The Journal of Experimental Secondary Science

Editorials

Transforming Science Education

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It is an exciting time in science education. We are at the start of a new vision for teaching science that promises to transform the experiences of students in all grades across the country. This new vision calls for science classrooms that bring science alive for students, emphasizing the satisfaction of pursuing compelling questions and the joy of discovery. The vision is articulated in a new report from the National Research Council: "A Framework for K-12 Science Education[1]", which provides a blueprint for new state standards in science education. Based on this framework a consortium of educators and scientists from 26 states are developing Next Generation Science Standards. These standards will be available for states to adopt to guide what students learn in science for the next decade or more.

A major goal of the framework is to shift the emphasis in science education from teaching facts to immersing students in doing science. A central tenet of the framework is that throughout elementary, middle and high school, students should have opportunities to DO science. This might look different in second grade, eighth grade and tenth grade, but at all levels students have the capacity to think scientifically and engage in the practices of science.

The new framework is based on the current body of work and draws on the experience and wisdom of hundreds of experienced educators, scientists and education researchers brought together over nearly 10 years by the Board on Science Education at the National Research Council. The National Research Council is a non-profit, non-governmental organization whose mission is to improve government decision making and public policy, increase public understanding, and promote the acquisition and dissemination of knowledge in matters involving science, engineering, technology, and health. Within the NRC, the Board on Science Education focuses on science education for all ages, in school settings, and across the many venues outside of school including museums, aquariums, nature centers, zoos, after school programs, and community organizations. BOSE brings together groups of experts who draw on their professional wisdom and examine research on learning and teaching to make recommendations about how to improve science education.

The new framework is based on the results of research studies conducted by scores of researchers in education and the professional wisdom of numerous experienced educators. The framework brings to life a major conclusion that has cut across many of the reports published by BOSE; that to learn science deeply and to appreciate the wonder and beauty of science students need to have opportunities to engage in scientific practices. That is, students need to do the things that scientists do: pose questions, plan and carry out investigations, gather and interpret data, develop arguments about their findings, and then communicate their arguments to peers.

The emphasis on practices – on doing science – represents a shift from what happens in typical science classrooms where there has too often been an emphasis solely on the facts of science. Emphasizing practices acknowledges that reading textbooks, listening to lectures and memorizing terms alone does not lead to deep understanding. Nor does focusing only on facts help students appreciate how scientists develop an understanding of the world and the rigorous process by which the scientific community comes to accept one explanation or theory as better than another. We now know from research that students come to understand scientific ideas best when they actively use their knowledge while engaging in the practices of science.

Unfortunately, at present many students in grades K-12 do not have access to opportunities that allow them to experience science as envisioned in the framework. For example, a previous report of BOSE, America's Lab Report[2] found that most laboratory experiences for high school students were not high quality. They were often disconnected from the ideas presented in lectures or the textbooks and were of the "cookbook" variety where students follow a scripted set of steps with little opportunity to express their own ideas and pursue their own curiosity.

The vision of the framework will help to address this problem of access. It emphasizes that ALL students can learn science and that they should have opportunities to engage in the full range of science practices. The over arching goal of the framework is to ensure by the end of 12th grade that all students have some appreciation of the beauty and wonder of science, possess sufficient knowledge of science and engineering to engage in public discussions on related issues, are careful consumers of scientific and technological information related to their everyday lives, are able to continue to learn about science outside school, and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology.

Now more than ever, it is essential for every American citizen to understand science. Science, engineering, and the technologies they influence, permeate every aspect of modern life. Indeed, some knowledge of science and engineering is required to engage with the major public policy issues of today as well as to make informed everyday decisions, such as selecting among alternative medical treatments or determining how to invest public funds for water supply options. In addition, understanding science and the extraordinary insights it has produced can be meaningful and relevant on a personal level, opening new worlds to explore and offering lifelong opportunities for enriching people's lives.

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Connecting High School Students to Opportunities with NASA

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It is no secret that we learn through the combined experiences that make up our lives. This fact has been well established and studied. Experiential learning and "learn by doing" mantras have long been a foundation for the best practices of teaching; however, technological advances over the past decade and the pervasive use of the internet in our daily lives begs to renew old questions. Are simulated or digitally replicated experiences as efficacious as the "real thing"? When are the two types of experiences most productive and where do negotiations begin and end to measure the benefits and drawbacks of each?

During the dawn of computer simulations in science education, it was easy to focus on two scenarios for use of simulations in place of the hands-on lab experience: if the laboratory experience was too dangerous with the available safety precautions and if the cost of the laboratory experience exceeded its practical classroom use. As classroom and laboratory budgets have diminished, computer simulations may replace more activities that were once a common part of the secondary high school experience.

Today's simulations are growingly sophisticated and there is an ever-astonishing blur between reality and CGI for the high-end productions. This is clearly evident in the film industry. For example, it doesn't take long for the viewer to forget that half of the characters in the fantasy movie Avatar[1] do not actually exist outside of the production.

Randy Bell and Lara Smetana[2] have published research through NSTA that suggests four content and instructional considerations when using simulations: 1. Use computer simulations to supplement, but not replace instruction, 2. Keep the instruction student centered, 3. Clearly recognize the limitations of the simulations and 4. Make the content, not the technology, the focus of the simulation.

Bell and Smetana's work reinforces that simulations should not stand alone in place of investigational experiences and instruction. They are just one other tool available to teachers and students on the quest for understanding and learning. Real world opportunities will always include computers crunching the data or creating the models to help us better understand the data, but studying the Earth sciences, for example, should involve getting wet or dirty in the process. It is for this reason that the Apollo astronauts spent a great deal of time in the desert southwest to learn the in situ skills required to don the hat of a geologist during their sample collecting journeys on the lunar surface.

For the past seven years, I have had the great privilege to work with NASA Education and many of its missions. Throughout this experience, I have learned volumes about what is available to students for practical and authentic research. Short of boarding a spacecraft and orbiting the Earth, many of these opportunities are available via Internet based data sets and imagery. Teachers and students can use this data to interpret a myriad of changes in our Earth's environment. Most of this online data is not a simulation, rather reflective of the actual data collected remotely by Earth Observing Satellites and Sensors. As Bell and Smetana suggest students would need to have a conceptual understanding of the questions they would pose for their research. Research conducted through NASA data would be very much student and content centered, as the data exists for interpretation by the researcher and, in most cases, is not in a prepackaged right or wrong answer scenario.

Need a place to start? Try the NASA Earth Observatory site[3]. This site has articles authored at a variety of reading skill levels and connected to the discussions being held by the scientists who manage the research for the respective satellites and sensors. From the background information of the NASA Earth Observatory, NASA Earth Observations (NEO)[4] offers a site where NASA Earth Science Data can be visually manipulated and data sets can be compared across environmental parameters.

NASA's Giovanni[5] is also a web based application "that provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth science remote sensing data without having to download the data." Giovanni is a bit more involved than NEO, but extremely useful for real time research that is applicable across the scientific community.

If this feels like jumping in at the deep end, the My NASA Data[6] site has been used by teachers at the middle grades and offers an introductory approach to using NASA Data for research. My NASA Data offers You Tube tutorials and lessons, and a series of lessons and project suggestions. It is a more guided path for the secondary teacher or student, but provides many of the skills that lead to the paths less worn for use of NEO and Giovanni.

These resources represent just a handful of Earth Science opportunities for students interested in these fields of study. On the NASA Student Programs web site[7] there are more than eighty opportunities described across a wide variety of disciplines and populations.

These opportunities are not all data set sources. In deed, most offer the very real world connections to NASA personnel and resources that many student researchers may assume are not within their reach.

With the new NASA Education Portfolio currently being developed, the following areas have been identified as Key Achievements for fiscal year 2013[8]:

- Providing experiential opportunities, internships, and scholarships for high school and undergraduate students
- Using NASA's unique missions, discoveries, and assets to inspire student achievement and educator teaching ability in STEM fields

Each of these outcomes are based on experiential learning that connects teachers and students to NASA personnel and its resources. At NASA's Goddard Space Flight Center, 200-300 high school and college interns regularly participate in real world experiences throughout the summer months and for many their research continues into the following semesters, often with technological career connections to NASA or one of its contractors upon graduation.

While I am partial to seeing students pursue studies in Science, Technology, Engineering or Mathematics (STEM), whatever career path a student pursues should be one for which they have developed a passion for learning and discovery. The next generation of careers may be based upon the foundations of today's learning, so building experiential foundations is essential to the life long learning process required to compete for future STEM careers. The "real world" of the future will consist of a whole new genre of experiences gloriously innovative and immersive. Take your steps now to start this exciting journey: become a participant, instead of a spectator, and collect experiences that will separate your portfolio from the rest.

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The American Junior Academy of Sciences

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The American Junior Academy of Sciences (AJAS) is America's only research honor society for high school students aspiring to become scientists. The AJAS believes that the most effective way for students to learn science is to perform authentic research, and to follow the scientific process to its logical end by writing a research paper and either publishing or presenting it to a group of scientists. If students are not given this opportunity, it is somewhat like a musician who composes music but never performs for an audience. *The Journal of Experimental Secondary Science* serves a pivotal role in the scientific process by providing a venue for students who have done outstanding research and been through a scientific peer review. The journal's rigorous review of student research by accomplished scientists allows young scientists to experience one of the most important and challenging elements of the scientific process.

Membership in the AJAS is by invitation only. Each state Academy of Science chooses premier high school students from their state to nominate as AJAS delegates. Eighth grade students are also invited in some cases. Each state Academy of Science also determines the guidelines by which their state AJAS delegates are chosen. Usually, scientists in each state's senior academy organize their respective junior academy of science. Under the direction of the Junior Academy of Science, a statewide scientific research program is organized whereby students who have done outstanding research are chosen to attend the national AJAS convention.

The national AJAS convention meets in conjunction with the American Association for the Advancement of Science (AAAS) annual symposium. The AAAS is the world's largest general science organization and publishes the journal "Science". With more than 138,000 members and 275 affiliated societies, the AAAS serves as an authoritative source for information on the latest developments in science and bridges gaps among scientists, policy-makers and the public to advance science and science education. An important purpose of the AAAS is to support young scientists in middle school and high school. It recognizes that these young people are its future and provides a venue for these young scientists to present their research along side the world's leading researchers at their annual symposium.

Early Matters

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Why has it become accepted practice for our youth to play musical instruments, sports and video games early but not to conduct independent lab experiments and research until much later? This science education convention persists in the face of our own personal experiences and objective findings from neuroscience and pedagogy, for example, which declare affirmatively that - early matters.

As we all know, while there are some exceptions, by and large, our educational system does not provide real authentic independent research opportunities for the majority of students until graduate school. This means the majority of students complete four years of high school and four years of college without any research experience. This in itself means that they are not generally exposed to and competent in such marketable skills as careful observation, documenting data/experience accurately, communicating results effectively, and critically thinking through what their observations mean. These are skills urgently and broadly needed in our 21st century information-innovation economy, regardless of job, career or field.

In my opinion this is an unfortunate waste. A waste of time and a waste of talent. It is wasted time and opportunity since we all know that human curiosity is very high in our early years. Our current science education system does not maximize fully, leverage effectively, or nurture efficiently this window of opportunity in the human life cycle. In fact, many have argued convincingly, and I agree completely, that we have traditionally done the opposite: discouraging curiosity and creativity, valuing conformity, rote-memorization and standardization rather than independence and critical thought. It is as if we all seem to forget that experiments made us modern.

Our current system also wastes the most valuable resource in the 21st century economy – our human resource. By not fully utilizing and harnessing our human resources early in our pursuit of knowledge and for the purpose of innovation, we are losing out. Students in this content-obsessed system become disinterested in science early and consequently the science talent pool and STEM workforce is diminishing. This means we are losing insights, discovery, creativity, and productivity in a world where more is needed to address global problems such as health, energy, rapid urbanization, and scarcity of essential resources from water to minerals.

For the last 17 years, I have been engaging both high school and college students, curricularly and non-curricularly, in early research. I can assure you that our students are not too young to research but are in fact very eager to do so. These years of experience has embolden my efforts to advocate and provide our youth with opportunities to conduct research early regardless of whether their career goals are in science, technology engineering, and mathematics.

There is no valid reason why high school students who drive cars, use computers, excel at video games, and navigate a host of 21st century technologies cannot also recrystallize solids, isolate DNA, rotovap solvents, reflux reactions, separate mixtures, analyze protein gels, or operate infrared, Raman, UV-Vis, NMR and AFM instruments.

Early research participation facilitates a host of desirable and needed outcomes, such as: (a) building the STEM workforce, (b) capturing the most innovative and productive years of the human life span, (c) increasing investments in young 'homegrown' researchers rather than foreign post-docs, (d) providing an avenue for seamless transitions and interactions between secondary and tertiary science education, and (e) facilitating a sustainable culture of innovation, discovery and development.

Our democratic western societies are built, in part, on the values of open and free. I believe that with respect to research, discovery and innovation, we need to institutionalize another value – early. I believe that universal adoption of early research participation programs is fully consistent with former United States President Franklin D. Roosevelt's statement: "We cannot always build the future for our youth, but we can build our youth for the future." Furthermore, it is in the spirit of our best pedagogical practice as eloquently, succinctly and powerfully expressed by the American poet, Theodore Roethke, "I learn by going where I have to go."