Received: 17 December 2018 | Revised: 8 March 2019 | Accepted: 27 March 2019

DOI: 10.1002/jnr.24429

RESEARCH ARTICLE

Quantitative assessments reveal improved neuroscience engagement and learning through outreach

Vidya Saravanapandian[1,2,3,5] | Erin M. Sparck[1,4,6] | Karen Y. Cheng[1] | Fei Yu[7] | Courtney Yaeger[1] | Terry Hu[1] | Nanthia Suthana[5,8] | Rafael Romero-Calderón[1,5,9] | Cristina A. Ghiani[1,2,10] | Christopher J. Evans[2,5] | Ellen M. Carpenter[1,2,5] | Weihong Ge[1,2]

[1]Interdepartmental Program in Neuroscience, University of California, Los Angeles, Los Angeles, California

[2]Department of Psychiatry and Biobehavioral Science, David Geffen School of Medicine, University of California, Los Angeles, Los Angeles, California

[3]Center for Autism Research and Treatment, Semel Institute for Neuroscience, University of California, Los Angeles, Los Angeles, California

[4]Department of Psychology, University of California, Los Angeles, Los Angeles, California

[5]Brain Research Institute, University of California, Los Angeles, Los Angeles, California

[6]Office of Instructional Development, University of California, Los Angeles, Los Angeles, California

[7]Department of Biostatistics of UCLA Fielding School of Public Health, University of California, Los Angeles, Los Angeles, California

[8]Department of Neurosurgery, David Geffen School of Medicine, University of California, Los Angeles, Los Angeles, California

[9]Department of Molecular Cell and Developmental Biology, David Geffen School of Medicine, University of California, Los Angeles, Los Angeles, California

[10]Department of Pathology & Laboratory Medicine, David Geffen School of Medicine, University of California, Los Angeles, Los Angeles, California

Correspondence
Ellen M. Carpenter and Weihong Ge, Department of Psychiatry and Biobehavioral Science, David Geffen School of Medicine, University of California, Los Angeles, 635 Charles E Young Dr. South, room 307, Los Angeles, CA 90095.
Emails: Ecarpenter@mednet.ucla.edu; Wge@mednet.ucla.edu

Funding information
UCLA Neuroscience Interdepartmental PhD program (NSIDP); UCLA Brain Research Institute (BRI); UCLA Instructional Improvement (IIP) Grant from UCLA's Office of Instructional Development, Grant/Award Number: NIH 5U54HD087101-04

Abstract

Lack of resources and exposure to neuroscience in K-12 education has resulted in a limited number of K-12 students pursuing higher education in the field. Meanwhile, the rapid expansion of the field of neuroscience has encouraged many higher educational institutes to offer neuroscience majors. This has opened up the opportunity to engage faculty, as well as graduate and undergraduate students in bringing the most needed knowledge and awareness about neuroscience into K-12 classrooms. However, undergraduate neuroscience curricula have limited formal opportunities to engage in outreach, and few existing programs have assessments to determine their effectiveness. To address these needs, we developed quantitative assessment tools that complement an existing neuroscience outreach program—Project Brainstorm—at the University of California, Los Angeles (UCLA). 29 UCLA undergraduates enrolled in the 2016 and 2017 programs participated in this study, along with 298 K-12 students from local schools across the Los Angeles area. In undergraduate students, we assessed (a) improvement in students' teaching/communication abilities across the course of the outreach program, and (b) confidence in explaining neuroscience topics and interest in pursuing teaching career. In K-12 students, we evaluated (a) knowledge gain in neuroscience topics and (b) interest in pursuing higher education. Overall, Project Brainstorm showed significant improvement in all the above-mentioned categories. The assessment tools and data presented here provide a data-driven approach for optimizing neuroscience outreach programs and can easily be adapted to other outreach programs within neuroscience and in other STEM fields.

KEYWORDS

K-12 STEM education, learning, neuroscience outreach, quantitative assessment, teaching

1 | INTRODUCTION

Opportunities for exposure to neuroscience are often limited in K-12 education due to a variety of factors including: (a) lack of curricular resources, (b) K-12 teachers having little formal training in neuroscience, (c) scarcity of the overall funding dedicated to develop K-12 neuroscience educational programs, and (d) limited textbook space devoted to the nervous system or other interdisciplinary intersections of neuroscience (Darling-Hammond & Baratz-Snowden, 2007; National Center for Educational Statistics, 2011). As a result, only a small number of K-12 students become aware of the exciting advances and wealth of information available about the nervous system. This lack of exposure to neuroscience, and to science in general, contributes to the relatively low number of K-12 students who pursue science in higher education or prepare to enter the science and technology workforce (National Science Board, 2010).

Meanwhile, the rapidly expanding field of neuroscience has encouraged an increasing number of higher education institutes to offer majors in neuroscience (Coskun & Carpenter, 2016; Ramos, Esposito, O'Malley, Smith, & Grisham, 2016). An undergraduate major in neuroscience is a worthwhile investment as it provides a strong foundation for graduate or professional education and it opens doors to multidisciplinary careers, including biomedicine, data analytics, and health policy. The establishment of these majors has thus opened up the opportunity to integrate community outreach into college education. Having been recognized as a great complement to currently under-resourced public STEM education by federal agencies (Editorial, 2009; Stevens, 2011), outreach programs at universities engage faculty, graduate, and undergraduate students, providing opportunities to impart much-needed awareness and knowledge from their expertise to a broader audience. Given the lack of resources in K-12 education, anecdotal evidence indicates that some institutions of higher education have recognized these needs and are developing outreach activities/programs for neuroscience students both nationally (Brabb, Lack, & Rector, 2008; Butcher, Do, Wensler, Shah, & Thorne, 2010; Deal, Erickson, Bilsky, Hillman, & Burman, 2014; Gittis, 2009; McLaughlin et al., 2010; Stevens, 2011) and internationally (Yawson et al., 2016). Undergraduates additionally benefit from outreach activities as they receive opportunities to develop communication skills, understand the public perception of neuroscience, and gain teaching experience while testing their own expertise. However, formal opportunities to engage in outreach as part of an undergraduate curriculum are still limited and even less effort has been devoted to developing assessment tools to evaluate the effectiveness of existing outreach programs. Thus, formalizing an assessment for effectiveness of these programs would serve as a useful step to integrating outreach efforts as part of neuroscience education.

Significance

Most K-12 students have limited exposure to neuroscience, due to insufficient school resource and lack of K-12 teacher knowledge about neuroscience. UCLA has developed a neuroscience outreach program engaging faculty, graduate, and undergraduate students to impart awareness and knowledge of the brain to K-12 students. Here, we demonstrate quantitative assessment tools that measure the efficacy of an existing neuroscience outreach program in UCLA. The assessment tools and findings, together with teaching resources and framework of our program, provide an effective model for outreach programs in other institutions. We strongly believe these tools will improve neuroscience engagement and learning through outreach, and ultimately facilitate the making of a strong STEM workforce.

To address this need, we sought to develop sustainable assessment tools for an existing outreach framework at the University of California, Los Angeles (UCLA). Project Brainstorm, a field experience and outreach course (Romero-Calderon et al., 2012) offered by the Interdepartmental Program in Neuroscience every year provides a well-defined opportunity for neuroscience graduate and undergraduate students at UCLA to interact with K-12 students in the local community. As originally conceived (Romero-Calderon et al., 2012), this 10-week course provides formal guidance to undergraduate students in developing lesson plans on a variety of timely neuroscience topics that are tailored to specific age groups (elementary school, middle school, or high school), and requires that they design creative hands-on activities to complement their lesson plan (Figures 1a and S1). In addition, undergraduate students present a series of interactive "stations" (Figure 1b) that demonstrate foundational concepts in neuroscience (e.g., human brain anatomy, comparative brain anatomy, brain injury, and brain plasticity) to K-12 students. Project Brainstorm students also participate in the annual Brain Awareness Week activities, a well-received global initiative to educate the public about the brain and diseases of the nervous system. Since the inception of Project Brainstorm in 2006, over 100 schools have been visited

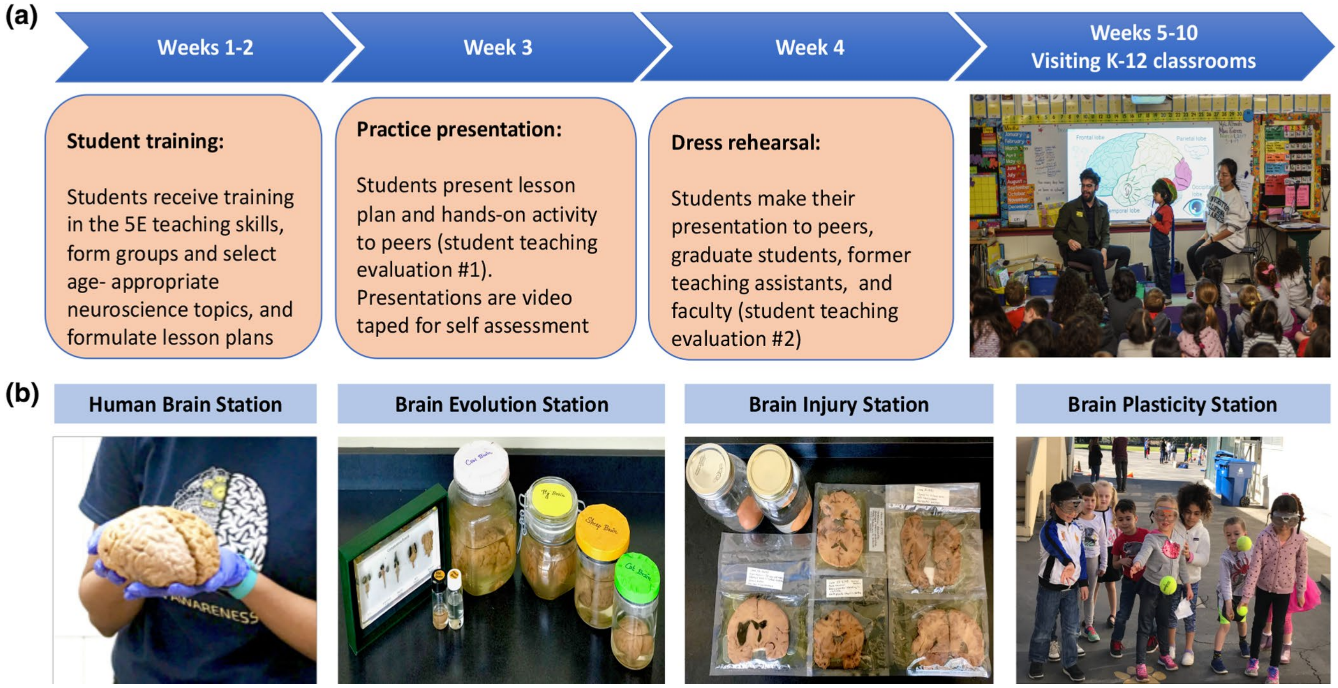

FIGURE 1 Project Brainstorm program outline (a) Flow chart and description of activities during the 10 weeks of the quarter. (b) Illustration of materials used for the different interactive learning stations

(a)

Project Brainstorm students	Program Objectives
7 Graduate Students	• Exercise Neuroscience expertise through coaching • Build leadership abilities • Strengthen advocacy and fund raising skills • Enhance organizational abilities
150 Undergraduate Students	• Consolidate neuroscience knowledge through teaching • Improve teaching and communication skills • Enhance teamwork and organizational skills • Inspire young minds
6000 K-12 Students	• Gather insightful interactive exposure to neuroscience • Build interest in STEM and higher education • Develop self-awareness to brain research

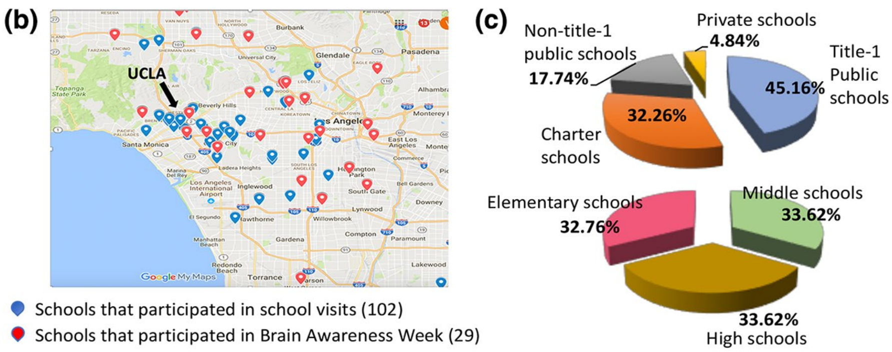

FIGURE 2 Impact of Project Brainstorm from 2011 to 2017. (a) Program objectives for Project Brainstorm participants. (b) Distribution of greater Los Angeles schools that participated in Project Brainstorm and/or Brain Awareness Week between 2011 and 2017. Number of schools in each category is given in parentheses. (c) Distribution of school type and grade level of participating schools

within the greater Los Angeles community. Locations and demographic distribution of schools visited between 2011 and 2017 is included in Figure 2b,c.

To improve and strengthen Project Brainstorm's outreach efforts, we developed a series of assessments to quantitatively measure the efficacy and effectiveness of this program. Herein, we have summarized these assessment tools and data collected from 298 K-12 students and 29 undergraduate students. We first studied the development of teaching and communication skills in undergraduate students, as well as their preference for teaching as a career, before and after participating in Project Brainstorm activities. We then examined K-12 students' neuroscience learning and interest in science before and after exposure to Project Brainstorm activities. Our results demonstrate that K-12 student participants and undergraduates alike show an improvement in neuroscience knowledge. Project Brainstorm's activities have a positive impact in motivating K-12 students toward pursuing higher education in science, as well as inspiring undergraduates to pursue teaching careers. The assessment tools and data presented here can be easily applied to facilitate the evaluation of other outreach programs in general and provide a data-driven pathway for optimizing outreach programs in the future.

2 | METHODS

2.1 | Participants

29 UCLA undergraduates who enrolled in Project Brainstorm in 2016 and 2017 participated in this study along with 298 K-12 students. The latter were from 15 schools in the Los Angeles area, which received visits from Project Brainstorm in 2016 and 2017 and completed pre- and post-visit surveys. Demographic information for representative schools visited are included in Figure S2. Prior to the day's activities, parents and/or legal guardians of the K-12 students provided signed consent forms to allow for the activities to be recorded and used for educational purposes.

2.2 | Ethical standards and subject consent

This study was reviewed by the Ethics Committee of the Medical Faculty of the University of California Los Angeles, and was found to be exempt under section 45 CFR 46.102(d) of the Federal Regulation for Protection of Human Subjects. Subject consent forms were collected and properly documented before all the surveys were performed.

2.3 | Good teaching practices training

The Project Brainstorm course began by providing undergraduate students with some basic teaching skills. Students received evidence-based training on effective teaching practices. Lectures introduced the 5E (Engage, Explore, Explain, Elaborate and Evaluate) Instructional Model (Bybee, 1997), and covered the importance of "desirable difficulties," or strategies that lead to better long-term retention and flexible representations of knowledge (e.g., retrieval practice, spacing of important points, etc.) in teaching and learning (Bjork & Bjork, 2011). Students also played a "Tappers and Listeners" game that demonstrated the "curse of knowledge," a cognitive bias that occurs when experts or individuals with more knowledge of a situation assume that novices understand and have access to the same knowledge (Froyd & Layne, 2008). The "curse of knowledge" is a roadblock to effective communication during teaching and learning, as teachers may have a difficult time placing themselves in the position of the learner (i.e., the presenters assume that K-12 students have the same scientific background knowledge and try to present their topic with materials and explanations geared toward undergraduate neuroscience majors). Students were required to implement these skills into their teaching preparation. Over the course of the class, student presentations were assessed through a series of practice presentations in class, before their school visits (Figures 1a and S1).

2.4 | Undergraduate student teaching assessment

Teaching evaluation forms were created based on common good practices recommended to new teachers in general. Fifteen questions were chosen to form the assessment. Each question (Q) was carefully designed to measure different components of effective teaching: Q1–Q10 evaluated whether the 5E effective teaching approaches were properly applied; Q11–Q12 were content-related assessments to determine whether lesson plans were organized systematically with age appropriate information; Q13–Q15 tested improvement on general speaking skills, such as fewer verbal fillers, more eye contact or proper voice projection, to name a few. Teaching evaluation forms were scored on a Likert scale 7-point survey, where 7 indicated outstanding (needed no improvement) and 1 indicated poor (needed much improvement). Each lesson plan was evaluated twice, during both the practice presentation and dress rehearsal presentation by instructors, coordinators, and student peers involved in the outreach program. Additionally, presenters were given the opportunity for self-assessments through videotape recordings of practice presentations (Figures 1a and S1). As students prepared to deliver their lessons at K-12 classrooms, these video assessments were used to help strengthen their communication skills and improve their overall presentation. For each question, the following comparisons were performed using the Mann–Whitney test to evaluate students' improvement: (a) 1st quarter practice versus 1st quarter dress rehearsal, and 2nd quarter practice versus 2nd quarter dress rehearsal to evaluate the improvement after training in each quarter; (b) 1st quarter dress rehearsal versus 2nd quarter practice to check whether training effect gets carried over to the second quarter; and (c) 1st quarter practice versus 2nd quarter dress rehearsal to evaluate the overall improvement after two trainings.

2.5 | Undergraduate student survey on neuroscience and teaching interests

All undergraduate students completed a survey at the end of the Project Brainstorm course to assess: Q1–Q2: their overall confidence/intention to pursue teaching as a potential career, and to determine if there were any shifts after Project Brainstorm experience; Q3–Q4: improvement in their ability to convey neuroscience topics to individuals with or without neuroscience background; Q5–Q6: whether Project Brainstorm helped to gain a deeper understanding of the particular neuroscience topic they or their peer students chose, and Q7: whether Project Brainstorm as a formal undergraduate course was an overall valuable experience. A Likert scale 7-point survey was used for these assessments, where 7 indicated "strongly agree" and 1 indicated "strongly disagree" (Figure S3). The change to each survey question after Project Brainstorm experience was assessed among all students using the Willcoxon matched-pairs test.

2.6 | Evaluation of K-12 student learning on neuroscience concepts

To measure K-12 students' comprehension of neuroscience topics, we developed assessments that evaluated their understanding and knowledge retention of the specific neuroscience topics presented in their classrooms. These assessments addressed the unique topic covered in each classroom and were thus individually tailored for use in a specific class. The assessments were composed of 3–6 multiple-choice questions that were designed to address key learning objectives drawn from lesson plans established for each classroom and adjusted for age-appropriate difficulty levels. An example of these questions is provided in Figure S4.

The sets of questions for each K-12 classroom visit were generated by the presenting undergraduate students and vetted by the instructors of the course prior to being administered to K-12 classrooms before (pre-visit) and after (post-visit) Project Brainstorm's visits. Pre-visit surveys were administered to K-12 students either immediately before the presentations or a week before the school visit, while post-visit surveys were administered a week after the presentation, in order to assess long-term, but not immediate, knowledge retention (Soderstrom & Bjork, 2015). To assess individual K-12 students neuroscience topic-specific learning, we gathered the students' ID numbers on these surveys as identifiers, and applied a paired comparison to detect differences between the pre and post-test for each student and to assess individual progress.

2.7 | Survey of K-12 student STEM interest

To gauge the interest of K-12 students in pursuing higher education in STEM, and to determine if exposure to Project Brainstorm activities affected this interest, we designed another category of questions, i.e., "STEM interest questions" (Figure S5). This set included six questions constructed to assess K-12 students' overall interest in learning neuroscience and science in general, and their intention to pursue higher education. The same set of STEM Interest Questions was administered to each classroom and school that was visited. These questions were administered both pre-visit and post-visit, following the same schedule as the neuroscience topic-specific questions. Since the pre- and post-visit survey were performed anonymously, two sample Mann–Whitney test was performed to examine the difference after Project Brainstorm experience.

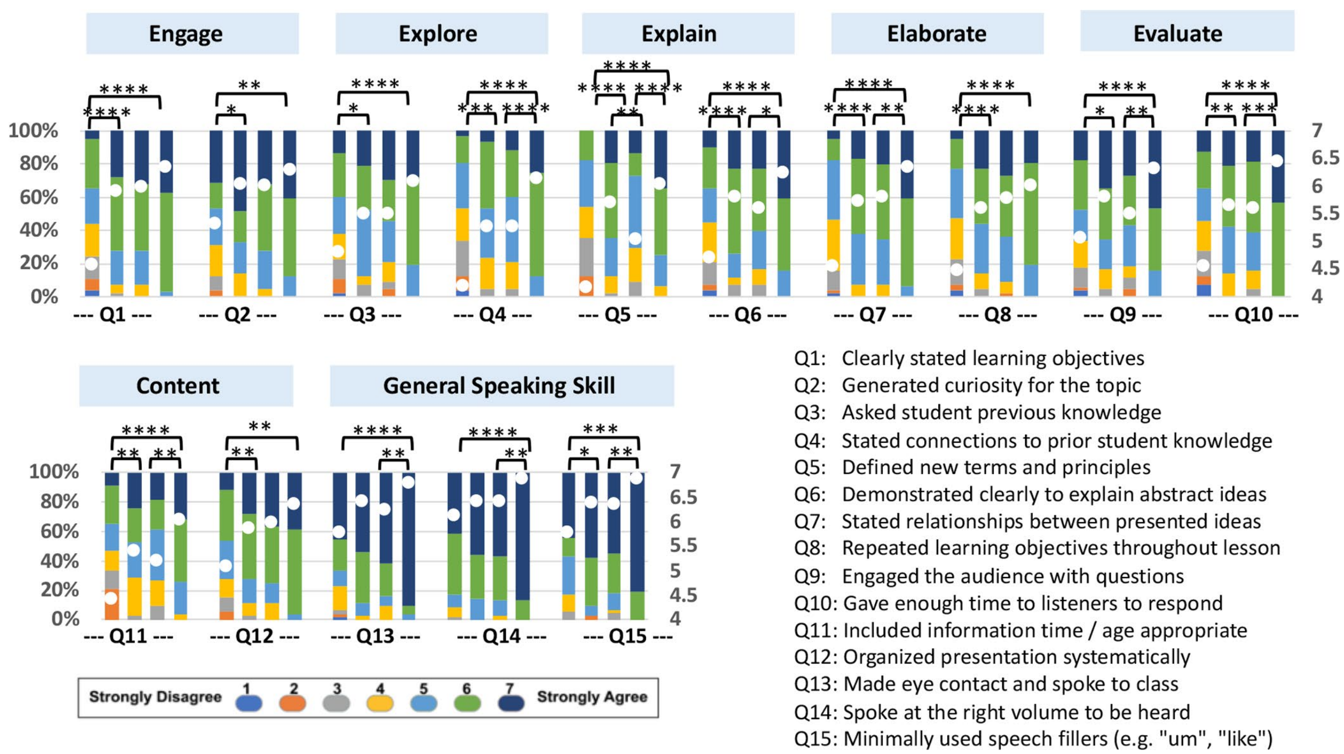

FIGURE 3 Undergraduate students showed continued improvement in their teaching and Communication abilities after having taken Project Brainstorm class. Likert scale assessment survey was administrated to evaluate 11 undergraduates' presentation skill in 2017 Project Brainstorm class. For each question in the survey, there are four columns corresponding to 4 presentations from left to right (a) 1st quarter practice, (b) 1st quarter dress rehearsal, (c) 2nd quarter practice, and (d) 2nd quarter dress rehearsal. For each column, stacked percentage of the response for each of 7-point scale with different colors was shown on the left *Y*-axis, while the white dot indicated the mean score of the response based on the scale in the right *Y*-axis. Statistical significance of corresponding comparisons from Mann–Whitney test were shown at the top across the columns (****$p < 0.0001$, ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$)

3 | STATISTICAL ANALYSES

For Likert scale survey, we assessed the difference in responses across all participants before and after Project Brainstorm experience using nonparametric tests. We performed Mann–Whitney test for two-sample unpaired comparison and Wilcoxon matched-pairs test for two-sample paired comparison. While sum of ranks or signed ranks was used to assess the statistically significant differences in the comparisons, the means of score was displayed to show the direction of changes. GraphPad Prism 8.0 (GraphPad Software; La Jolla, CA, United States; www.graphpad.com) was used for all analyses. Cohen's *d* analysis was used to describe the standardized mean difference of an effect, measuring the practical significance of the work (http://staff.bath.ac.uk/pssiw/stats2/page2/page14/page14.html). Statistical significance was defined by $p < 0.05$ and statistical tests were two-sided in all the analyses.

4 | RESULTS

4.1 | Undergraduate students showed improvement in teaching and presentation skills after attending Project Brainstorm

During the 1st quarter of 2017, shown as in the first two stack columns in Figure 3, undergraduate students showed significant levels of improvement between practice and dress rehearsal presentations (Figures 1 and S1) in the majority of the categories. The biggest improvements were related to 5E teaching approach assessments (Figure 3 top panel), such as clearly stated learning objective (Q1), stated connection to prior student knowledge (Q4), defined new terms and principles (Q5), demonstrated clearly to explain abstract ideas (Q6), stated connections between presented ideas (Q7), repeated learning objectives throughout lesson (Q8). Approximately 75% of these students were part of a special program that required them to enroll in both Winter and Spring quarters to qualify for full course credit. Hence, we compared the 1st quarter dress-rehearsal presentations and the 2nd quarter practice presentations (the second and third columns in Figure 3) to determine whether such improvements were maintained. No significant changes in scores were found for most of the questions, except for Q5: defined new terms and principles. When we compared performances between practice presentations versus dress rehearsal presentations from the 2nd quarter of 2017, students continued to show a significant improvement in 10 out of 15 categories (the third and fourth columns in Figure 3). The remaining five categories did not show significant improvement in the second quarter. This could be due to students having higher baseline scores to begin with, or students maintaining improvement through the course of the second quarter. The most significant improvements overall were still related to the 5E teaching approach assessment, such as stated connection to prior student knowledge (Q4), defined new terms and principles (Q5), and gave enough time to listeners to respond (Q10). Moreover, we found significant improvement in all categories between 1st quarter practice presentation and 2nd quarter dress rehearsal presentation (the first and fourth columns in Figure 3).

4.2 | Undergraduate students expressed increased confidence in communicating science and increased interest in pursuing teaching careers

Surveys (Figure S3) for gauging undergraduate students' interest in neuroscience and teaching revealed a significant increase in their interest in teaching (Q1) after participating in Project Brainstorm (Figure 4). Importantly, they showed a significant boost of confidence in their overall teaching skills (Q2), as well as in communicating neuroscience to others, including a general audience unfamiliar with neuroscience topics (Q3–Q4; Figure 4). Moreover, a majority of students strongly agreed that they had a better understanding of both the neuroscience topic that they picked for their presentations (Q5: Mean => 6.18/7) and of those their peers presented (Q6: 6.63/7). Most students (Q7: 6.9/7) strongly agreed that Project Brainstorm was overall a rewarding and worthwhile experience.

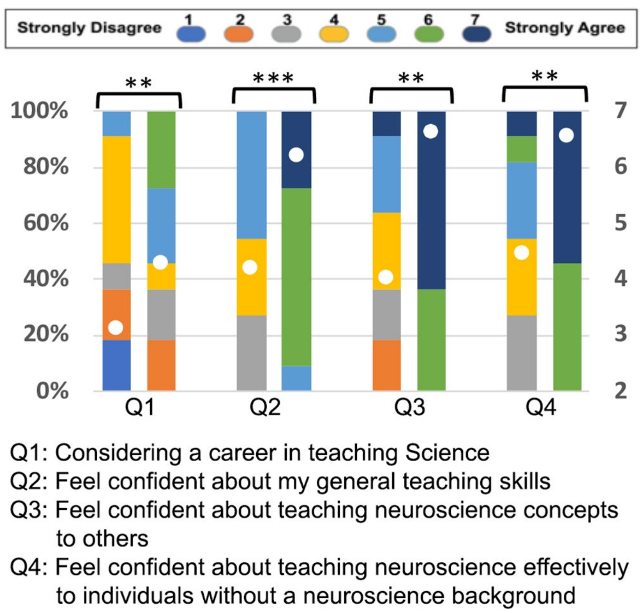

FIGURE 4 Project Brainstorm significantly boosted their ability to effectively teach and communicate their knowledge to a general audience, and positively influenced undergraduate students' interest in pursuing a career in teaching. Likert scale 7-point self-assessment survey was administrated to 11 undergraduates who enrolled 2017 Project Brainstorm class. Two columns for each question represented answers before (the first column) and after (the second column) taking Project Brainstorm. For each column, stacked percentage of the response for each of 7-point scale with different colors was shown on the left *Y*-axis, while the white dot indicated the mean score of the response based on the scale in the right *Y*-axis. Sum of signed ranks was used in Wilcoxon matched-pairs test (***$p < 0.001$, **$p < 0.01$)

4.3 | Project Brainstorm significantly enhanced K-12 students' neuroscience learning

Pre- and post-visit responses to neuroscience topic-specific questions were analyzed from seven K-12 schools—three elementary, two middle, and two high schools—visited during the Winter and Spring quarters of 2016 (Table 1). Despite the variation in topics and student ages, all the subject groups showed gains in topic-specific knowledge as indicated by the medium to very large effect size between the pre- and post-visit responses, suggesting that the presentations' main learning objectives had been met. More importantly, long-term learning appeared to have occurred as shown by post-visit retention of topic-specific knowledge.

4.4 | Project Brainstorm significantly enhanced K-12 students' STEM interest

Finally, pre- and post-visit STEM Interest Question surveys were collected from 298 K-12 students across a variety of ages and grade levels (Figure S5). A significant change was observed for all questions between the pre- and post-visit surveys (Figure 5), indicating that Project Brainstorm effectively increased K-12 students' interest in learning science and understanding the brain and its functions (Q1, Q5–Q6, Figure S5). Notably, our analysis revealed that K-12 students showed a much stronger intention to attend college or pursue science as a future career (Q2–Q 4; Figure S5) after the Project Brainstorm visit.

TABLE 1 Comparisons of K-12 students' pre- and post-visit responses to neuroscience topic-specific questions on the topics the K-12 students were taught

Topic & type of school	Number of students per classroom	Number of questions	Pre-TEST (mean ± *SD*)	Post-TEST (mean ± *SD*)	Inferential statistics[a]	Effect size[b]
Vision & Sleep Elementary School	24	3	1.750 ± 0.794	2.333 ± 0.761	$t\,(23) = 2.933$; $p = 0.007$	0.599
Motor High School	33	4	1.364 ± 0.929	2.394 ± 1.029	$t\,(32) = 4.36$; $p < 0.001$	0.759
Neuroplasticity Middle School	37	5	2.054 ± 0.998	3.189 ± 0.938	$t\,(36) = 6.524$; $p < 0.001$	1.073
Memory Elementary School	38	6	2.868 ± 1.398	4.895 ± 1.134	$t\,(37) = 7.346$; $p < 0.001$	1.192
Senses Elementary School	40	3	1.216 ± 0.787	1.973 ± 0.726	$t\,(39) = 4.976$; $p < 0.001$	0.818
Motor Middle School	116	5	2.405 ± 1.165	3.578 ± 1.136	$t\,(115) = 7.811$; $p < 0.001$	0.725
Stress High School	23	6	3.696 ± 1.396	4.783 ± 1.166	$t\,(22) = 2.926$; $p = 0.008$	0.610

[a]Paired student's *t* test. [b]Cohen's *d* analysis.

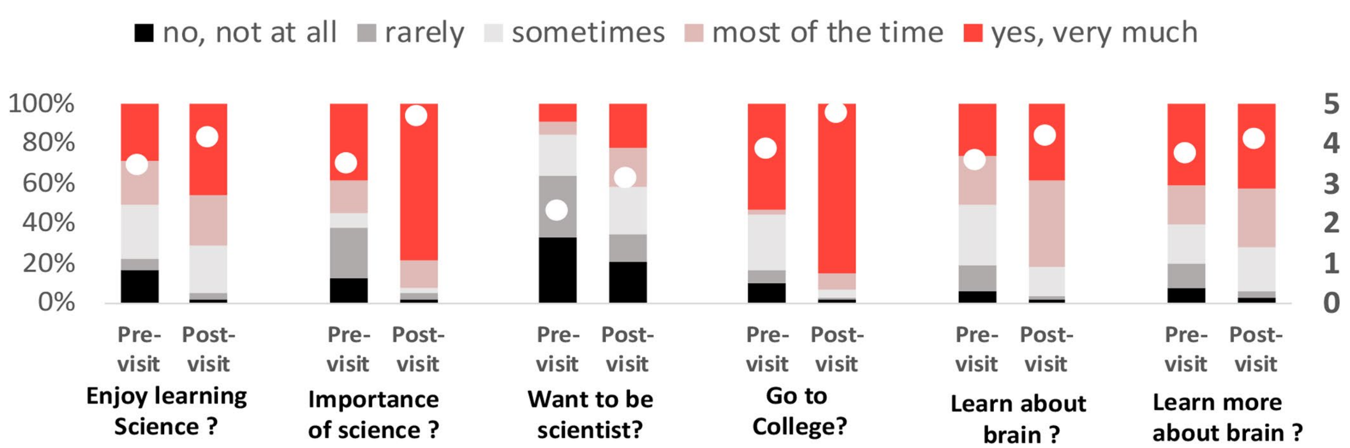

FIGURE 5 Project Brainstorm significantly enhanced K-12 students' interest in Brain research and motived them to pursue higher education. For each column, stacked percentage of the response for each of 5-point scale with different colors was shown on the left *Y*-axis, while the white dot indicated the mean score of the response based on the scale in the right *Y*-axis. Sum of ranks was used in Mann–Whitney test (****$p < 0.0001$, *$p < 0.05$)

5 | DISCUSSION

We have developed teaching and learning assessment tools to measure the effectiveness and efficacy of an existing outreach program, Project Brainstorm, at UCLA. Teaching evaluations were based on general common good practices recommended in training new teachers. Undergraduate students developed questions for the pre- and post-visit tests based on the main ideas K-12 students were taught. Through these newly developed tools, we found that Project Brainstorm is effective in improving undergraduate students overall teaching/communication skills, developing their interest in pursuing teaching as a career, and increasing K-12 students science knowledge and interest in STEM.

Overall, the students who participated in Project Brainstorm retained the improved teaching/communication skills throughout the second quarter (Figure 3). It is worth noting that Q5 was the only skill that didn't retain the improvement in the beginning of the second quarter. Defining new terms and principles successfully, requires that the presenter has a good "a priori" understanding of their audience's background, as well as their knowledge and comprehension of the topic. This observation suggests that the "curse of knowledge" is a continuous hurdle for students and initially can prevent effective communication. Remarkably, Q5 together with Q4 are also the two skill sets that showed the most significant continuous improvement in the second quarter between practice presentations and dress rehearsal presentations (Figure 3 top panel). The most effective teachers will connect students' previous knowledge to the novel unknown and guide them to explore and learn (Ambrose, 2010). Hence, the continuous positive effect that Project Brainstorm had on the students' ability to define new terms effectively and connect with the audience's previous knowledge strongly supports its usefulness in effectively improving teaching skills.

Furthermore, participation in Project Brainstorm clearly boosted the undergraduate students' confidence in communicating neuroscience and helped consolidate their neuroscience knowledge. A growing body of evidence suggests that teaching or even just preparing to teach others (Cohen, Kulik, & Kulik, 1982; Nestojko, Bui, Kornell, & Bjork, 2014; Peets et al., 2009; Rohrbeck, Ginsburg-Block, Fantuzzo, & Miller, 2003; Roscoe & Chi, 2007) has learning benefits not only for the pupil, but also for the teacher. Effective teaching requires a strong grasp of knowledge, and above all that the knowledge be structured and communicated in a clear and logical fashion. From interactions during teaching, teachers are required to continuously update their knowledge, as well as refine the structure and methods of communication. University opportunities in which students teach others can thus serve as a valuable learning-through-teaching experience, consolidating student knowledge and developing communication skills that may help facilitate the transition to post-college positions. For instance, undergraduate students enrolled in Project Brainstorm have shown evidence of improved confidence in teaching and better understanding of the variety of neuroscience concepts. These are skills that would directly transfer to teaching or neuroscience research careers, but would also assist students in preparing for careers involving strong communication skills, such as journalism, public policy, and law.

Our observations also provide strong evidence that Project Brainstorm significantly benefited the K-12 school students who participated in the program. STEM interest survey questions administered in every school visit generated a large sample size of 298 K-12 students and their analysis suggested a significant improvement in every category, including both the general interest about neuroscience and basic neuroscience learning. For each school visit, a different topic-specific questionnaire was designed to gauge learning specific to each lesson plan. Hence, the sample size was limited to 30–50 students per class. Using their student IDs as identifiers, we were able to detect improvements of each student before and after presentation. Additionally, based on anecdotal observation, we noticed that when we sent pre-visit surveys before our school visit and asked K-12 classroom teachers to administer the survey, we usually obtained higher average scores in pre-visit surveys than what we obtained when we administered the survey ourselves right before presenting the lesson. One possible reason for this could be that teachers prime the students on the topic being evaluated. Thus, it is imperative to remind K-12 classroom teachers not to prime their students before testing, in order to generate an objective result. Future studies will also address the influence of gender of trainees and K-12 students on the outcome measures. This would be valuable in understanding the impact of outreach programs in motivating more women to pursue STEM careers.

This is a comprehensive study to quantitatively assess both neuroscience undergraduates' and K-12 students' knowledge gain through a neuroscience outreach program. In order to help outreach programs in other schools to adapt and generate classes and lesson plans about the brain, we have provided these assessment tools (surveys, pre- and post-visit assessments, etc.) together with course description and curriculum (Figures S1, S3–S5). Representative lesson plans/presentations and presentation videos can also be provided upon request.

In summary, UCLA's Project Brainstorm outreach program incorporates learning-through-teaching strategies in the undergraduate classroom and is truly making a significant impact on the community. It provides a valuable experience that can foster the undergraduates' interest and knowledge in neuroscience and a teaching career. Such efforts should not be and are not limited to neuroscience outreach, and can easily be adapted by and applied to other STEM fields. We make it our mission as a public university to bring our expertise from classrooms to communities, particularly those with modest resources (45.16% of K-12 schools we visited are Title 1 schools), and provide a dynamic and impactful learning experience. By bringing our enthusiasm and expertise to K-12 students, we strive to improve their understanding of neuroscience as well as to create an opportunity to promote and grow the interest in STEM. The quantitative assessment tools provided here, together with our outreach program framework and teaching resources, provide effective models for other educational outreach programs to adapt. Moreover, the assessment tools and data presented set up a data-driven pathway for optimizing outreach programs. We strongly believe these efforts into quantitative assessments to improve neuroscience learning and engagement through outreach will facilitate the making of a stronger STEM workforce.

ACKNOWLEDGMENTS

We warmly thank all our neuroscience undergraduates, as well as the K-12 students who participated in our program and made this work possible. We thank Drs. Arnold Scheibel and Joseph Watson for their effort in establishing Project Brainstorm as an outreach education program in UCLA. We thank Dr. Elizabeth Ligon Bjork for assistance with developing an approach for assessment. We especially thank the UCLA Brain Research Institute (BRI) for supporting this outreach work throughout the years. This work was funded by the BRI, the Neuroscience Interdepartmental PhD program (NSIDP), and an Instructional Improvement (IIP) Grant from UCLA's Office of Instructional Development.

CONFLICT OF INTEREST

All the authors listed above declared no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. *Conceptualization*, W.G., V.S., E.M.C., C.J.E., and C.A.G; *Methodology*, E.M.S., K.Y.C., V.S., E.M.C., and W.G.; *Investigation*, V.S., E.M.S., K.Y.C., C.Y., T.H., and W.G.; *Formal Analysis*, V.S., E.M.S., F.Y., and W.G.; *Writing—Original Draft*, V.S., E.M.S., E.M.C., and W.G.; *Writing—Review & Editing*, V.S., E.M.S., K.Y.C., F.Y., C.Y., N.S., R.R., C.A.G., C.J.E. E.M.C., and W.G.

ORCID

Cristina A. Ghiani https://orcid.org/0000-0002-9867-6185

Weihong Ge https://orcid.org/0000-0003-2218-6291

REFERENCES

Ambrose, S. A. (Ed.). (2010). *How learning works: Seven research-based principles for smart teaching*. San Francisco, CA: Jossey-Bass.

Bjork, E. L., & Bjork, R. A. (2011). Making things hard on yourself, but in a good way: Creating desirable difficulties to enhance learning. In M. A. Gernsbacher, R. W. Pew, L. M. Hough, & J. R. Pomerantz (Eds.), *Psychology and the real world: Essays illustrating fundamental contributions to society* (pp. 56–64). New York, NY: Worth Publishers.

Brabb, S., Lack, J., & Rector, D. (2008). *Undergraduate neurophysiology students as role models for engaging elementary school students in science through a Kids Judge! Neuroscience Fair, Program No. 222.16*. 2008 Neuroscience Meeting Planner. Washington, DC: Society for Neuroscience.

Butcher, G., Do, R., Wensler, H., Shah, G., & Thorne, S. (2010). *Brain awareness week as a vehicle for undergraduate service- learning, Program No. 22.14*. 2010 Neuroscience Meeting Planner. San Diego, CA: Society for Neuroscience.

Bybee, R. (1997). *Achieving scientific literacy*. Portsmouth, NH: Heinemann.

Cohen, P. A., Kulik, J. A., & Kulik, C. C. (1982). Educational outcomes of tutoring: A meta-analysis of findings. *American Educational Research Journal*, *19*(2), 237–248. https://doi.org/10.3102/00028312019002237

Coskun, V., & Carpenter, E. M. (2016). Life science-based neuroscience education at large Western Public Universities. *Journal of Neuroscience Research*, *94*(12), 1384–1392. https://doi.org/10.1002/jnr.23928

Darling-Hammond, L., & Baratz-Snowden, J. (2007). A good teacher in every classroom: Preparing the highly qualified teachers our children deserve. *Educational Horizons*, *85*(2), 111–132.

Deal, A. L., Erickson, K. J., Bilsky, E. J., Hillman, S. J., & Burman, M. A. (2014). K-12 neuroscience education outreach program: Interactive activities for educating students about neuroscience. *Journal of Undergraduate Neuroscience Education*, *13*(1), A8–A20.

Editorial. (2009). Encouraging science outreach. *Nature Neuroscience*, *12*, 665. https://doi.org/10.1038/nn0609-665

Froyd, J., & Layne, J.. (2008). *Faculty development strategies for overcoming the 'curse of knowledge'*. 2008 38th Annual Frontiers in Education Conference. https://doi.org/10.1109/FIE.2008.4720529

Gittis, A. (2009). *Brain awareness as a laboratory project in an undergraduate behavioral neuroscience class, Program No. 24.3*. 2009 Neuroscience Meeting Planner. Chicago, IL: Society for Neuroscience.

McLaughlin, M., Moeller, M., Brandt, S., Guns, A., Kimbro, A., & Dever, B. (2010). *Integrating course requirements with brain awareness objectives in the community. Neuroscience Meeting Planner*. San Diego, CA: Society for Neuroscience; Program No. 22.16. Online.

National Center for Educational Statistics. (2011). Retrieved from https://nces.ed.gov/pubs2011/2011317.pdf

National Science Board. (2010). Science and engineering indicators. Retrieved from https://wayback.archive-it.org/5902/20160210221014/http://www.nsf.gov/statistics/seind10/pdfstart.htm

Nestojko, J. F., Bui, D. C., Kornell, N., & Bjork, E. L. (2014). Expecting to teach enhances learning and organization of knowledge in free recall of text passages. *Memory & Cognition*, *42*, 1038–1048. https://doi.org/10.3758/s13421-014-0416-z

Peets, A. D., Coderre, S., Wright, B., Jenkins, D., Burak, K., Leskosky, S., & McLaughlin, K. (2009). Involvement in teaching improves learning in medical students: A randomized cross-over study. *BMC Medical Education*, *9*, 55. https://doi.org/10.1186/1472-6920-9-55

Ramos, R. L., Esposito, A. W., O'Malley, S., Smith, P. T., & Grisham, W. (2016, April 15). Undergraduate neuroscience education in the U.S.: Quantitative comparisons of programs and graduates in the broader context of undergraduate life sciences education. *Journal of Undergraduate Neuroscience Education*, *15*(1), A1–A4.

Rohrbeck, C. A., Ginsburg-Block, M. D., Fantuzzo, J. W., & Miller, T. R. (2003). Peer-assisted learning interventions with elementary school students: A meta-analytic review. *Journal of Educational Psychology*, *95*(2), 240–257. https://doi.org/10.1037/0022-0663.95.2.240

Romero-Calderón, R., O'Hare, E. D., Suthana, N. A., Scott-Van Zeeland, A. A., Rizk-Jackson, A., Attar, A., ... Watson, J. B. (2012). Project brainstorm: Using neuroscience to connect college students with local schools. *PLoS Biology*, *10*(4), e1001310. https://doi.org/10.1371/journal.pbio.1001310

Roscoe, R. D., & Chi, M. T. H. (2007). Tutor learning: The role of explaining and responding to questions. *Instructional Science*, *36*, 321–350. https://doi.org/10.1007/s11251-007-9034-5

Soderstrom, N. C., & Bjork, R. A. (2015). Learning versus performance. In D. S. Dunn (Ed.), *Oxford bibliographies online: Psychology* (pp. 176–199). New York, NY: Oxford University Press.

Stevens, C. (2011). Integrating community outreach into the undergraduate neuroscience classroom. *Journal of Undergraduate Neuroscience Education*, *10*(1), A44–A49.

Yawson, N. A., Amankwaa, A. O., Tali, B., Shang, V. O., Batu, E. N., Asiemoah, K., Jr., … Karikari, T. K. (2016). Evaluation of changes in Ghanaian students' attitudes towards science following neuroscience outreach activities: A means to identify effective ways to inspire interest in science careers. *Journal of Undergraduate Neuroscience Education*, *14*(2), A117–A123.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Saravanapandian V, Sparck EM, Cheng KY, et al. Quantitative assessments reveal improved neuroscience engagement and learning through outreach. *J Neuro Res*. 2019;97:1153–1162. https://doi.org/10.1002/jnr.24429