What Science and Technology Mean to the High School Learner: Impact of the NSF GK-12

Kathleen Gabric (kgabric@hinsdale86.org) Hinsdale Central High School District 86, Illinois
Sharon L. Comstock (scomstoc@uiuc.edu) University of Illinois, Urbana-Champaign
Steve Moore, Fellow Eli Lilly (former UIUC Fellow)
Delwyn Harnisch (harnisch@unl.edu) University of Nebraska at Lincoln
Ron Shope Grace University
Bertram C. Bruce (chip@uiuc.edu) and Jim Buell (jbuell@uiuc.edu)
University of Illinois at Urbana-Champaign

Abstract:
This paper is based on thick data collected over two years in science classrooms across the state of Illinois, with a focus on one high school biology educator and visiting scientist fellow team. Both were participants in a significant research project sponsored by the National Science Foundation that involved graduate teaching fellows in K-12 education programs. The objective of this paper is to present evidence of what "science" and "technology" mean to freshman and sophomore high school students in a suburban high school via narrative data and artifacts collected. The students' own voices make clear the type of impact programs such as the Graduate Teaching Fellows in K-12 can have, and they give guidance for schools seeking to effectively integrate technology into science classrooms.

The GK-12 Program:

The National Science Foundation Graduate Teaching Fellows in K-12 Education (GK-12) Program supports teaching fellowships for graduate students in the sciences, mathematics, engineering, and technology (SMET) disciplines. The GK-12 Program is a collaboration of three campuses: University of Illinois at Urbana-Champaign (UIUC, which is the lead institution), University of Alabama at Birmingham (UAB), and University of Alabama at Huntsville (UAH) (http://gk12.ncsa.uiuc.edu). The graduate students collaborate with SMET and Education faculty and participating K-12 teachers to integrate the use of computer-based modeling and scientific visualization in science and mathematics education. Responsibilities of these graduate students include visiting classrooms to observe, offering assistance to the collaborating teachers, and co-teaching courses with these teachers, as well as participating in program-related meetings and training sessions. Responsibilities of the faculty include mentoring the graduate students and the participating teachers.

The goals of this GK-12 program include (Jakobsson & Braatz, 2000):

- Develop sustainable partnerships among SMET faculty, education faculty, and school districts through the participation of graduate students with math and science domain expertise.
- Provide professional development opportunities for participating teachers and education faculty related to computer-based modeling, scientific visualization, and informatics.
- Provide professional growth opportunities for aspiring scientists, mathematicians, and engineers, especially encouraging them to concern themselves with education at all levels.
- Integrate computer-based modeling, scientific visualization, and informatics in K-12 classrooms.

The GK-12 program in the first (2001-2002) and second (2002-2003) years at UIUC involved three public high schools and one vocational education school in year 1, and three public high schools in year three. These schools were in four geographically distributed cities in Illinois. Six GK-12 teams were placed in six classrooms within these settings. Each GK-12 team was comprised of a graduate fellow, a teacher, a university mentor, and an evaluator. The graduate fellows, who are scientists-in-training, and their collaborating teachers, however, make the core of each GK-12 program team. The graduate fellows (3 women, 3 men in years 1 and 2) in the first year at Illinois included a computer scientist teaching calculus in a high school classroom, a mathematician teaching college algebra in a vocational classroom, a molecular biologist teaching bioinformatics in an advanced placement high school biology classroom, another molecular biology fellow teaching bioinformatics in a freshman high school honors biology classroom, a chemist teaching molecular visualization in high school biology and chemistry classrooms, and an information scientist with a mechanical engineering background teaching heating, ventilation, air conditioning and repair in a vocational classroom. Year two, the program added a computer scientist working with a regular biology teacher and an environmental scientist working with both biology and chemistry classrooms. Two fellows graduated, earning positions in educational institutions.

Overview:

Over two years, and now entering the third, we are indeed identifying factors of what can be described as successful models of technology integration in effective science education. Employing Web-based tools in asking high school freshman and sophomore students to describe their experiences, GK-12 team members have been able to capture student responses, offering a great degree of triangulation and confirming year one patterns in student learning. Impacts include: (1) students overcoming anxiety of technology when faced with a clear objective, (2) heightened participation levels in the classroom and outside "after hours", (3) evidence of more complex thinking and problem solving skills (artifact creation: websites and, in some cases, suggesting improvements to bioinformatic databases and actual interface creation to those databases), (4) improved latent information literacy skills, and (5) increased awareness—and interest—in science as a professional choice that they had previously never considered. By gathering data in the classroom over time, we can—with some confidence—state that the impact of teaming teachers with active scientists-in-training who offer a technological window on real-world tools is a promising model for science education.

Of particular note, too, is the professional growth of the classroom teacher, who learned to become a research practitioner. Her awareness of her students' growth shifted toward the analytical, with a keener sense of science education practice and pedagogy. This teachers' reflections on both her own and the research team's data from her classroom form the body of this paper; and it positions the teacher as researcher in her own learning culture.

Educating Students to be Scientists:

What often distinguishes the veteran teacher from the new is the incorporation of stories into the conveyance of information. It's the weaving of these tales into the material that helps give the information meaning to the students. Proteins found in the cell membrane become more significant in students' minds after hearing stories about why pygmies don't grow to full height or how cyanide actually ends one's life. Before the stories, the proteins are just another set of facts to be memorized for a test and then quickly forgotten.

Imagine, now, actually involving students directly in the story of a scientist. This is not just a career day on which they learn of the scientist's research. This is a person the students work with over the course of a year; someone who is involved in the students' academic endeavors, and who involves the students in his or her own scientific explorations. The NSF GK-12 Fellows Program put just such a scientist in my classroom: Steven Moore, a Ph.D. candidate in molecular biology. Steve's presence and experience altered the meaning of "science" and "technology" for my students. This was not just a story they heard from Steve and their teacher, this was the making of their own stories as they became involved in Steve's research and acquired the technological skills necessary for that involvement. It's also a story from which educators, scientists, and policy makers can learn.

Beginnings: Partnerships and Connections

A collaborative partnership needed to be formed between Steve and myself in the classroom before we could bring this fresh learning experience to our students. A connection had to be found that would weave Steve into the learning process of my introductory honors biology classroom. Steve brought with him a link to the real world of scientific research. I brought with me an understanding of 14 year olds, how they learn, and of the learning standards that they need to achieve in the course of a year. The struggle to find workable connections altered the teaching-learning process for each of us: Steve, myself, and—of course—the students. Ultimately, the thread that tied us together was something termed the "central dogma of biology." It is the idea that DNA controls the making of all proteins and functioning of the cell, and that in turns governs the ability of cells to function as an organism and to evolve. This is the core of biology and is known by every biology teacher.

In my classroom, as in many others, this idea is obvious to the teacher but is often lost to the students as they move from one chapter to another, from one test to the next. In the effort to make Steve's presence in the classroom valuable to all involved, this dogma became the essential thread that held everything together. It connected many topics: protein structure and biochemistry, protein function, nucleic acids, protein synthesis, cell biology, genetics, genetic diseases, evolution, and human physiology. Most students view these topics as individual chapters in a book, unrelated to one another despite a teacher's attempts to unify the material. Students study biochemistry, get their test grade, and then forget the material. But Steve's presence gave such emphasis to this thread that I altered my method of presentation, and the students began to see the interrelatedness of the individual units that we cover and realize that it had real applications. One student noted:

> *It has been interesting because it seems more like what we were learning is actually used by real scientists.*

The students' growing understanding became obvious in student discussions. Students were relating back to information studied earlier in the year in a way that I had not witnessed in my previous years of teaching. Their questions began to integrate the information they had studied, drawing on the experiences in the classroom to anticipate topics we had not yet introduced. Students began to frame their own inquiries, and we supported these leaps they themselves were making. Because we followed the lead of their questions, students felt as if they were in more control of their learning. They began to think like scientists. Steve conveyed one day after class how impressed he was with the reasoning and questioning we had seen that day. He was amazed at the connections our 14 year olds were making, and wished he had seen that sort of thinking in the introductory college classes he had taught.

At the end of each semester, a final exam is given over everything covered that semester. It is generally difficult for students, not because the questions are so hard, but because many of the questions are from information covered several months earlier. With students better able to construct meaning from the content and showing a greatly increased ability to make connections between units of study, this information was now something essential in all that we did and was not forgotten as we moved forward. For the first time since I started teaching, I did not have to curve the final exam because the grades were so high. As an experienced teacher, I was totally amazed and it felt very rewarding.

With the Human Genome Project has come a phenomenal amount of new information and technology. The database of biology is exploding with new information everyday as can be seen in our newspapers and magazines. Students often come in with questions about this latest information in an effort to understand it in context with what they are learning from the textbook. Having a scientist in the classroom was a valuable resource regarding current scientific thinking. Students came to view Steve as an additional teacher. As one student noted,

> *Steve was really cool to have there because he was like having another teacher to go to for help. He was always very enthusiastic and willing to help and always gave great explanations. It's neat to know that he's also still in school practicing and improving his knowledge so on that level I could relate to him, even though he's far more advanced than me.*

If Steve was not in the classroom and I couldn't answer the question, we zipped off an email. By the next day, Steve would answer that student's question. We even started an "Ask Steve" bulletin board. He was much better than "Ask Jeeves"! According to a student

> *When Steve's there we have discussions most of the time and he's willing to answer any questions. Also when we ask our teacher a question and she doesn't know the answer its really easy because we just write them down and Steve always know the answer right away so it helps us come up with harder and harder questions.*

An observer noted one day that Steve and I did not always agree on the answer to a student's question, and she wondered how we dealt with that. My response was that at the first free moment we researched it online and then came back to it the next day. When asked how we dealt with being wrong, both Steve and I had the same response. We felt that it wasn't important who was right and who was wrong, but that it was very important for students to understand that science is continually expanding its understanding of different concepts. What was right even a few years ago may not be the current thinking today. What was far more important for students to view was the continued learning process that Steve and I were going through and to realize that the term "lifelong learning" is not just for mission statements, but is something anyone involved in science must willingly accept as part of their life.

Students as Scientists:

More important than the learning of concepts in a biology class, was the greatly increased student understanding of science and the scientific method. When a person reads about a scientific discovery it is extremely difficult to comprehend the amount of work that went into it. I take a project- and problem-based learning (PBL) approach in the classroom. In our introductory unit on the scientific method, students were "hired" by the local government to carry out a research project on the effects of road salting on grass. After 2 weeks of gathering data, Steve came in to discuss the results with students. What entailed was a discussion crucial to the doing of science. The discussion centered on what the data showed us, but also what it didn't show us. Students quickly realized that the experiment needed to be revised and came up with a number of different revisions. One student even exclaimed, "We could be doing this all year long!" Steve proceeded to explain to them how his research on just 3 amino acids in a very important protein had resulted in 5 years work. For the first time, students realized that research is not just an experiment that is done in a 50-minute class period and written up that night. Research is something that goes on for years, perhaps even a lifetime. One student summed it up

> *Until I met him, I really didn't know anything about what a professional scientist would do. Knowing Steve has given me a better idea as to what they actually do.*

As these discussions continued throughout the course of the year, students gained insight into "the good, the bad, and the ugly" of science. The "good" aspects of science for these students were not as new to them. They had come from traditional science classrooms where inquiry was not necessarily risk taking; experiments, in their experiences, always were calibrated by the teacher to be "successful." But for the first time, students were discovering the "bad" side of science: even after hard work many experiments fail, the work often can be meticulous and monotonous, and it is—by necessity—repetitive. Also new to them was the "ugly": the politics behind science, the difficulty of getting funded, and the concept of intellectual espionage and industry competitiveness. I am sure a few students were turned off by the prospect of science as a career, but many *more* seemed intrigued by the whole process as can be seen in their comments:

> *Steve's presence proved that what we learn in bio class actually can be used in the real world. His job deals with exactly what we were learning about protein sequences, and I normally wouldn't expect to see anyone doing this for a living.*
>
> *Meeting Steve has helped to motivate me and make me more enthusiastic about a career in science. We are able to hear more about exciting aspects in a career in science from meeting Steve, than if we were reading a textbook. Steve has shown us why he is so passionate about science and it makes me wonder if I could be that passionate.*

Students also felt a real world connection to the world of science as they assisted Steve with his research. Since part of what we study is proteins and the importance of the sequence of amino acids, they were able to gather information via the Biology Student Workbench (BSW). From our classroom they had access to a supercomputer in San Diego, which put all the protein databases at their fingertips. Steve suddenly had 180 eager assistants.

> *Steve's presence in the classroom has motivated and encouraged me to be involved in science because he has taught me it can be fun and interesting. When we helped him with his protein research, I thought it was interesting to do and it made me feel like I was actually doing real science.*
>
> *It has made me far more interested because it allows me to see what a real scientist does. Instead of listening to lectures, we were able to do some actual research and participate in some real life science.*

Their involvement gave the students a sense of commitment and helped them to become more confident. They felt as if they were being treated as scientists, not as kids.

> *…we are doing something to make a difference. To help someone that is asking freshmen students!! Making us feel more confident, mature, responsible, and needed.*
>
> *It has showed me that my role as a student in Honors Biology is very important, and that by working hard in the projects with which he is related, I am helping his studies. It also makes me feel like I am an actual scientist.*

As stated earlier, their ability to formulate questions and to project those questions into future areas was rapidly improving.

Real-world Technology for Real-world Science:

At every turn possible, Steve and I attempted to work technology into our activities with students. Technology was an integral part of helping students think as scientists. In order to do this, technology must be put in the hands of the students. As stated in the *Benchmarks for Science Literacy* (1993)

> *The task ahead is to build technology education into the curriculum, as well as use technology to promote learning, so that all students become well informed about the nature, powers, and limitations of technology.* (p.42)

We wanted students to experience technology as a scientist experiences technology, to realize that it is more than word processing and games. We wanted students to have opportunities to use the technology available to them to solve problems, to improve their skills in measurement and calculations, to access information, process ideas and communicate results, and to explore the social consequences of the use of technology.

There were several benefits to using technology in the classroom. First, students were able to use some of the technology that scientists use to perform experiments and do research in the classroom. Recent advances in biology and drops in the prices of equipment had put a lot of new technology at our disposal. Much of this is relatively new and few biology teachers have had the experience of using it. A scientist in the classroom made experimenting with this equipment much more feasible. Suddenly we were using computer probes, DNA fingerprinting, protein electrophoresis, PCR (polymerase chain reaction), and supercomputers on a weekly basis. Students were able to gather data and experiment in areas that previously we had just to read about. Although frustrations were met along the way, the end result was worthwhile. When asked what the benefits of using technology were to the learner, student comments included

> *The benefits of using technology in the classroom are that I absorb the material more effectively by doing hands-on work. I also get more comfortable with new technology and also it helps me to explore things that are done in different scientific careers.*

> *The benefits are that I will be able to understand the subject better because of the hands on experience I have. When I am in an actual situation in which I need what I have learned, I will remember what I have done rather than what I have read about in a book.*
>
> *I have a better feeling as to what real scientists do everyday. It is easier to get a feel for the trail and error scientific process. It was also fun to know that we were using the same technology that scientists around the world are using. I learned a lot by applying my knowledge in new ways, and in new mediums.*

There was great value in doing experiments that were not straight out of the textbook. We were able to make the process much more inquiry oriented and incorporate new tools like electrophoresis, BSW, and PCR as they related to Steve's work. Students worked side by side with Steve and helped in the problem solving process as problems arose. Rather than teach the concept and then do a 50-minute lab that proved that everything we said was true, students performed the experiment and developed the concept themselves. Discussions about their findings would follow to ensure that no major ideas were missed. For example, students manipulated the DNA sequence of a protein found in the cell membrane. The correct DNA sequence allows the cell to function normally, but the incorrect sequence results in an altered amino acid sequence and the person becomes very seriously ill. Students were able to manipulate the DNA sequence by substituting bases, adding bases, deleting bases, and inverting bases. Then the different tools could be used to view how that would affect or not affect the amino acid sequence of the protein. Students gained insight into DNA transcription and translation and the affect of mutations upon the resulting protein before being inundated with the terms. This activity had students questioning whether or not a change could end up making the organism better or stronger. Unknowingly, they moved themselves forward into the theory of evolution.

Second, using technology helped students to develop technology skills that prepared them for their future. While most students enjoyed and looked forward to our uses of technology, not all did. One such was an extremely bright, young woman who wanted little to do with computers or any of the other high tech equipment we were using. Being the conscientious student that she was, she did everything we asked of her. At the end of the year, I asked her if she enjoyed technology any more than she had when we started the course. Her response was no. I proceeded to ask her if she was any more comfortable with technology than she had been at the beginning of the year. She said most definitely yes. In my mind an important goal had been achieved. She, like many students, realized that—like it or not—they will have to be able to use technology as they enter the workforce. And if they do move into the sciences, as some have expressed they wish to, they will have been exposed to the emerging trend toward bioinformatics.

> *… it prepares us for the future when we will grow up and have jobs on our own that require a lot of technology. This way we will already be experienced in what has to be done.*
>
> *Since technology is becoming a more integral part of our daily lives, using it in the classroom helps me to connect basic knowledge to what we are learning. It also makes certain things, like research, more efficient and more interesting. Projects have become easier as well. Technology is only going to become more and more prevalent in our lives, and applying the knowledge to our learning will prepare us well.*

A third benefit of using technology in the classroom was visualization. Visualization made it easier to understand concepts, made learning more efficient, and added interest to the subject. Technology in the hands of the teacher can be an invaluable tool for helping students visualize difficult content. The Internet provides innumerable sources for animations of concepts. A student can watch DNA replicate or see a protein being synthesized and folding in its own peculiar way. With the use of a digital camera and an LCD projector, we were able to take every student through Steve's lab at the University of Illinois. It's the only way 180 students could have experienced it. When asked how a teacher who uses technology skills teaches differently, students replied

They are able to give more vivid examples that help me to see what I need to know. Much more organized presentations, and it makes me pay attention because I know this is good information.

A teacher that uses technology can relate any topic to the real world and give examples. They don't make students do busy work because technology can take things a step farther and explain things more visually.

The teaching is more interactive and in my mind, fun. We are able to see more things from different angles and put it all together in a hands on experience.

Several students even noted:

I think that a teacher that uses technology does much more self-directed projects with the students to allow for more self-discovery and independent learning. He or she teaches how to use the technology, but it is up to the student to take the initiative to their own learning.

Technology in the hands of the learners allows them to create their own visualizations of the concepts they are dealing with and promotes critical thinking. Labs that dealt with the computer probes allowed students to watch the graph develop as the data was gathered. Students could be seen actively discussing the data together rather than simply spending the class time attempting to record it and graph it by hand. This allowed time for students to play with the variables and see how small alterations would change the final outcome. It also gave Steve and I more time to interact with students during the lab and question them for understanding. BSW also provided students with numerous tools for manipulating data. Students did not have to spend years of tedious work to collect the data, but rather had data from around the world on every known DNA and protein sequence. The data manipulation provided these students with a much richer understanding of DNA, genetics, and evolution than I have ever seen in previous students.

Biology workbench has connected our classroom with the rest of the scientific world. It has provided our classroom with information that we use to strengthen our understanding of science. For example, we studied evolution. Using Biology Workbench we could find how organisms are related and how they've changed through evolution of their proteins. With Biology Workbench we could line up all the proteins and spot specific sites where they differ.

Using biology Workbench has helped me visualize the material we work with on a day-to-day basis. I can usually understand things better when I am told about them and then that information is backed up with a visual aid. DNA and amino acid sequences are hard to visualize by yourself and Biology Workbench makes this type of thing easy to see.

Students presented their research to their fellow classmates and anyone else interested through websites that they designed. These websites were then posted to the World Wide Web. The development of their processing skills can be seen as one looks from their first website to their second. Students became much more adept at presenting their research on DNA and protein sequences, demonstrating literacy benchmarks for authentic information technology understanding.

Conclusion:

So, what did we learn? The students' own voices made clear the impact technology and programs such as the Graduate Teaching Fellows in K-12 schools can have. Student comments describe the value of science education that exposes students to how scientists do "real science" and demonstrate how science is integrated with and depends on technology. This will require scientists to become more involved in education (if we are to have a future generation of scientists), technology be put in the hands of students, and continued education provided for teachers to update their knowledge and skills. Reading through 2 years of data from more than 200 students reinforced my views that standardized tests do not show much of the learning that can occur in a classroom. The depth of their thoughts and the richness of their answers is a glimpse into what the future could hold if educators focus on authentic learning skills rather than teaching to the test.

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