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Article

Neuroscience Workshops for Fifth-Grade School Children by Undergraduate Students: A University–School Partnership

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The National Science Education Standards recommend that science be taught using inquiry-based approaches. Inspired by the Dana Alliance for Brain Initiatives, we examined whether undergraduate students could learn how to conduct field research by teaching elementary school children basic neuroscience concepts in interactive workshops. In an inquiry-based learning experience of their own, undergraduate psychology students working under the close supervision of their instructor designed and provided free, interactive, hour-long workshops focusing on brain structure and function, brain damage and disorders, perception and illusions, and drugs and hormones to fifth-graders from diverse backgrounds, and we assessed the effectiveness of the workshops using a pretest–post-test design. The results suggest that the workshops enhanced the children's knowledge of neuroscience concepts as measured using pre- and post-open-ended assessments. The undergraduates also found their learning experience engaging and productive. The article includes detailed descriptions of the workshop activities, procedures, the course in which the undergraduates implemented the workshops, and guidance for future university–school collaborations aimed at enhancing science literacy.

INTRODUCTION

Neuroscience Workshops for Elementary School Children: A University–School Partnership

It is well established that learning is more durable and easily applied to real-world settings when interactive teaching methods are used (Pascarella and Terenzini, 1991; National Research Council [NRC], 1996). The inquiry-based approach whereby students are actively engaged in meaningful, student-centered knowledge building is better than the traditional lecture format for developing higher-order thinking (Thier, 2000) and active problem-solving skills (Polman, 2000). Inquiry-based learning experiences develop stronger independent and critical thinking skills, more positive attitudes and curiosity toward science, and increased achievement in content knowledge compared with lecture-format learning experiences (Kyle *et al.*, 1982, 1988; Leonard, 1983; Shymansky, 1984; Hall and McCurdy, 1990; Knight and Wood, 2005).

In addition to recommending more interactive science-learning experiences, educational reform movements also increasingly argue for K–12/higher educational partnerships to engage universities in issues of importance to the community such as improvement of teaching and learning in our schools (Edgerton, 2001). Project 2061 (http://www.project2061.org/default_flash.htm) is a long-term initiative of the American Association for the Advancement of Science (AAAS) to enhance science, technology, and mathematics literacy and to engage the public in the process. To encourage early scientific literacy, Project 2061 recommends that the brain be introduced to children as early as kindergarten.[1] The current official California state curriculum re-

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[1] Project 2061 recommends that K–2 students learn that thinking happens in the brain, that senses warn about danger, and that the

quires that physiology be introduced to students in the fifth grade (California Department of Education, 2000). Although the brain and nervous system could be introduced as a physiology topic, there is no explicit mention of the brain or related functions in the California standards beyond the level of the senses. None of the schools contacted for this project currently included neuroscience concepts in their fifth-grade curriculum beyond introducing the students to biological systems and the visual and auditory senses. School representatives that we contacted, however, communicated that they would be eager to add basic neuroscience concepts to their curricula. Although California's state curriculum guidelines are in alignment with the National Science Education Standards (NRC, 1996), they lag behind the neuroscience recommendations of AAAS at the elementary school level, highlighting an area where the public might be well served by university–school partnerships.

In a recent national survey, 98% of parents reported that they think that science education is important, even for children who will advance to nonscience or engineering careers (Bayer Foundation, 2003). In addition, 81% indicated their belief that science education should be given the same emphasis in elementary school as reading, writing, and math. Science is not given this emphasis in their child's early education, 56% of the parents reported, a finding corroborated in a more recent survey (Johnson et al., 2006) where 52% of parents of elementary school children reported that they believed their children's schools were not teaching the "right amount" of science and math courses. The Bayer Foundation survey also shows that 87% of the participants agreed that hands-on learning is the most effective teaching method for science. These beliefs are consistent with the recommendations of the AAAS (1993) and the NRC (1996), which endorse the practice of inquiry-based and other interactive experiences.

Neuroscience can easily be taught to elementary school children using interactive approaches. Cameron and Chudler (2003) recommend that children be exposed to neuroscience concepts in a fun and interactive format, and they suggest that doing this in the early school years has several important advantages.

1. Children are naturally curious about their senses at this age and can easily learn to gather empirical evidence.
2. Children, who may themselves be afflicted with neurological or learning disorders, or know someone who is, may benefit directly from learning about neuroscience.
3. Neuroscience education can be a way to show children the harmful consequences of illicit drug use.
4. Students will be in a better position to critically evaluate the complex and often contradictory findings reported in the media and popular culture.
5. Exposing children to neuroscience may help to influence their decisions to enter the neuroscience-related professions that offer many job opportunities.

An effective way to introduce neuroscience to elementary school children is to use university students as facilitators by forming partnerships between universities and elementary schools (NRC, 1997). As Cameron and Chudler (2003) aptly point out, undergraduates may be better able than scientists to be effective teachers. This partnership model whereby universities and schools work together to enhance educational opportunities for university students and school children, was successfully adopted, for example, by Emory University and Binghamton State University using graduate teaching fellows (Stamp and O'Brien, 2005). Partnerships between university faculty and students and K–12 teachers have the potential to confer benefits for all parties involved (for a helpful discussion of possible pitfalls and recommended approaches, see Moreno, 2005). The schools benefit from instruction as long as the instructors are well trained and have specific expertise in their teaching area, and the universities may benefit by providing opportunities for their students to learn directly about teaching environments and to learn specific teaching skills. These partnerships may also inspire future teachers from the ranks of the undergraduate students and the children (Tomanek, 2005).

If structured, organized, and supervised, a university–school partnership can be used as an opportunity to engage undergraduates in applied inquiry-based science, especially when the effectiveness of the partnership is evaluated. As a way to expose students in the psychology department to neuroscience concepts beyond a single introductory course in their sophomore year, to actively engage them in scientific inquiry, to expose elementary school children to more information about the brain than they would experience in their standard curriculum, and to engage university students in the university–school partnership, the first author developed a university course where undergraduates could use their neuroscience backgrounds in a community service project addressing the mission of the Dana Alliance. The project was designed for the undergraduates to learn about research by addressing a real-world problem and for them to learn how to design, conduct, analyze, and report on the outcomes of the project using an open-ended inquiry approach (D'Avanzo and McNeal, 1997). Thus, the course provided an opportunity for inquiry-based learning for the undergraduates as well as for science enrichment for the fifth-graders.

We hypothesized that the undergraduates would be able to effectively teach basic neuroscience concepts to elementary school children and that the course in which the university students developed, presented, and evaluated the workshops would provide a valuable learning experience for the undergraduates. We surmised that these interactive workshops could help schools to meet National Science Education standards (NRC, 1996), while also enhancing their students' science literacy as recommended by Project 2061 (http://www.project2061.org/default-flash.htm).[2]

brain sends messages to the rest of the body to make it work. In grades 3–5, they should learn about communication between the brain and other body parts. AAAS also recommends that children at the elementary school level learn that drugs can harm the body, including the brain.

[2] As a result of these workshops, students should understand the form and function of the brain and its relation to the body (unifying concepts and processes content standard). They should also develop an understanding of general characteristics of the human brain and that a behavioral response requires coordination and communication at many levels including cells, organ systems, and whole organisms (life sciences standard). The workshops should also engage

Table 1. Demographic summary of workshop participants

School	Type of school	Ethnicity	Income description
1	Public school on the urban fringes of large city	73% White (non-Hispanic), 7.9% Asian, 7.7% Hispanic, 0.6% African American	4% Students eligible for free/reduced lunch; most families middle to high income
2	After-school program for public school in inner city	67% African American, 25% Hispanic, 1.3% Asian, 2.4% White	Family income at/below 75% of the federal poverty level was required for participation in after-school program
3	Private nonsectarian school in large city	28% Students of color	12% Receive financial aid for tuition; most families middle to high income
4	Private Catholic school in inner city	75% Hispanic, 4.7% Asian, 4.33% African American, 2.75% White	Approximately 75% low income

Undergraduate students who were enrolled in an upper-division research course in psychology conducted the workshops described in this article. All students had successfully completed introductory courses in research methodology, statistics, and brain and behavior. The students, several of whom are coauthors on this article, were responsible for reviewing the literature on curriculum for elementary school-aged children, the AAAS, and California State curriculum guidelines, and for developing age-appropriate goals with associated activities for the workshops. They devised questions based on the workshop goals and conducted pre- and postworkshop assessments, in addition to running the workshops.

The research question we examined was whether fifth-graders' knowledge about the brain could be enhanced in workshops aligned with AAAS standards using interactive approaches (D'Avanzo and McNeal, 1997), and whether the project developed by the undergraduates would be an engaging and positive learning experience for them.

MATERIALS AND METHODS

Workshop Facilitators

Eight undergraduate psychology majors (six females, two males) who were enrolled in a class in the Psychology Department of Loyola Marymount University planned, created, and facilitated the workshops. The senior seminar course, which was titled Special Studies: Neuroscience for Kids (worth three semester units) and was developed by the instructor, counted toward the departmental upper-division Empirical Methods requirement for graduation. Five of these students were juniors, whereas one student was a senior and two students were sophomores. Requirements for admission to the class, limited to eight students, were that the students had achieved at least a B grade in Brain and Behavior, Statistics, and Research Methods and had previous experience working with children. Final admission to the class was determined on the basis of an interview with the instructor assessing interest in the topic, graduate school plans, and work ethic.

students in scientific inquiry (science as inquiry standard) and enhance their appreciation of technological advances in neuroscience (science and technology standard). The workshops should enhance the students' understanding of their own health and cognition, provide them with an appreciation for how drugs and hormones can change their behavior, health, and processing and augment the students' knowledge about characteristics and changes that occur in people as a function of how their brains are working (science in personal and social perspective standard).

Participants

We conducted a citywide search for elementary schools that would be interested in participating in our workshop, and, through personal contacts, contacted their principals. In our initial communications, we proposed a workshop that would educate their fifth-grade students about the functions and structures of the brain. After the initial contact, we selected schools that expressed an interest in the program and could devote the necessary time (at least one 1-h-long workshop) and resources (a large room with space for the workshop stations, including access to an electrical outlet for the computer). Four different school sites (an after-school program and public, private secular, and private nonsecular schools) agreed to host our class presentation at a selected time in April 2004. They were also willing to distribute a preworkshop assessment, given a week before the seminar, and a postworkshop assessment, given a week after the seminar,[3] to be used as a way to determine the effectiveness of the workshop. The study was conducted with the approval of the Human Subjects Review Board of Loyola Marymount University and the teachers, school principals, and program directors, and with consent of the children's parents and assent of the children.

The parents of 117 children consented to have their fifth-grade children participate in the workshops. Of these children, 99 (50 males, 49 females) completed both the pre- and post-tests. Attrition was due to the children being absent from class on the days the tests were given. As shown in Table 1, the participants were from diverse socioeconomic backgrounds and represented a cross-section of ethnic groups in the Los Angeles area.

The undergraduate students, teachers, and principals were provided with free copies of *The Dana Sourcebook of Brain Science* provided by the Dana Foundation, which also supplied free handouts of resources about the brain (*Brain Connections* and *Answering Your Questions about Brain Research*) that we gave to the parents, and an activity booklet (*It's Mindboggling*) for the children to keep.

Method and Procedure: Senior Seminar Course

The course was structured by having specific short-term goals, such as topic selection, community interest reports, activities presentations, scoring rubric development, data scoring, data analysis, and poster development.[4] After review of the AAAS guidelines for science curricula (AAAS, 1993), the National Science Education Standards (NRC, 1996), and the California State Curriculum guidelines (California Department of Education, 2000), the undergraduate students and instructor chose the following as major workshop topics: brain structure and function, brain damage and disorders,

[3] One school forgot to administer the assessment before spring break, affording us the inadvertent opportunity to assess the longer-term effects of our workshop, as we address in *Results*.

[4] The course syllabus is available upon request from J.G.F.

perception and illusions, and drugs and hormones. Two undergraduate students were responsible for the activities and assessment questions chosen for each topic, and they continued to work in these small groups throughout the duration of the course.

In the first week of the class, students divided into groups of two. The professor assigned specific tasks to each group so students could achieve the course goals. The groups shared their progress with the class on a weekly basis, after which the professor and other students provided feedback. Several weeks were spent on topic selection and activity selection with the professor and other students providing feedback about appropriateness of the topics and activities. The criteria required for each activity were that they be both informative and interactive. The resources consulted for the specific workshop goals are provided below. General resources are provided in Supplemental Material A. They included Internet and text resources. If the students were unable to find a published activity for their topic they developed activities on their own.

The undergraduate students then gave pilot presentations of the selected activities, which were followed by feedback from the team. The professor guided discussion about assumed background knowledge of the children, difficulty of the tasks for children of that age, as well as their educational value, and whether the task would sustain the children's interest. In circumstances where we disagreed, we made final decisions by voting.

The specific roles of the professor were to provide structure and organization for the 15-wk course and to facilitate inquiry and decision-making by the group. The students were expected to meet the deadlines for the subgoals in the course, to fully participate in classroom discussions and decision-making, and to work together as a team. The team members shared contact information such as e-mail addresses and phone numbers so that they could regularly consult with each other and with the professor. This team approach facilitated a strong sense of collaboration among the members.

The undergraduate students ran the workshops with supervision provided by the professor. The students decided to have four workstations corresponding to the four selected topics through which the children rotated in the workshops. The two members of the group who had planned and prepared the activities for that topic ran each workstation.

During the last week of the course, the students were required to present their findings at a regional undergraduate conference in a format of their choice. They chose to present their findings in a poster format at the Stanford Undergraduate Psychology Conference. The students were also invited to present the findings at the 34th Annual Meeting of the Society for Neuroscience, accompanied by the instructor, the following fall (this was not a course requirement). All of the students elected to present. Poster development was a collaborative exercise, with two students assigned to develop drafts of each section.

All of the students were invited to be coauthors on the present article (also not a course requirement). Those who chose not to be coauthors were unable to meet the time requirements due to work, class schedules, or both. Preparation of the manuscript was conducted on the instructor's and student's own time; in retrospect, it would have been helpful to have a second course dedicated to preparation of the final manuscript.

Method and Procedure: Workshop

We visited four schools for the hour-long workshop on weekdays in April 2004 that were convenient for the undergraduate students, teachers, and school principals. Although we had asked each school to give us as much time for workshops as possible, and as many as possible, each site only allowed us one workshop of 1 h each. Although we realized that this time allotment was not ideal for achieving our objectives, we understood the reasons for the reluctance of the schools to devote more time to the workshops that might have taken valuable time away from the regularly scheduled activities or curriculum, a critically important issue in spring when standardized testing is typically given. Furthermore, none of the sites had previously engaged in university–school partnerships like this workshop, and they were reluctant to devote any more time to our novel intervention without first knowing if it was effective.

We allowed approximately 15 min for setup and another 15 min for cleaning and packing up at the conclusion of each workshop. We found it most convenient for all involved if we could set up during recess or lunch break, when the children were not in the room. The workshop began with a 10-min introduction to the brain, using visual aids (as described below) presented to the entire class. The other three main topics were presented in small stations that the children rotated between after 10-min intervals. We used a kitchen timer to signal when to rotate to the next station; this was useful for both the presenters and the children, who were often too engrossed in activities to pay attention to time. Furthermore, this enabled us to use the limited amount of time as effectively as possible. Although we accomplished our workshop goals in the hour-long intervention, future programs would accomplish more by having several workshops throughout the year. The disadvantage to the schools of having multiple workshops is the loss of class time, a particular problem during spring, when schools prepare for standardized testing. We recommend that scheduling be carefully coordinated with classroom teachers.

Workshop Outline

Brain Structure and Function. Instructional goals: to be able to identify major parts of the brain (the hemispheres; frontal, parietal, temporal, and occipital lobes; and the cerebellum), to describe the brain (size, weight, texture, and color), to describe the major components of a neuron, and to be able to explain the function of neurons as messengers.

1. A life-sized plastic model of the brain was used to facilitate the children's learning about the major parts of the brain, as well as the size, weight, texture, and color of the brain.
2. Using a black-and-white handout of the four lobes of the brain and the main structures of the brain (http://faculty.washington.edu/chudler/neurok.html) and referring to a color overhead transparency of their handout on an overhead projection system, the children color coded the lobes of the brain with crayons by referring to the transparency.
3. The next activity consisted of constructing a candy neuron (modified from http://faculty.washington.edu/chudler/lesson1.html) from one large marshmallow, 10 gumdrops, one jellybean, five toothpicks, a red licorice stick, and one wooden skewer. Referring to a large poster showing what part of the neuron each candy represented and using stepwise demonstrations, we placed the licorice on the skewer (axon), attached the large marshmallow to the tip of the skewer (cell body), placed two gumdrops on each of the five toothpicks and attached the toothpicks to the marshmallow (dendrites), and then attached the jellybean to the other end of the skewer (terminal button). The children were told that they could eat their "neuron" during the workshop or take it home, depending on the school's preference.
4. In our final activity for this unit (modified from http://faculty.washington.edu/chudler/chmodel.html), the group formed a circle to display how messages are transmitted in the brain. We gave each child a piece of candy representing the message being transmitted in the brain. The candy was to be held in the student's left hand. One person started the transmission by passing the candy to the person on the left. On receiving the candy the next person would pass their candy to the left. This activity continued until the "message" reached the last person in the circle.

Brain Damage and Disorders. Instructional goals: to be able to identify some major symptoms of brain damage or disorders (e.g., seizures, learning or memory problems, difficulties with attention, and depression), to be able to name some major brain disorders (e.g., attention deficit disorder [ADD] or attention deficit hyperactivity disorder [ADHD], dyslexia, depression, stroke, and Alzheimer's disease), to have an understanding of how fragile the brain is, and how important it is to protect it, and to understand how medical drugs can help people with brain problems (e.g., depression and ADHD).

1. We began by asking the children for examples of brain disorders. One boy told us that his uncle had just been diagnosed with brain cancer after having several seizures, and another child had a grandfather with Alzheimer's disease who was no longer able to recognize his family. This led us into a discussion of other conditions linked with brain disorders, such as ADD, ADHD, depression, and dyslexia, emphasizing that these conditions were also associated with distinct symptoms.
2. Through the use of visual aids (see Supplemental Material A), we illustrated how scientists and doctors can identify brain damage using positron emission tomography scans and magnetic resonance images (MRIs). For example, we showed the children images of the brain of a stroke patient compared with an adult with no brain damage, and asked them if they could identify the differences in the images. Likewise, we showed them images of the brains of depressed compared with recovered or nondepressed individuals, and asked them to speculate about the differences they saw in the images.
3. The children then participated in a candy neurotransmitter game developed by the undergraduates to show how the transmission of messages may malfunction due to a neurotransmitter deficiency. Four plastic cups containing different amounts of candy (representing the neurotransmitter serotonin) were used to demonstrate the effects of a neurotransmitter deficit. The students were told that they needed a specific amount of the neurotransmitter for their group to win (representing successfully sending the message across the synapse). If the students did not have enough of the candy in their cup (neurotransmitter), they had to find someone with the necessary amount from another group to win. We then discussed what would happen if there was an insufficient amount of a neurotransmitter, such as serotonin, and how medicines can help to make up for missing neurotransmitters. When the issue was raised in questions from the children,[5] we also discussed what would happen if children who had sufficient amounts of a neurotransmitter took the medicine, and the harmful consequences that might ensue.
4. To simulate the consequences of external trauma to the brain, we placed two eggs in separate Styrofoam cups: one egg was unprotected, whereas the other egg was protected (before the workshop) by a "helmet" made out of cotton balls, cellophane, and rubber bands (http://faculty.washington.edu/chudler/injury.html). Two students volunteered to drop the cups from elbow distance, and the group compared the resulting "damage" done to the "brains" to illustrate the function of the helmet and the importance of wearing one.

Perception and Illusions. Instructional goals: to understand that perception is not always accurate, that it may be influenced by past experiences and expectations, that the brain does not simply record every experience like a photograph but instead organizes similar experiences or bits of information together in groups, and that different people can see or hear the same thing but perceive it differently.

1. The children were asked to describe pictures of common scenes that contained hidden faces (for examples, see Supplemental Material A). The children were not told about the hidden faces, and most of them did not mention the faces in their description. Invariably at least one of the children would say that he/she saw a face in the picture. Then, the rest of the children would look for faces and eventually start pointing out faces that they saw in the scene. We then facilitated discussion as to why so many of us had missed seeing the faces at first, and how focusing on one aspect of a picture may make it difficult to notice other aspects.
2. While the laptop was warming up to display the video, we asked the children to compare the brain and eye to a camera and a computer. We explained that the eye is like a camera in that it records what we see fairly accurately, but that the brain is more like a computer because it uses what it knows (e.g., if this is a forest, we expect to see leaves on the trees, not faces) to process the information that the senses send it.
3. To show the children how much we normally miss in perception (Simons and Chabris, 1999), we showed a video of visual inattention (Simons, 2003) in which the children were instructed to count the number of times a person in a white shirt caught a ball being thrown from person to person in a small group. This is a distracter task. Afterward the children were asked whether they had seen anything unusual. A gorilla had in fact walked among the people in the group, unrecognized by most of the children. Rather than spoil the fun, we asked any children who had seen the "unusual" event not to reveal it, and we repeated the video and the question. It was usually necessary to run the video a final time to point out the gorilla to all of the children. We facilitated discussion as to why distractions can make accurate perception difficult and the fact that perception problems are common to all of us. We asked the children to speculate as to whether more of them would have seen the gorilla if we had not asked them to count in the distracter task.
4. The CD used in the previous activity (Simons, 2003) also contains a perception activity where the task is to identify an object in a complex scene that changes over the course of the presentation. The change is gradual, and viewers usually miss it the first time. We would then ask them to look somewhere else than they had before. The beginning image was then compared with the final image to highlight the change. We discussed why this might be a difficult task (the changes are hardest to detect when in the periphery of the picture or in a relatively unimportant detail) and what this shows us about perception (that we sometimes are not aware of changes in our environment). If time allowed, we discussed what effect changing some of the parameters of the task such as making the changes happen more quickly, would have on our ability to detect the changes.
5. Next, students examined examples of optical illusions. They discussed possible ways in which the illusions might work within the nervous system and how those mechanisms contribute to understanding about perception. For example, an image of the Three Streams (http://www.grand-illusions.com/gregory2.htm) was used to show the children that although the picture seems to contain three moving streams, there is nothing moving in the picture. We discussed how afterimages could affect perception in this illusion.

Next, we showed an image of rows of black-and-white squares (http://www.scientificpsychic.com/graphics/). The lines are parallel, although they do not seem to be parallel. We provided a ruler so that the children could prove to themselves that the lines were indeed parallel by holding the ruler directly onto the image.

In the next image, black dots fade in and out of white circles (http://www.scientificpsychic.com/graphics/). This phenomenon was explained, in simple terms, by the process of lateral inhibition. It was explained that cells (rods) in the back of the eye detect the black squares; the afterimage from the squares carries over to the white circle, explaining why people perceive black dots where the white circles are for a brief moment. Examples of other illusions can be found in Supplemental Material A.

Drugs and Hormones. Instructional goals: to understand that drugs and hormones both have effects on the brain, that they interact with each other, that medical drugs can help people with brain disorders, that drugs can hurt your brain if you do not have a problem, and that illegal drugs are especially dangerous for teenagers because their brains are growing and changing.

[5] Such as the use of someone else's prescription medicine for ADD or depression.

Table 2. Mean number of correct answers for pre- and post-tests by workshop unit and school

School	Brain structure[a]		Brain damage/disorders[a]		Perception and illusions[a]		Drugs and hormones[a]		n	
	Pretest	Post-test	Pretest	Post-test	Pretest	Post-test	Pretest	Post-test	Pretest	Post-test
1	1.89 ± 1.86	5.16 ± 2.45	3.98 ± 2.31	8.23 ± 3.48	7.15 ± 3.86	10.28 ± 3.07	2.65 ± 1.35	3.83 ± 1.75	46	43
2	1.07 ± 1.07	1.67 ± 0.82	3.57 ± 1.87	3.33 ± 2.08	5.64 ± 3.52	10.00 ± 2.35	1.07 ± 1.07	1.67 ± 0.82	14	4
3	1.57 ± 1.38	9.62 ± 5.08	4.70 ± 3.21	6.46 ± 2.91	6.73 ± 3.71	7.09 ± 4.39	2.03 ± 1.46	3.30 ± 1.70	37	33
4	1.10 ± 1.26	5.16 ± 2.65	4.00 ± 1.81	8.74 ± 3.16	6.47 ± 3.47	8.55 ± 5.02	1.50 ± 1.00	3.15 ± 1.50	20	19
Total									117	99

[a] Data are shown as mean ± SD.

1. We showed MRIs illustrating differences in the brains of people using drugs compared with those who do not use drugs. For example, brain images of a 15-yr-old drinker and nondrinker were compared (http://apu.sfn.org/content/Publications/BrainBriefings/brain_on_alcohol.html). The children were asked to describe the differences they observed and to speculate on the causes. We explained that the more red in the MRI image, the more activity in that area of the brain, and we asked the children to speculate as to why the MRI image of the drinker's brain has dramatically fewer red areas.
2. A diagram of the endocrine system was shown to the students to help explain hormones (http://www.gcsesciencedoubleaward.co.uk/images/hormones_diagram1.gif). We facilitated the children's understanding of what hormones are, the roles they play, and the names of some hormones. We also addressed the issue that, in the case of deficits, "good" drugs can be used to restore the proper amounts of hormones in the body, and in response to questions, we discussed the dangers of elevating hormone levels (e.g., through the use of steroids)[6] when no such deficit exits.
3. To demonstrate how drugs may affect memory, a volunteer from the group played the hand-held Simon game (a Hasbro product). The volunteer then played a second round after being spun in a circle. We asked the children to speculate why the second performance was not as good as the first, and what this might illustrate about the effects of drugs on memory.
4. A food "tasting" activity developed by the undergraduate students was used to illustrate the effects of drugs, "good" and "bad," on the brain. We showed the children a bag of rice cereal covered in cocoa powder, representing the healthy brain, and then showed them a bag of plain rice cereal, representing the brain with a deficit and asked which bag they would prefer. Students preferred the bag with the cocoa powder. We then asked the students what they could do to make the bags look the same (add cocoa powder to the plain cereal). We then asked the children to consider the effect of giving medicinal drugs to help someone who has some chemical missing from his/her brain. Harmful drugs were then illustrated using onion powder, which is malodorous, and we asked the children to hypothesize as to what the powder might represent (bad drugs). We ended this activity with a discussion about why good drugs help people who have some chemicals missing in their brain, and why bad drugs can hurt a healthy brain. We also discussed why taking bad drugs is especially harmful for children and teenagers while their brains undergo rapid growth, rendering them especially vulnerable.
5. Images were used to depict the negative effects of commonly known drugs such as caffeine, marijuana, cocaine, and steroids. For example, we showed a picture of a cat with enlarged eyes to show the effects of caffeine (http://mstu.cz/~bozek/obrazky/Animals/Caffeine.jpg). We then discussed these drugs and their effects.
6. We then handed out a word search puzzle that the children could take home created with words relating to drugs and hormones (for examples, see Supplemental Material A).

Assessment

The undergraduate groups independently designed questions for a workshop assessment to be handed out by the teachers 1 wk before our visit and approximately 1 wk after our visit. Each group developed four (brain structure and function, perception and illusions, and drugs and hormones) or five (brain damage and disorders) questions that represented workshop subgoals (Supplemental Material B). The instructor and undergraduates discussed these questions in class. Criteria for selection of the questions were that they be clear, age-appropriate, and reasonable, given the activities. Draft questions were submitted to the class and instructor who debated their effectiveness in meeting these criteria. The instructor further revised edited questions.

In consultation with the instructor, each group also designed a detailed scoring rubric of their assessment questions. Answers to each question were scored according to the rubric by both group members assigned to that topic and determined by consensus of the group members. The instructor resolved disagreements. Inter-rater reliability ranged from 0.90 to 0.97. To maintain the children's anonymity, they selected their own codes to use on the pre- and post-tests for identification purposes.[7] Postworkshop assessments were conducted in a similar manner, with the scorers blind to the children's responses on the pretest. Maximum scores possible for each unit ranged from 11 (for drugs and hormones) to 28 for the brain structure unit. The highest scores possible for the brain damage and disorders and the perception and illusions units were 15 and 22, respectively.

RESULTS

The data were analyzed with four separate 2 (time) × 4 (school) mixed analyses of variance (ANOVAs). The descriptive statistics are given in Table 2. The means represent the score each school received on the pre- and post-test questionnaires.

Brain Structure

Results from the mixed ANOVA revealed significant effects of time [$F(1,36) = 80.51$; MSE = 6.05; $p = 0.001$] and school

[6] Several students at each school confided that they personally knew preteens or teens who regularly used steroids to boost their athletic performance.

[7] In retrospect, this was not a good idea; we recommend that the children use their initials to facilitate matching pre- and post-test responses.

[$F(3,36) = 12.07$; MSE = 8.852; $p = 0.001$] as well as a significant interaction between time and school [$F(3,36) = 15.28$; MSE = 6.05; $p = 0.001$]. All of the sites showed significantly higher scores at the time of the second testing compared with the first, as shown in Table 2.

Brain Damage and Disorders

Results from the mixed ANOVA revealed a significant effect of time [$F(1,36) = 22.71$; MSE = 4.76; $p = 0.001$] and a significant interaction between time and school [$F(3,36) = 7.93$; MSE = 4.76; $p = 0.001$]. There was an overall improvement in scores for the second testing compared with the first. Paired samples *t* tests examining the improvement in scores from time 1 to time 2 revealed that the improvements were statistically significant for all of the schools except school 2.

Perception and Illusions

Results from the mixed ANOVA revealed a significant effect of time [$F(1,36) = 12.57$; MSE = 10.53; $p = 0.001$] and a significant interaction between time and school [$F(3,36) = 3.14$; MSE = 10.53; $p = 0.029$]. Although there was an overall improvement in the scores (Table 2), the differences were only significant for schools 1 and 4, as revealed by post hoc paired samples *t* tests.

Drugs and Hormones

Results from the mixed ANOVA revealed a significant effect of time [$F(1,36) = 42.80$; MSE = 1.494; $p = 0.001$] and school [$F(3,36) = 6.12$; MSE = 2.89; $p = 0.001$]. A significant interaction between time and school was not found. Scores at time 2 were significantly higher than at time 1. Paired samples *t* tests revealed that all of the sites showed significant improvements from time 1 to time 2.

Assessment of Learning Experience for Undergraduates

Undergraduates evaluated the course anonymously on the standard evaluation form used by the university. On a scale from 1 to 5, where 5 indicates "constantly" or "strongly agree," 100% of the students answered with 5 to all of the questions on this form.[8]

The course-related comments by the students are included in Supplemental Material C. In summary, the undergraduate students enjoyed the course, and they felt it was a valuable learning experience, especially during the workshops themselves, when they had to answer the children's questions and give clear answers that the children could understand.

Product evaluation criteria were also used to assess the effectiveness of the learning experience for the undergraduate students. The students were required to submit an abstract for review by the Stanford Undergraduate Psychology Conference and, upon acceptance, to present a formal poster for presentation at the conference. Although not required because the conference took place the following academic year, and students were no longer enrolled in the course, all of the undergraduate students chose to present a poster at the annual meeting of the Society for Neuroscience. One-half of the students also chose to continue to work on the manuscript, despite there being no mechanism for them to receive course credit for their investment of time and effort in our program.

DISCUSSION

In this article, we examined whether a university–school partnership could effectively provide undergraduate and fifth-grade students with meaningful and engaging science learning experiences. The undergraduates developed a research study to evaluate the effectiveness of teaching neuroscience concepts to children in interactive, inquiry-based workshops. The children would not have been exposed to these concepts in their regular science curricula, although the inclusion of specific instruction about the brain is highly recommended by national experts advocating for science reform in our schools (e.g., AAAS).

The results of our statistical analyses showed that the children's knowledge about the brain improved significantly from the pre- to the post-tests in all categories of the workshop. School 3 was of special interest to us; due to events beyond our control, the children at this school took their post-test 3 wk after the workshop, affording us an opportunity to observe the durability of their workshop knowledge. As shown in Table 2 and in the detailed results we have provided, there was no significant difference in the post-test scores for this school compared with the other schools. The knowledge that the children acquired during the course of the workshop had not diminished 3 wk later, illustrating the relatively long-term improvements in their scores. Although these results do not show conclusively that the workshop was responsible for these changes, they suggest our workshops were effective in meeting our goal of increasing knowledge about the brain in the fifth-grade students.

Two of the school sites did not show significant gains on some of the measures. One of the sites, school 2, was an after-school program (Table 1) with low numbers of children whose parents consented to participation and where attendance is a general problem. As can be seen from Table 2, only four of the 14 original workshop participants completed the post-test, suggesting that the lack of gain at this site for the brain damage and disorders and the perception and illusions units may have been affected by the small sample size and high rate of attrition. The only other school

[8] The statements on the evaluation form to which the undergraduates responded were as follows: professor was available for consultation during office hours; classroom presentations seemed organized with a sense of direction to instruction; class time was used effectively; out-of-class assignments or projects were relevant to defined course content; professor's presentations facilitated learning of course content; tests were representative of course content; professor provided helpful/timely oral/written evaluation regarding performance; professor provided a description of grading standards and procedures at beginning of course; required texts were both used in and useful during the course or were useful as a reference; if your schedule allowed it, would you take another course by this professor, or would you recommend this professor to someone else?

failing to show statistically significant gains from pre- to post-test was school 3, and only for the perception and illusions unit. As mentioned previously, the post-test at this site was given later than at the other sites. Although the gains were significant for the other units at school 3, the knowledge acquired in the perception and illusions unit may have been especially sensitive to the longer interval between the pre- and post-tests.

The open-ended inquiry experience for the undergraduates described in this article also clearly enhanced their understanding of research methodology, design, analysis, and disseminating results, as demonstrated by their course evaluations, the quality of their poster presentation at the conclusion of the course, and the undergraduates' sustained interest in the project beyond the traditional time limits of the course.

Although we believe that the model of university–school partnership described in this article was effective in providing engaging and meaningful learning experiences for the undergraduates and elementary school children, we have some suggestions for improving upon it. Future workshops could provide the following.

1. A formal assessment by the teachers as to the effectiveness of the workshop, and the extent to which the workshop enhanced their science curriculum.
2. A more specific assessment of undergraduate neuroscience education and science literacy goals by the undergraduates.
3. A more formal alignment of primary assessment with AAAS guidelines and National Science Education Standards.
4. Inclusion of more schools and children.
5. A second semester component to the undergraduate course devoted to manuscript preparation.
6. More workshops providing a longer period of intervention.

Benefits of the workshop clearly include increased awareness of the brain by the fifth-graders who participated in the workshop, addressing the goals of Dana Alliance and AAAS and meeting the National Science Education Standards. The project also benefited the undergraduates who learned how to work collaboratively on a real-world problem, determining what to test, designing a study, conducting the workshops, analyzing the data, and disseminating the results. This community partnership provided an opportunity to enhance the children's science background with regard to the brain in a stimulating and fun supplement to the state curriculum. The project also provided a unique and challenging opportunity to expose the undergraduate students to more neuroscience beyond their basic introductory course, to engage them in an interesting and relevant scientific question, to study the topics we selected in depth, and to discover ways to share our excitement about and interest in neuroscience with the children who participated in the workshops.

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REFERENCES

American Association for the Advancement of Science (1993). Benchmarks for Science Literacy (Benchmarks for Science Literacy, Project 2061), New York: Oxford University Press.

Bayer Foundation (2003). Bayer Facts of Science Education IX: Americans' Views on the Role of Science and Technology in US National Defense. http://www.bayerus.com/msms/news/index.html (accessed 1 February 2005).

California Department of Education (2000). California Department of Education Science Content Standards, Kindergarten through Grade Twelve, Sacramento, CA: California Department of Education Press.

Cameron, W., and Chudler, E. (2003). A role for neuroscientists in engaging young minds. Nat. Rev. Neurosci. *4*, 1–6.

D'Avanzo, C., and McNeal, A. (1997). Research for all students: structuring investigation into first-year courses. In: Student-Active Science: Models of Innovation in College Science Teaching, ed. A. P. McNeal and C. D'Avanzo, Philadelphia, PA: Saunders College Publishing, 279–300.

Edgerton, R. (2001). Education white paper. http://www.pewundergradforum.org/wp1.html (accessed 10 March 2006).

Hall, D. A., and McCurdy, D. W. (1990). A comparison of a biological sciences curriculum study (BSCS) laboratory and a traditional laboratory on student achievement at two private liberal arts colleges. J. Res. Sci. Teach. *27*, 625–636.

Johnson, J., Arumi, A. M., Ott, A., and Remaley, M. H. (2006). Education insights. A public agenda initiative to build momentum for improving American schools. http://www.publicagenda.org/research/pdfs/rc0601.pdf (accessed 9 March 2006).

Knight, J., and Wood, W. B. (2005). Teaching more by teaching less. Cell Biol. Educ. *4*, 298–310.

Kyle, W. C., Jr., Bonnstetter, R. J., and Gadsden, T., Jr. (1988). An implementation study: an analysis of elementary students' and teachers' attitudes toward science in process-approach vs. traditional science classes. J. Res. Sci. Teach. *25*, 103–120.

Kyle, W. C., Jr., Shymansky, J. A., and Alport, J. M. (1982). Alphabet soup science: a second look at the NSF-funded science curriculum. Sci. Teach. *4*, 49–53.

Leonard, W. H. (1983). An experimental study of a BSCS-style laboratory approach for university general biology. J. Res. Sci. Teach. *20*, 807–813.

Moreno, N. (2005). Points of view: science education partnerships: being realistic about meeting expectations. Cell Biol. Educ. *4*, 30–32.

National Research Council (1996). National Science Education Standards, Washington DC: National Academy Press. http://www:nas.edu (accessed 1 February 2005).

National Research Council (1997). Every Child a Scientist: Achieving Scientific Literacy for All, Washington, DC: The National Academies Press.

Pascarella, E. T., and Terenzini, P. T. (1991). How College Affects Students. A Third Decade of Research, San Francisco, CA: Jossey-Bass.

Polman, J. L. (2000). Designing Project-Based Science: Connecting Learners through Guided Inquiry, New York: Teachers College Press, Columbia University.

Shymansky, J. A. (1984). BSCS programs: just how effective were they? Am. Biol. Teach. *46*, 54–57.

Simons, D. J. (2003). Surprising Studies of Visual Awareness, Champaign, IL: VisCog Productions, Inc.

Simons, D. J., and Chabris, C. F. (1999). Gorillas in our midst: sustained inattentional blindness for dynamic events. Perception *28*, 1059–1074.

Stamp, N., and O'Brien, T. (2005). GK–12 Partnership: A Model to Advance Change in Science Education. http://www.rednova.com/news/display/?id=122950 (accessed 1 February 2005).

Thier, H. D. (2000). Developing Inquiry-based Science Materials: A Guide for Educators, New York: Teachers College Press, Columbia University.

Tomanek, D. (2005). Points of view: effective partnerships between K–12 and higher education. Cell Biol. Educ. *4*, 28–29.