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OPINION

A Win for Science: The Benefits of Mentoring High School Students in the Lab

Cynthia M. Harley
Department of Entomology, University of Minnesota, Saint Paul, MN 55108

Involving high school students in research has been shown to be beneficial for the student. These programs not only contribute to student understanding and confidence in scientific material, but also foster an interest in pursuing careers in science in both the short and long term (Knox et al., 2003; Markowitz, 2004). It also fosters an understanding of scientific method and process, something which may not be the easiest for students to learn in the classroom. Indeed, the most recently released framework for K-12 scientific education strives to create changes in the classroom to teach students scientific practices; including carrying out investigations, analyzing data, and using evidence to create and evaluate scientific arguments (NRC, 2012). However, there will be a lag to implement these standards and, in the past, according to the National Research Council, such efforts have left much room for improvement. As such, today's high school students are encouraged to seek out research opportunities, especially if they are interested in majoring in a science and/or applying to a top school. Moreover, in a recent statement President Obama suggested that scientists should think of creative ways to engage young people in science and engineering to improve student achievement in math and science (Obama, 2009).

Despite that these experiences are shown to benefit the student, researchers are often resistant to the idea. Even though modern day NSF and NIH proposals require an outreach component, only 18% of these efforts are focused on K-12 education (Kamenetzky, 2012). This resistance stems from a lack of peer support and reward for these efforts, and a lack of time to devote to them (Andrews et al., 2005; Ecklund et al., 2012). This attitude is not only present among professors but also graduate students (deKoven and Trumbull, 2002). In my own experience talking to people about having high school research assistants, the predominant view appears to be that a high school student would not be able to generate useful or valid data. As such, tasks given to high school research assistants are often menial at best, perhaps making this a self-fulfilling prophecy.

Can we have our cake and eat it too? Can we create a lab environment that (1) allows high school students to learn about the process of science (2) get real work out of them and (3) fulfill our granting agency's outreach requirement? While a few years ago I too would have been a skeptic, my mind has been changed by two high school students. Here, I would like to tell my story, and a few tricks that I learned along the way so that you, the reader, can decide if mentoring a high school student is worthwhile.

I started working at Caltech in the fall of 2010. I had switched the animal model system I was using and was somewhat lost in the process. It took me six months just to learn how to work with a different animal. I knew that I needed data and publications and fast. To do that, I needed help. I attempted to find undergraduates who were interested in my work, but to no avail. I had nearly given up on the idea of acquiring an assistant when I got contacted by a colleague. He had been contacted by the local high school's AP biology instructor about high school students who were interested in a real-life research experience. My colleague had two excellent candidates but felt that he only had space for one. I jumped on the opportunity to have the other student in my lab. I had no clue what to expect, but figured that some help was better than none.

When my first high school student entered the lab, I was terrified. What little I knew about education, I had learned from being a teaching assistant in graduate school—what was I going to do with a 16 year old kid? So, I did what I suspect any researcher would do—I gave the student a seminar introduction, slides and all. I told him about the previous work, what I was trying to do, and where I was currently. Despite that my work is about how *leeches* find *blood sources*, the kid was still sitting there when I finished, though I suspect he was appreciative that I did so in under 20 minutes. I had finished my introduction. Now what?

TIP 1: HOW TO MAKE A HIGH SCHOOL STUDENT THINK LIKE A SCIENTIST

I thought back to when I started working in a lab. I knew nothing of animal behavior let alone the secret lives of cockroaches. My PI sat me down and started showing me movies of the cockroaches climbing blocks—the lab was interested in what I would now call 'navigation of complex environments'. He asked, "What do you see?". I would answer and a few videos later he would say, "How would you test that?". This strategy is precisely the tactic I used. Together, as when I was a student, we steered the conversation toward our hypothesis and determined how we would test it. These recollections thus bring me to my first point-- for the student to contribute fully to the laboratory; they must understand its mission. The better the student understands the project the more relevant their questions and the more useful their observations. This sort of talking about the data allows for lay and scientific vernacular to be utilized and for the student to get an idea of how their project fits into the lab's mission and how that fits into a bigger picture.

Regardless of the student that we are mentoring, our goal as scientists remains the same, to develop scientists. Achievement of this goal requires the development of scientific thinking. While the term 'scientific thinking' is quite broad, here we use the criteria determined in (Burmester, 1953) for evaluating scientific thinking. These elements are the ability to:

1. recognize problems
2. understand experimental methods
3. organize and interpret data
4. understand how data relates to the solution of the problem
5. plan experiments to test hypotheses
6. make generalizations and assumptions

One difference between high school students and graduate students, however, is that the ability for critical scientific thinking is less developed and thus needs more cultivating. When working within the lab as trained scientists, we are constantly observing, creating hypotheses, and thinking of the next steps in our research. This process is not unlike the process presented in our papers. Through implementing a weekly journal club, students can become better acquainted with the scientific process. However, even for upper level undergraduates, the task of reading a scientific paper can be daunting, let alone for high school students. How do we overcome this intimidation? The way I did this was as follows: First, I gave the student some background on the material—why this study would be interesting. Next, I explained the goal of the researcher. Last, I would send the student home with the paper. I would explain that all I wanted them to do was to understand the meaning of each figure and how this information helped the researcher support their hypothesis. Under this direction the students quickly after 3-5 papers—learned to read scientific papers so well that I could give them only the background and then ask them to tell me: 1) what was the goal of the work, 2) how the researcher tested their hypothesis, 3) what the paper concluded, and 4) what questions remained unanswered. As these papers would relate to our work, I would also have the student think about how a previous study was impacting our current work. This method of examining scientific papers can be done in an hour a week and takes the student through each of the 6 steps above. I used this process as a primer for my first and subsequent students for a month or two before they would enter the lab itself.

The next step is that this process has to be translated from paper to experiment. To do this I would show the student raw data. Regardless of the type of raw data, be it a gel, a behavior video, or a neurophysiological trace, the process of leading the student through how to approach the data as a scientist remains the same by asking the students the following questions: What have you observed? How would you test that hypothesis? What results would you expect? What is your interpretation if the opposite were to be true? It is no coincidence that these questions follow the same sequence as the students were taught when reading a scientific paper. This process can be applied to assays or analysis. The importance of it is not what is being done but rather that the student is supplied with an explicit framework for logical thinking.

TIP 2: MOVING SCIENCE FROM CLASSROOM TO JOB

Even if a high school student has had a job, the likelihood is that they have not worked in a science lab before. In fact, many of the jobs that my friends or I held in high school had one thing in common—the daily tasks were defined. However, when doing research, things can change rapidly. This is further complicated by the fact that many high school students, unless it is summer, work part time. To adapt high school students to this environment and make sure that they knew what they had to accomplish in a day, I adopted a morning meeting modeled after what is called a 'scrum' technique. Scrums are micro meetings used in agile software-development environments, which, like research, are constantly changing (Schwaber, 2004). The meeting focuses on the following elements:

1) What progress was made yesterday?
2) What are our goals for today?
3) What problems may we run into?

These meetings are short, quick, and to the point—ideally under 15 minutes. Everyone should contribute. However, unlike most lab meetings, these meetings are not about detail. Rather they are about focusing each person on their day and what should get done. At the end of the day I would have a similar meeting just asking how things went that day. Here, when earned, praise should be given. At least once a week the student should be reminded how their work fits into the goal of the lab and the big picture. Often times, what I would do is graph out the student's data, hang the graph on a bulletin board, and go through the questions—What trends do we see in the data? What does this mean? And how does this relate to our hypothesis?

While much of the student work was self-motivated, I found it beneficial to give the students additional daily goals. I would give them a modest goal of how many animals they should test or videos they should analyze. I would tell them that was what they should be able to get done. Then I would also give them a more difficult goal to reach if possible. These goals would keep the students on task and motivated. My original plan was that this exercise would give the students direction for what to do when they finished their task in the event that I did not assign enough work to keep them busy. However, my students took the modest goal as a minimum and would strive to exceed the high goal. This is beneficial as it gives the students a clear idea of what they should be doing and allows them to self-assess their progress.

TIP 3: ORGANIZATION IS KEY

One of the challenges in a lab is making sure that data are clearly organized. This is of extreme importance with high school students as they are often only associated with the lab for a short period of time and may or may not know how to take good notes. Further complicating this issue was that each figure often involved multiple animals, multiple assays, and multiple elements to be analyzed. I taught the students to draw a grid in their notebook. Animals would be rows, and columns would represent assays or what was analyzed. These grids kept data extremely organized and thus easy to read, understand, and access even after the students had left for college.

Beyond organization, however, the grids also gave students a visual representation of their progress and allowed for goals to be set. This plan worked not only for analysis, but also during data acquisition, when we had a modified grid on a whiteboard where we would check off which trials were done. Thus, the grids allowed for transitioning of an experiment or analysis from one person to another—something extremely important when dealing with part-time employees, as they may have to hand the rest of the day's experiments off to myself or another student.

TIP 4: SOMETIMES HIGH SCHOOL STUDENTS HAVE BETTER IDEAS

Each of us comes from a unique background and has had unique experiences, all of which can be brought to the lab. Even high school students have great ideas that are capable of helping the lab. Furthermore, by incorporating their ideas, you are incorporating the students in the lab and that inclusion gets them to work harder.

For instance, during one of our projects we had to determine how to perform our assay in low light conditions. However, this meant creating a low light video camera. I mentioned this to the student who immediately determined (via a Google search) that we could remove the infrared filter from a webcam, a solution commonly used by home astronomers to connect them to telescopes. Doing so was an easy, inexpensive solution to our problem. Later we found that we needed to block certain wavelengths of light from the camera. The same student, as he had been involved in a number of high school plays, suggested using the gel inserts that theaters use over their lights-- again, an excellent, inexpensive and easy solution to implement. Without these solutions we would have had a harder time obtaining the data for two of the three assays in our 2011 paper (Harley et al., 2011).

As many of us know, repetitive tasks such as doing an assay over and over to reach our desired 'n' can result in a degree of monotony that can be de-motivational. As such, a certain bit of fun has to be injected into tasks to break monotony. One of these elements came from the students who suggested that instead of my numerical leech identification scheme, we give them actual names. I thought it sounded like nonsense but allowed the students to name the animals provided that they also gave them a unique number. The students began entering the lab with lists of names and would get excited each time we would test a new leech as they would be able to assign it a new name. They also explained that it helped them not to get discouraged with animals that just would not perform the assay. Coincidentally those animals often had the most humorous names. While even writing about naming our leeches still seems like nonsense, it added an element of levity to the daily lab occurrences. Furthermore, our excitement about being able to assign a new name increased motivation and productivity because we wanted to have as many new animals tested as possible.

TIP 5: IT GETS EASIER

The benefit of having one good student is that it makes adding more quite simple. I engaged my more experienced student in mentoring the new student. The first student trained the second during which time the second student was very comfortable asking questions of the first. This peer mentoring not only spares you some time that would otherwise be spent training a new student but also often makes it easier for you to get more students. If the student enjoys the lab they will tell their friends and teachers such that you will get a continual influx of new applicants.

TIP 6: THE LUCK OF THE DRAW AND BIASING YOUR ODDS FOR SUCCESS

Just as each student is a unique snowflake, some students are wonderful in the lab and some are not. How can you ensure that you get students who will thrive in the lab rather than flounder? While, at the end of the day, good students are the luck of the draw, you can bias your odds so that you have a higher probability of mentoring a great one. In my experience, a few factors helped me to acquire successful students. Key was my relationship with the high school advanced placement (AP) biology instructor. She was interested in establishing opportunities for students who were interested in research. From her standpoint, recommending poor students would reduce my likelihood of ever accepting another student. If the instructor sent me excellent students, the relationship would continue, allowing more students to have an opportunity in the lab (and in other labs that may adopt the practice of mentoring high school students if they saw the benefits). Thus instructors who teach students who have elected to be in a more rigorous biology class, have a great pool of potential candidates to recommend. Although many of the AP biology students would have been excellent, a reference for the top students meant that I was getting the best of the best. Through establishing a relationship like this one with a local teacher you can obtain high quality applicants.

Second, just as with any student, you interview them, try to assess their legitimate interest, get letters of reference, grades, etc. If all of that looks good, you accept the student into the lab. My high school students both started as volunteers during their spring semester. They would come to the lab after school once a week to have a journal club. These journal clubs were used partially to teach them and partially to assess them.

Within a journal club setting, there are several parameters that can indicate whether or not a student is likely to perform well in the lab. During this process, it is important to remember that reading a scientific paper is difficult for young students. However, this is a good thing—if the student persists at attempting to understand the paper even though it is difficult, they are probably a good student. My high school students would return to the lab with a paper covered with notes in hand. They would be interested, engaged, and full of questions—all signs that they were driven and curious enough to thrive in the lab. I have had undergraduate students in the lab that showed the opposite behavior; they did not read the paper, had few questions about the paper, could not repeat what I had told them about the background of the study, showed no excitement or curiosity about the material, and/or could not think critically about the paper's content. In my experience, such students do not do well in the lab. Through these little tests you can separate students who are hard-working and curious from those who just want to build their resume. The former get hired, the latter are released back into the wild.

Even with these 'indicators', finding a good student is still subject to the luck of the draw. You can bias your odds, but some students will work out and others will not. Some mentoring styles will work and others may not as there is no one size fits all.

CONCLUSION

The prevailing attitude among academic scientists is that scientific outreach takes time away from science (Andrews et al., 2005; Ecklund et al., 2012). While it is true that when these students started, I had to take time to train them, it is true of any employee. If that time is appropriately targeted, the students can be trained to function like any other student within the lab. In fact, my experience with this training method is that it makes high school students and undergraduates alike more productive; something which, in my case, has proven to be more than worth the small time spent implementing it. In my case, these students were involved in the data acquisition and analysis for two papers (Harley et al., 2011; Harley et al., 2013). These students were involved, in some way, in the data reported in all of the figures in the 2011 paper and four of the six figures in the 2013 paper. Beyond their involvement in the actual data reported, the concept behind the 2013 paper was high-school-student inspired, with its most important assay (Figure 6) stemming from a student project. While the prevailing attitude is that this sort of activity takes away from 'real science,' I have noted the opposite - it benefits it. Indeed, my experience is not the only example; a recent study has shown that dissemination activities actually correlate with an increase in academic performance, including publication rate (Jensen et al., 2008).

One may look at these results and wonder how many hours the students worked. While employing a high school intern you cannot expect a full-time employee. The students have school, sports, lessons, and other extracurricular events that hinder their ability to be full-time employees. Because of these commitments and time off taken for college visits, one must be very flexible about the work schedule. (That said, the students were paid, providing additional incentive for them to be in the lab.) During the school year the students worked from 3:30 p.m., when school ended for the day, until 5:30 p.m. During the summer, the students were allowed to work a maximum of 25 hours a week. One student worked from May 2010 to August 2011 and the other started working April 2011 until January 2012. In total, the students worked nearly 1300 hours over the course of 1.5 years. To put this in perspective, for a full time employee only working 40 hours a week this would equate to about 6.5 months—a more than reasonable time to obtain data for two publications.

The benefits of this experience clearly extend beyond publications. First, the extra organization put in place to increase the effectiveness and focused efforts of the high school students also improved the work of my undergraduate students. When first implementing the organizational charts and notebooks, I worried that the undergraduates (juniors and seniors) would find them too simplistic. This outcome was not the case, in fact not only did they like it, but it allowed multiple students to work on the same project. It works exceptionally well if one student needs to pick up where the previous student left off. Furthermore, these methods organize the day, allowing undergraduates and high school students alike to have a benchmark of what they should be doing, encouraging continual self-assessment. An additional indirect benefit of this experience for the mentor is an improvement in communication skills. By explaining a scientific concept to adolescents whom have a limited knowledge of science, you enhance your ability to communicate with lay people as well as the media (Friedman, 2008). In addition, it increases teaching ability via enhancing communication. Perhaps this is why academic scientists involved in outreach activities note an increase in productivity (Jensen et al., 2008).

Studies show that the academic scientist's perception of outreach is that it will take time away from the lab and lead to no reward (deKoven and Trumbull, 2002; Andrews et al., 2005; Ecklund et al., 2012). I hope that I have shown here that there are direct benefits, such as publication-quality data, and indirect benefits, such as an increase in communication skills and organization. What little time it takes to help the student adapt to the lab is quite small in comparison to what one gets out, and for the student the experience is often priceless.

EPILOGUE

People often ask what happened to the high-school students I mentored. Both went on to Ivy League schools. One has continued to be involved in research including doing a summer project in a well-known lab in the field. He stated that working in the lab showed him for the first time in his life that academia was a feasible career option—one that he is seriously considering. As for the other student, he is majoring in science but still deciding what he wants to do for a career. He stated that the experience showed him that while science can be difficult and tedious, at times, the hard work made it even more rewarding.

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Address correspondence to: Cynthia Harley, Department of Entomology, 1980 Follwell Avenue, 219 Hodson Hall, St Paul, MN 55108. Email: cmharley@umn.edu