A PERSONAL VIEW

Science after school: way cool! A course-based approach to teaching science outreach

Kathleen S. Curtis

Department of Pharmacology and Physiology, Oklahoma State University-Center for Health Sciences, Tulsa, Oklahoma

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OUTREACH EFFORTS DIRECTED toward improving STEM (Science, Technology, Engineering, and Mathematics) literacy are vitally important to ensure that all of our citizens are prepared to fully participate in an increasingly complex and technology-driven world. Attempts to maximize the effectiveness of STEM outreach have focused on younger populations, targeting high school, middle school, and even elementary school students. But who provides this outreach? Outreach typically originates at the university level, delivered by undergraduate and, more commonly, by graduate students, often with faculty supervising them (2, 3). These efforts often are discrete, limited-duration events. As a representative example, graduate students in the Biomedical Sciences Graduate Program at Oklahoma State University-Center for Health Sciences (OSU-CHS) provide outreach to a local elementary school in the form of an annual 3rd grade science fair. This is a week-long event that culminates each year in a poster competition. The elementary students love it. Their teachers love it. Our graduate student volunteers love engaging with the elementary students. As one of the judges of this science fair since its inception in 2008, I love it.

However, I also appreciate the challenges in identifying projects for elementary students that are age-appropriate and interesting and can be completed in one or two afternoons so that the posters can be finished in time for the competition. As a result, we tend to use easy-to-conduct experiments with predictable and reliable outcomes that lead to straightforward poster presentations. Moreover, no matter how well-intentioned graduate student volunteers may be, the necessity of taking courses, conducting research, writing papers, taking exams, etc., often impedes their participation. This reinforces the need for experiments that are simple and reliable, and with minimal prep time, so that graduate students can more readily assist elementary students in conducting the experiments and, when schedule conflicts arise, step in more easily and cover for each other. Despite these issues (which undoubtedly are common in outreach efforts), our science fair is an annual tradition that we feel is sparking an interest in science in these elementary students. But this raises the question of how the people in the outreach trenches (undergraduate students, graduate students, and even faculty) learn to effectively deliver science outreach, especially to elementary students and particularly within the existing elementary science curriculum. Certainly, there are resources that can be utilized (and many are first rate); in addition, partnerships can be developed with professional societies, community groups, and elementary educators. But our experience is that outreach efforts that rely on volunteers, especially graduate student volunteers, are notoriously difficult to coordinate and sustain, and requiring additional time for training in how to deliver outreach is likely to reduce the number of volunteers.

At OSU-CHS, we capitalized on our existing partnership with a local elementary school to take a different approach and developed a semester-long, for-credit course to train graduate students in delivering science outreach at the elementary level. This approach arose from the realization that although outreach has become an important part of a career in academic science, we seem to expect it of undergraduate and graduate students without actually training them in how to do it. Indeed, in a statement to the National Institute of General Medical Sciences in 2016, the American Physiological Society identified “mentoring and leadership” and “educational outreach” among the key skills that graduate students should develop (1). However, it is difficult to train volunteers in providing outreach without requiring additional time. So, to achieve the longer-term commitment necessary for a meaningful training experience, we opted to give graduate students two credits toward their degree for completing the training (i.e., taking the course). This course never was intended to replace the science fair. Indeed, we take advantage of our interactions with 3rd grade students at the science fair to “recruit” them as participants for the course next year. The goals and strategies of the course are different from those of the science fair, as are the challenges and rewards, and after two semesters of serving as the course instructor, I am increasingly confident that we are onto something with this approach. Both the graduate students and the 4th graders are learning skills, science-related and otherwise, that will benefit them in their education and in their careers. Accordingly, the goal of this report is to share our experiences and the strategies we employed in the hope that others may use the information to develop their own outreach courses.

In designing the course, I had an overall vision of what we wanted our graduate students to do (expose 4th graders to “everyday science,” i.e., using the scientific method for real-life problem solving) and how to go about it (pairs of graduate students, each working with two to four 4th graders during hour-long weekly meetings at the elementary school over the course of a semester, a strategy that also would allow graduate students to serve as scientific role models for the 4th graders). I developed a syllabus with an overall

Address for reprint requests and other correspondence: K. S. Curtis, Dept. of Pharmacology and Physiology, Oklahoma State University-Center for Health Sciences, Tulsa, OK 74107 (e-mail: kath.curtis@okstate.edu).
course objective best summarized as “training the trainers,” i.e., developing outreach skills for graduate students. In accomplishing this overall course objective, five learning objectives were addressed:

1. **Develop and deliver age-appropriate science experiments.** It was necessary for the experiments (plural) to be logically linked, but correct answers were absolutely not required.

2. **Instruct 4th graders in laboratory methods and practices.** This was an extensive list that included laboratory safety, operation of laboratory equipment, experimental design, record keeping, troubleshooting, data collection, and reporting results.

3. **Develop and deliver brief “lectures” to 4th graders about topics related to the experiments.** This ranged from how to measure using the metric system to understanding discrepant results, genetic alleles, blood pressure, and heart rate.

4. **Communicate about outreach activities with scientific and educational communities and with the general public.** This took diverse forms, including talks at scientific conferences and for community groups, writing articles for local newsletters, and initiating a blog.

5. **Identify and apply for funding to support outreach.** This was fairly broadly defined, and as a result, one important lesson we learned was about the extent of support from local businesses for outreach.

Graduate students also were required to maintain a journal throughout as a way of processing their experiences, identifying things that did or didn’t work, and developing strategies that might be useful immediately or down the road.

Overall, the objectives were accomplished. The graduate students gave talks and poster presentations at a variety of local, national, and international meetings as well as for local community groups; they wrote articles describing the course (e.g., for inclusion in our alumni newsletter), they built a web page that was “signed over” to me for subsequent years (objective 4). They found that a department store chain was very supportive of our efforts and contributed a gift card for supplies (objective 5), although a big-box office supply store was less enthusiastic about doing so. Objectives 1–3 also were accomplished, although admittedly not always as planned. In many cases, we simply got lucky. The first and most important bit of luck was that the delivery of our course was associated with an ongoing after-school activity program, which conferred several important advantages. First, we were not pulling 4th graders out of classes and/or trying to coordinate with information currently being covered in class. Second, 4th graders signed up for what they called the “Science Club” as an after-school activity; thus, they were a self-selecting group with some level of interest in science at the onset. Next, since it was after school, we had fewer time constraints, and we could set up in the elementary school cafeteria, because room to spread out was crucial. We also were lucky in having an elementary school principal from a nearby school district serve as an informal consultant (which is to say, an answerer of questions and a source of advice). Among other things, the principal made us aware that the 4th grade science learning outcomes for the state/school district were accessible online. Through some combination of planning and luck (again!), our outreach plans touched on many of those outcomes.

In implementing the course, our established partnership with the elementary school laid the groundwork that enabled us to “hit the ground running,” as did the tradition of outreach and volunteerism at OSU-CHS. I developed a schedule of activities for the semester that, frankly, was based on my own research experience/expertise, the availability of supplies to conduct the experiments, and the idea that 4th graders would relate to snack foods and cereal. In the long run, I believe that employing relatable and related experiments is more important than specific experiments, although I would be happy to share details of the experiments we used!

Graduate students guided the 4th graders in asking questions about why they liked particular chips or cereals, about salt or sugar content in their favorite chips or cereals, and about genetic differences in taste perception and the consequences of salt or sugar overconsumption. They helped the 4th graders to develop hypotheses based on these questions and then to test them in a series of experiments that built on each other. As a few examples, the 4th graders conducted “taste tests” to determine which was the favorite chip and whether the favorite chip tasted saltiest; they counted taste buds and assessed taste sensitivity with propylthiouricil taste strips to investigate individual differences in how they rated tastes; they examined flow

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**Fig. 1.** Graduate student demonstrating states of matter to 4th graders as a way of explaining how salt dissolves. *Left: solid. Middle: liquid. Right: gas.*
rates through tubes of various sizes to evaluate the effort necessary to move fluid through narrow vs. wide tubes (i.e., blood vessels); they examined the effect of exercise on heart rate.

While assisting the 4th graders with experiments, the graduate students emphasized experimental design, laboratory methods/equipment, and laboratory safety; they focused on data collection and record keeping, and presentation of the results, stressing math, reading, and oral and written communication. In all of this, the emphasis was on critical thinking and problem solving, rather than particular results. In short, the focus was on the process, not the product. In keeping with this approach, we conducted an end-of-the-semester wrap up at which all of the 4th graders presented posters to their families and others in the community. This was not a competition but a demonstration of what they had done during the semester. Full disclosure: the 4th graders each got personalized Science Club t-shirts, laboratory notebooks, etc., but there was no “best” poster. In short, the focus was on the reward, not the award.

We also were lucky in having institutional and administrative support for developing this elective course. In fact, our graduate program director encouraged us to take advantage of our “Special Topics” course designation so that our graduate students could take the course twice and receive credit for it both times. Several graduate students took advantage of the opportunity, and these “repeat” students shouldered more responsibility for developing and coordinating activities. They were in charge of troubleshooting experiments, and they built upon their previous experiences to help newcomers with how to “lecture” to 4th graders, etc. In short, these graduate students got hands-on practice with the development and organizational aspects of delivering science outreach while still receiving feedback and guidance from the course instructor as necessary.

To this point, it may sound as though everything went smoothly. It absolutely did not. However, since we were not invested in particular results, none of the inevitable glitches derailed us. In fact, we used the unexpected occurrences to reinforce the critical thinking and problem-solving aspects of science for the 4th graders. We emphasized that science is asking questions and trying to answer them. Sometimes finding the answer takes time, and sometimes the answers are not what you expect, but if you can ask questions, you can do science. Of course, the 4th graders were not the only ones who learned from the experience. Along the way, we learned a number of useful strategies that fall into two general categories.

Planning, Preparation, and Postmortem

Review/preview. In this for-credit course, I required an additional weekly meeting before each session at the elementary school. There were times when at least one graduate student said something like, “We know what we’re doing, so why do we have to meet?” The answer was that nothing is as easy as it sounds (e.g., measuring salt content in chips or sugar in cereal), especially if everyone thinks someone else knows how to do it. But my goals in facilitating this weekly meeting were not only to allow graduate students to prepare for upcoming experiments and activities but also to provide an opportunity for them to compare notes and brainstorm about what did and did not work the previous week and what tactics might be useful in subsequent weeks. In addition, it gave them time to practice lectures and receive feedback from me and from the other students. Finally, it ensured dedicated time for instructional presentations (1–3/semester) from elementary educators or representatives from community groups like the YMCA to learn about educational strategies and challenges as well as from representatives from our OSU-CHS Offices of Outreach or Marketing to explore options for resources or avenues for increasing public awareness of our efforts to address the need for STEM Outreach.

β-Test experiments. Suffice it to say that for some reason, none of us realized that the sugar in cereals could not be measured by inexpensive glucose test strips. Unfortunately, doing so requires far more expensive sucrose test kits. A related strategy, which was obvious with the benefit of hindsight, is to ensure that β-tests use the same processes the 4th graders will use.

Time is relative. No matter how thoroughly we planned, and no matter how carefully the students scripted the “lectures” they delivered to the 4th graders, there were times when we were far behind where we intended to be and times when we were far ahead. So, during our weekly planning meetings, we learned to identify where to stop if time ran out and how to fill additional time if necessary. To a large extent, this means that a schedule of activities is a moving target. So be

Fig. 2. Fourth graders working with cool tools while conducting experiments. Left: student using a graduated cylinder to measure volume of water in which salt was dissolved. Right: student weighing chips with an analytical balance.
it; flexibility is an intrinsic aspect of science outreach at the elementary level.

Keep it simple. As scientists, graduate students had questions about the experiments, too, and often wanted to add just one more variable to that day’s experiment or one more experiment to that day’s activities. As the course instructor, I worked hard to ensure that we kept our focus on straightforward, tractable goals that all groups addressed. That meant that each of our small groups did the same experiments, made graphs, worked on posters, etc., although they definitely put their own spin on all of these.

Waivers and warnings. The elementary school required background information/checks for me and all of our graduate students; in addition, I required graduate students to complete the OSU-based training, which certified them to work with minors. We also sent paperwork to the 4th graders’ parents or guardians that included permission for their children to participate in the “Science Club,” waivers for photographs, as well as for the use of laboratory supplies and equipment, and information about sampling PROP paper to assess bitter taste responses. As an aside, the 4th graders saw this paperwork, which may have slightly skewed the results of some of our experiments (or maybe the kids were all supertasters...).

Stand and Deliver

Review/preview 2.0. Fourth graders can forget a great deal in a week. Therefore, we learned to begin each session with a review of what we had done the previous week and a preview of our goals for that day. To reinforce what we had done each session, we ended with a review of that day and finished with a preview of our plans for the next week.

Keep it simple 2.0. Open-ended questions are great, but 4th graders will take surprising paths when asked things like, “What kind of questions do you want to answer?” No matter how much we might have wanted to, we could not travel to the sun to measure the temperature. Therefore, we learned to limit choices to two or three alternatives and to direct the hypotheses but to let the 4th graders decide how to test them.

Explanations. Although 4th graders could define “hypothesis,” they had trouble formulating one. This was a surprising and important lesson for us: defining ≠ applying. We also learned that our science vocabulary was not always instructive for 4th graders (think “centrifuge”). In short, simple explanations are key; demonstrations (see Fig. 1) are even better. However, it is necessary to meet the kids where they live. A picture of a carnival ride to illustrate centripetal force seemed like a great idea until it became clear that none of our 4th graders had ever been to a carnival.

Cool tools. We were committed to allowing the 4th graders to use real laboratory equipment (see Fig. 2). They loved this, and graduated cylinders, centrifuge tubes, and pipetters are easily portable. Surprisingly, even centrifuges, microscopes, and balances can be transported. However, this required organization, planning, and a big trunk.

Color coding. We assigned each group a color that, insofar as possible, matched up with the colors of our tube racks, centrifuge tubes, etc. This strategy definitely simplified transporting supplies, equipment, etc., especially when an experiment took several weeks. In addition, it allowed each of the groups to establish their own identity.

Time to practice. Using laboratory tools is a skill set that, quite simply, 4th graders do not have. They had to learn how to use these tools, which meant that they had to have instructions, demonstrations, and time to practice (Fig. 2).

Time to have fun. Fourth graders thought surprising things were fun. They spent a great deal of time pipetting water onto salt to watch it dissolve under the microscope. We let them (see Time is relative above). It reinforced two things: 1) states of matter and 2) the fact that science is fun. However, a cautionary note is called for here; what they thought was fun varied from year to year.

Tactful time czar. Whether practicing with the tools, conducting experiments, or making graphs, it was very easy to lose track of time and/or get “lost in the weeds.” The former was
likely to happen when everything was going well; the latter was more likely to happen to graduate students when the 4th graders were not getting it (a notable example is making graphs using the metric scale). Therefore, as course instructor, my two most important roles at the elementary school were to keep track of time (and keep the groups informed of how much time remained) and to redirect any groups that got off track. We also developed a neutral code phrase for use by graduate students when they needed help from me, which allowed them to receive assistance but maintain their roles as science mentors.

**Chalk talk.** Although each group put their own spin on the experiments, it was important for them to see what the other groups did and what they found. We established big group discussions that allowed the 4th graders to talk about why different groups got different results. Graduate students guided the 4th graders as they used the chalkboard (or whiteboard) to present their group’s results and to total the results from all the groups and then helped them to interpret the findings and identify the next experiments (Fig. 3). This strategy allowed the 4th graders to see the big picture while practicing math and communication skills.

**Agility.** Each year there were different 4th graders and different graduate students, which required minor adjustments. A more significant challenge for us during our 2nd year was a lack of consistency in how many and which 4th graders attended each week. This meant that experiments that built on each other were problematic. It was necessary to do a course correction and include experiments and activities that did not rely on semester-long attendance. Based on this experience, the after-school coordinator assured us that, going forward, we would have the same 4th graders each week. Still, we will include some of the new activities. After all, what is not to like about building genetically modified monsters to illustrate inheritance of genetic traits (Fig. 4) or making poop...er, excuse me, feces...in panty hose to illustrate gastrointestinal function?

**Celebrate, assess, and plan.** In discussions with the after-school program coordinator and the principal while initiating this course, we had been informed that residence transiency is common at our elementary school partner. However, knowing that did not truly prepare us for the reality of having several of the 4th graders move during the semester. After bonding with “their kids,” this was difficult for graduate students to come to terms with. Thus, it was even more important to finish the semester with a celebration that allowed us to see the 4th graders’ excitement as they described their experiments, especially to their families, and to hear from their parents how much the kids enjoyed “Science Club.”

And after the celebration, I assess and plan. Graduate student journals are crucial for identifying areas to improve as well as new strategies we might employ. For the graduate students, these journals serve to facilitate reflection and self-assessment about their performance, their abilities and limitations, and contributing to outreach and science education. Without a doubt, graduate students earn their grades, which are based not only on journals but also on fulfilling the requirements of developing and delivering lectures, working with the 4th graders in small groups each week, presenting talks about outreach, and obtaining funding. Perhaps more important, however, is that graduate students are learning important skills, some of which will generalize to other aspects of their careers (e.g., preparing and delivering lectures, designing and troubleshooting experiments). At the same time, they are clearly learning about delivering science outreach. For example, one of our graduate students noted that she employed some of the things she learned in the course as the coordinator of the science fair. For graduate students who took the class twice, the benefits were even clearer. They were infinitely more skilled, organized, and capable the second time through. They also came up with marvelous new ideas to try out, several of which have been added to our list of experiments.

We began small: three teams of graduate students mentoring about eight 4th graders each year. In the upcoming years, we intend to increase those numbers, with a maximum of 10 graduate students (i.e., 5 teams) and 15 4th graders. For our course, and for me as course instructor, these numbers allow maximum impact while maintaining the level of instructor-to-graduate student interactions and, therefore, to evaluate the graduate students based on achieving the course objectives. We also will implement systematic assessment of the impact of our science outreach on the 4th graders who participated and hope to work with the school district to conduct longitudinal evaluations. In the meantime, my informal observations during the sessions at the elementary school suggest that we are having a positive impact. One of our 4th graders eventually stopped making “kitty noises,” began to participate in the experiments, and performed like a pro while demonstrating her favorite experiment at the end-of-the-year wrap-up. Another of our 4th graders who initially was disruptive and disrespectful during group sessions ultimately participated with more appropriate enthusiasm after his mentor quietly and patiently worked with him to understand and exercise self-control. Yet another 4th grader whom we had been told was a “special needs student” had a detailed discussion about the structure of DNA with his graduate student mentor. In short, for the 4th graders, the program seems to work. In fact, we are officially and permanently on the schedule of after-school activities at the local elementary school and have been asked to help set up similar programs at other elementary schools.

I hope that our for-credit graded course will serve as a useful model for others to employ in providing training in science outreach for graduate students, and possibly for undergraduates, as well. As a semester-long course, it has the advantage of allowing graduate students time to learn and practice valuable skills while guiding 4th graders in everyday science. At the same time, our outreach training course is helping our graduate students to build relationships with the 4th graders, stimulating an excitement about science in the 4th graders as they explore scientific principles and practices in more depth, and ultimately helping to better prepare the 4th graders to participate in our complex and technology-driven world.

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AUTHOR CONTRIBUTIONS

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