suggest that scientists engaged in scientific outreach and communication are often more academically productive (Jensen et al., 2008; Bentley and Kyvik, 2011). Increasingly, scientific societies, private companies, and granting agencies (e.g., National Science Foundation) are encouraging public outreach and communication. In addition, a number of higher education science programs across the country have realized the value of science communication and outreach and are introducing science communication courses and initiatives (Devonshire et al., 2014; Stony Brook University, n.d.). These courses are offered, both by universities and colleges as well as scientific societies, to encourage individuals in the sciences to make their research and career relatable to the everyday public (Baram-Tsabari et al., 2017; Turney J., 1994; Greer et al., 2018; Brownell et al, 2013). We are hopeful that with mentors who demonstrate the value of science outreach and communication the next generation of scientists will be more engaged in the public forum.

CONCLUSION

We have provided a simple lesson plan for an in-class outreach event led by undergraduate instructors along with an assessment technique that demonstrates that students are meeting many of the learning objectives put forward by the instructors. These gains were achieved through hands-on active learning, in combination with demonstrations and traditional teaching. In addition, we show that engaging undergraduates in outreach events led to improvements in science communication skills and an increased desire to continue engaging in science outreach events.

Increasingly, scientists are being asked not only to perform high quality science, but to communicate knowledge gained to both their peers and the general public. However, career scientists, faculty, graduate and undergraduate students rarely receive guidance in how to conduct such outreach. Here we have provided a blueprint for engaging undergraduate students with science communication and outreach through the development, implementation, and evaluation of an outreach event aimed at engaging middle school students who are underrepresented in STEM fields. Science outreach, similar to science education, is significantly improved when coordinators utilize some form of impact evaluation, yet this important step is often overlooked. With deliberate effort and careful evaluation design, it is possible to truly determine the effectiveness of an event (Jensen, 2015). In this way, organizers not only excite and entertain participants, but also help them reach specific learning objectives, even when those objectives are not explicitly laid out to the participants. Thus, undergraduate students were encouraged to incorporate assessment into the event to demonstrate the effectiveness of the event. Continued evaluation of our own event will attempt to measure both students’ and instructors’ general attitudes toward neuroscience, and their ability to explain how neuroscience shapes their interactions with the world.

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Address correspondence to: Peter J. Vollbrecht, Assistant Professor, Department of Biomedical Sciences, Western Michigan University Homer Stryker M.D. School of Medicine, 1000 Oakland Dr., Kalamazoo, MI, 49008. peter.vollbrecht@med.wmich.edu

Andrew J. Gall, Assistant Professor, Department of Psychology, Hope College, 35 E. 12th St., Holland, MI 49423. gall@hope.edu

APPENDIX 1

Supplemental Table 1. Questions (with foils) and the correct answer (bolded).

Question	Answer choices
1. Without this, you could very easily get a concussion.	A. Skin **B. Cerebrospinal Fluid** C. Optic Nerve D. Neurons
2. How does sound get to your brain?	A. Optic Nerve B. Your Hair **C. Auditory Nerve** D. Motor Nerve
3. Imagine that you touch a hot iron. Ouch! Which of the following is NOT involved in feeling the hot iron, and pulling your hand away?	A. Spinal Cord B. Sensory Nerves **C. Memory** D. Motor Nerves
4. True or False: Nerves can carry sensory information into the central nervous system OR they can carry motor information out from the central nervous system.	**A. True** B. False
5. What allows you to properly identify an object without seeing it?	**A. Memory** B. Optic Nerve C. Sight D. Reflex
6. What is the major function of the occipital lobe?	A. Interpret Hearing **B. Perceive Vision** C. Form Speech D. Recognize Touch
7. What is the major function of the temporal lobe?	**A. Interpret Hearing** B. Control Vision C. Form Speech D. Recognize Touch
8. How much does a human brain weigh?	A. About 7 pounds. B. **About 3 pounds**. C. About 12 pounds. D. About 1 pound.
9. Which of the following is part of the peripheral nervous system?	A. Brain B. Spinal Cord **C. Nerves** D. Frontal Lobe
10. The brain is part of the _____________ nervous system.	**A. Central** B. Peripheral C. Parasympathetic D. Autonomic

APPENDIX 2

Outreach Survey for Undergraduate Students

Open-Ended Questions

Directions: Please answer the following questions thoroughly and honestly.

1. Why did you choose to be involved with outreach?
2. What effect, if any, has outreach had on your neuroscience skills or knowledge?
3. Does outreach build any useful skills that aren't part of your neuroscience courses? If yes, please explain.
4. What responsibilities do you think scientists have for educating others?

Outreach Impact

Directions: Please rate how this outreach event has impacted you:
-5 (a significant negative impact on your life or skills)
0 (no impact)
+5 (a significant positive impact of your life or skills)

1. Your leadership skills
2. Your understanding of neuroscience concepts or skills
3. Your self confidence
4. Your confidence in your neuroscience knowledge of concepts or skills
5. Your communication skills
6. Your presentation skills
7. Your time management skills
8. Your organizational skills
9. Your teaching skills
10. Your excitement about science communication

Agreement with Statements

Directions: Please rate the extent to which you agree with the following statements.
1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, 5 = Strongly Agree

This outreach experience…

1. …increased my interest in conducting outreach.
2. …improved my communication skills.
3. …helped me explain concepts to non-scientists.
4. …was a valuable addition to my undergraduate training.
5. …was an engaging process.
6. …sparked my interest in teaching others.
7. …made me more confident.
8. …increased my interest in communicating with non-scientists.

Demographic Information

1. Please list your major(s).
2. Please list your minor(s), if any.
3. What is your graduating class?
4. What is your gender?
    a. Male
    b. Female
    c. Prefer not to answer
5. I identify my ethnicity as (select all that apply):
    a. Asian
    b. Black/African
    c. White/Caucasian
    d. Hispanic/Latinx
    e. Native American
    f. Pacific Islander
    g. Prefer not to answer
    h. Other: ____________
6. In what ways were you involved in this outreach event? (select all that apply)
    a. Lesson Plan Development
    b. In-class volunteer