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Innovative teaching and technology in the service of science: Recruiting the next generation of STEM students

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Abstract: This article examines innovative approaches to augmenting science lessons taught in middle and high school, with special emphasis on the importance of the early teen years, when experiences both in and out of school have significant impact on career decisions. This is a reflective essay on the recent work of science educators and educational researchers hoping to increase science literacy in American students and inspire them to choose STEM careers. The creativity and breadth of the techniques discussed have important implications for the way in which student teachers are prepared within college secondary education programs.

Keywords: science literacy, informal learning, analogies, metaphors, argumentation, science mentoring, science education.

Although researchers disagree on the extent of the shortage in the U.S. of science, technology, engineering, and mathematics (STEM) workers (Brown, 2009), most agree that STEM education needs revamping. And, while innovators themselves disagree about the target audience, whether every student should be exposed (“Some STEM for all”), or just the technically-gifted (“All STEM for some”), many see the need to move from content-driven lectures and texts to more inquiry-based group projects. And further, there is disagreement over the setting of educational reform, whether to innovate within the science classroom, or outside of the traditional schoolroom—or indeed, outside the traditional school. Some recent programs have shown that technical innovations and computer applications have a role to play in improving STEM education, as can the imaginative use of tools from other disciplines, like those of English teachers, as this paper will show.

I. Background.

Pervasive national anxiety about science education in the United States has reached the level where some scientists, like S. James Gates of the President’s Council of Advisors on Science and Technology, see the country as entering our third great crisis regarding STEM (science, technology, engineering, and mathematics) education (Witze, 2010). Just as the German threat during World War II and the Russian challenge posed by the launch of Sputnik prompted calls for the reform of science and technology education in the 20th century, the low comparative scores of American science and math students over the last decade have renewed the chorus of criticism about the effectiveness of American STEM pedagogy.

The test scores at the center of this controversy include the quadrennially administered Trends in International Mathematics and Science Study (TIMSS) from the Spring of 2007, in which the American 4th graders placed 8th out of 36 countries, while our 8th graders finished 11th

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out of 48 countries, and the Programme for International Student Assessment (PISA) in 2009, when U.S. 15 year olds (10th graders), came in 17th out of 30 countries.

How significant are these numbers? How worried need we be about losing the scientific and technological advantage over other countries? According to the Bureau of Labor Statistics, job growth for STEM workers was projected, in 2007, to grow 19% by 2018, compared to all other occupations achieving a 10% growth rate. With the ensuing recession, no shortages currently exist, prompting skeptics of the STEM worker shortage to downplay the seriousness of the projection (Atkinson & Mayo, 2010). But technological innovation, according to the U.S. Department of Commerce, has been responsible for 75% of the growth in the U.S. economy since World War II, and 55% from 1955 to 2005. Against this economic backdrop, the fact that the United States currently ranks 6th out of 40 developed nations in innovations, and 40th out of 40 in improvements to innovation and competitiveness (patents, R & D spending, STEM degrees, and workforce intensity), signals an unmistakable erosion of economic leadership (Atkinson & Mayo, 2010).

Because economic leadership flows from technological innovations, and currently, only 5% of American workers have the skills needed to be STEM workers, we risk falling behind in the generation of new ideas, and the success that flows from bringing those ideas to fruition. It is possible that our country may lack the domestic candidates to fill future STEM jobs (currently 18% are foreign workers, and many are now returning home to vibrant economies that place a premium on STEM proficiency). But our faltering economy already shows the strain of increased competition, and so a concerted national program to improve science education must also become a recruitment effort as well. And any worthwhile attempt at increasing the ranks of STEM students has to start at the point where U.S. science education begins in earnest, in middle school and high school. Here is where student test scores start to wane, where the emphasis shifts from elementary school's focus on animals, weather, and the local landscape, to lab experiments and difficult terminology, that is, to a perceived "distance" from everyday life—high in relevance to college admission, but low in creativity and student engagement.

Determining the scope of the effort for students at this age has significant implications for meaningful reform. Should science education be focused narrowly on technically-gifted students (the "All STEM for some approach") or must we employ a widespread effort to increase science literacy for all students ("The some STEM for all approach")? The answer has to be a combination of both. Advocates for the creation of hundreds of new specialty STEM high schools want to create a cadre of "Deep Divers" who can concentrate on the specific skills needed to acquire deep knowledge in one discipline, while forming "roots" in 2 others. Reformers intent on raising the scientific literacy of all our students point to the basic scientific knowledge voters must have to intelligently deal with the most pressing public policy issues for the future: climate change, ocean protection, food scarcity, energy use, water quality, waste reduction, economic policy, and of course, support for science.

This division over educational focus in many ways mirrors the changing understanding of the term "scientific literacy," which originally conveyed the attempt to make scientific concepts more comprehensible to more people, but now reflects dual usage by researchers. The more conventional use refers to examining the knowledge that results from teaching the language of science and from using various forms of science texts, which seems to fit nicely with the "all STEM for some approach." The other use involves promoting engagement with the natural world to illustrate scientific principles and the scientific way of thinking, which would easily assimilate with the more democratic "some STEM for all approach".

While such a bilateral approach necessitates programmatic changes at the high school level and beyond—it can begin with a unified approach to making science less formidable and more engaging at the middle school level. And it is necessary to begin with the middle school curriculum, before students decide that science is "not for them," or that school is "not for them." In addition to the inherent difficulty of the subject matter, secondary school innovators also have to deal with the natural reluctance of some students and the traditional pedagogical approaches endemic in most schools. Indiana University's High School Survey of Student Engagement in 2009 found that 66% of the surveyed students reported being bored in school every day, with 98% of them deeming the material either "not interesting," "not relevant," or "not challenging enough." The survey found that the standard pedagogical approach, the teacher lecture, engaged student interest only 26% of the time, while switching to more interactive approaches, such as group projects, engaged students 60% of the time, and group discussions and debates held students' interest 61% of the time (Yazzie-Mintz, 2010). Clearly, both the material and the methodology have to synchronize in such a way that students feel they "need to know this," and "want to know it now."

II. Methodology.

Innovative classroom approaches for engaging students in the pursuit of scientific literacy, as well as technical enhancements to learning and "informal" science programs outside of school, must all be subject to evaluation by rigorous and consistent standards. Five principles for developing materials and instruction for literacy in science show up consistently in classrooms across the country, and in the most recent research (Krajcik & Sutherland, 2010):

First, Linking new knowledge to prior, foundational learning;

Second, Stimulating student exploration by generating relevant questions about a topic's impact on their own lives;

Third, Making sense of models, diagrams, simulations, and graphs;

Fourth, Applying newly-learned scientific ideas to new contexts;

Fifth, Engaging students in the construction of arguments and explanations.

Matching these recent classroom innovations and technical enhancements to their underpinnings in Krajcik and Sutherland's principles can provide the theoretical justification for changing the training for new secondary educators. Establishing the value of interdisciplinary collaboration among teachers from the sciences and the humanities toward improving science literacy can provide the foundation for this change. Examining the role that enhancements in software design and the remote access to both scientific equipment and research scientists can play in career decision-making, strengthens the argument for structural change in our approach to science education. Recognizing the underappreciated contribution of "informal" science programs completes the triad of teaching tools available to educators.

III. Findings.

Most research into reforming science education has addressed the difficulty students have with comprehension. All of the sciences employ specialized vocabularies and abstract concepts, "many of which are chains of conceptual relations too long or complex to reside in working memory." (van den Broek, 2010). For beginning science students, these obstacles are compounded by texts written in passive voice and dense with information-bearing words (nominalizations). The texts offer no respite in the presentation of foundational ideas critical to understanding each scientific concept, so that one overlooked connection or misperception could derail those "chains of conceptual relations" necessary for comprehension. At the introduction to a new subject, maintaining this coherence presents the greatest challenge for teachers in their quest to engage students.

This quest for engagement leads us back to an examination of the dual understanding of the term "science literacy." Each understanding carries with it certain critical assumptions about the nature of the problem facing educators. The first meaning, dealing with language use and texts, characterizes the loss of interest in science as a failure of methodology—the wrong text, the wrong activities, the wrong approach. If our science pedagogy improves, this thinking goes, students will engage more readily in scientific inquiry. The second understanding of scientific literacy more directly confronts the national concern about STEM education by viewing the problem as one of recruitment. From this perspective, if students see science as an indispensable tool needed to achieve their career ambitions, and to enrich their relationship with the natural world--not just an academic requirement, then they will enthusiastically embrace scientific inquiry. Both approaches to scientific literacy can yield valuable outcomes, and both need to be pursued, not just by science teachers, but also with the collaboration of others, including English teachers.

A. Classroom Learning.

Krajcik and Sutherland's five principles serve as a useful tool for organizing proposed innovations. The first principle, linking new knowledge to prior, foundational learning, takes on an added challenge when teaching counter-intuitive concepts that do not match a child's everyday experience, in which the sun, not the earth, appears to move in a sky that seems empty of substance, not packed with various gases critical to the maintenance of life and the regulation of climate. So immediately the teacher faces three obstacles while introducing new ideas: modifying existing knowledge, and introducing unfamiliar, specialized vocabulary, that is used in surprising syntactical structures. And these obstacles appear even more daunting in the wake of No Child Left Behind's (NCLB) influence on educational policy. An emphasis on preparing for standardized tests in reading and math has left less time for science instruction. A much-cited 2008 survey of San Francisco area elementary schools (Dorph et al., 2007) documented the post-NCLB allocation of 60 minutes per week for science, compared with 200 minutes per week in 2001. So that students enter middle school with less of a scientific foundation. And, once students enter the full-period science classroom in middle school, they continue to encounter the time limitation resulting from the decision to assess content knowledge via multiple choice standardized tests, which requires the teaching of facts over broader scientific concepts.

Isolated in the science classroom, and short on class time for scientific inquiry, some teachers have addressed the problem of integrating new material by opting for texts utilizing more familiar vocabulary, and more straightforward grammar in order to have students spend less attention on language and more on learning key concepts. As van den Boek (2010) rightly points out, when introducing topics such as anatomical nomenclature, a simplified language approach doesn't always fit. And given the shear volume of material to be covered, time constraints limit the number of review lessons for mapping new terms to their correlates, forcing teachers to rely upon the "motivation and prior knowledge" of their students for lasting comprehension.

Now some alternatives are available. A supplemental text-based approach, Guided Inquiry supporting Multiple Literacies (GIsML) helps students conduct scientific investigations using a fictional scientist's notebook (Pearson, Moje, & Greenleaf, 2010). Students get practice at interpreting data and drawing inferences from the available evidence. And by adopting a collaborative approach, a science classroom activity like the scientist's notebook can be extended and complemented. In the English classroom, students can keep their own journals of new knowledge—translating the inferences from the scientist's language into their own terms, which aids comprehension. Similarly, English and social studies teachers can use web-based programs such as Word Generation (designed by the Strategic Education Research Partnership for middle school use), which inserts important vocabulary words into articles about real-life dilemmas to demonstrate the use, in-context, of words such as "hypothesis," "infer," and "data." This stimulates discussion, where students get further practice using these terms (Snow, 2002). Outside collaboration has also yielded significant benefits. The Beckman Institute's "Bugscope," a free, educational technology outreach program for teachers and students at all levels, offers online access to the University of Illinois at Urbana-Champaign's electron microscope so that students can view minute details of insect anatomy, and more importantly, interact with real scientists. Students can ask questions about insects, electron microscopy, or science careers. One fifth grader asked, at the end of their session with the scientists, "What does it take to be you guys?" (Korb & Thakkar, 2011). In this one short quote resides the rationale for educational innovation: direct involvement with scientists and the thrill of scientific inquiry provides the answer to the question students always ask, "Why do I need to know this stuff?"

Krajcik and Sutherland's second principle, driving student exploration by generating meaningful and engaging questions about a topic's impact on their own lives, also lends itself well to collaboration. For example, asking a scientific question like "What nutrients in food are essential for growth and good health?" can lead to discussions in a health or English class, during which students are encouraged to draw inferences from evidence in order to generate questions of their own, such as, "What should I eat to lose weight while maintaining good health?" or "Why do some foods do more harm than good?" By creating a purpose for continued reading, students hunt for specific information and remember it better (Lorch, Lorch, & Inman, 1993). It is this "need-to-know" that pushes students to tackle complex research material for written assignments and class discussions. Both written and oral sharing of new knowledge aids memory formation.

Classroom management, especially in the handling of grades, can also have a large impact on learning. Fortunately, some of the lessons learned in the video game industry are slowly coming to the assistance of education. Contrast the enthusiasm of gamers who attempt to "level up," that is, ascend to a more difficult round of challenges by acquiring needed skills, with the student questioning "when" this science material will ever be useful, and it becomes clear that invoking a difficult challenge that promises immediate feedback and rewards provides students with the kind of engagement they crave.

The efficacy of this approach is on display at New York City's Quest to Learn, a public charter school for students in grades six through twelve, where questions become "quest"ions in a game-based educational environment (McGonigal, 2011). Students on a "quest" to achieve mastery in a subject generate relevant questions to help them work toward a self-chosen goal, like master code-breaker, master storyteller, or master chemist. To "level-up" to master status, students must overcome "boss level" challenges, like facing an extremely difficult "boss monster" (the equivalent of a final exam). Achieving this goal creates the emotional rewards of a job well-done and the satisfaction of overcoming significant obstacles. They learn and they have fun—"hard fun", while mastering an academic skill to solve personally-relevant problems. Classroom management shifts to coordinating enthusiastic learners embracing concepts with a direct impact on their lives, as Krajcik and Sutherland propose.

The third principle, making sense of models, diagrams, simulations, and graphs is an indispensable skill for several reasons. Not only does the visual representation of data create quickly-grasped summaries of measurements and processes, but it also aids, especially with the advent of powerful new data visualization programs, in the recognition of emerging patterns and relationships in data, across many disciplines. For example, the Molecular Workbench (MW) software, developed by the Concord Consortium of scientists and educators in Concord, Massachusetts, is a research technique that has been successfully converted into a tool for teaching. MW transforms equations of natural phenomena into digital representations that allow students to carry out computational experiments on a wide range of science concepts (Xie et al., 2011). Similar to real experiments, students can observe visualizations, and formulate questions, hypotheses, investigations, and analyses of results, focusing on nurturing the ability to do quantitative analysis without needing to master complex mathematics and statistics.

Teaching individual scientific concepts like states of matter, gas laws, fluid mechanics, and chemical reactions, can often result in a view of fragmentary forces at play in nature. By viewing MW's simulation snapshot of the interacting forces in a classroom experiment, students perceive the interconnectivity, which paves the way for richer creativity in designing thought experiments. By crafting additional experiments themselves in an attempt to challenge existing laws, students learn to think like researchers. In partnership with science teachers, English and social science teachers can reinforce newly-acquired proficiency by relating the interplay of physical forces to real-world phenomena. Creating research projects in humanities classrooms to investigate societal problems that actually utilize the students' new understanding of scientific principles, helps long term memory formation.

The fourth principle of Krajcik and Sutherland, applying newly-learned scientific ideas to new contexts, opens up many opportunities for English and social studies teachers to craft units where students can integrate what they have learned in science into an explanation of, and then a solution for, societal dilemmas like water scarcity, climate change, soil depletion, overfishing of the oceans, and an unending host of other challenges. This reinforcement of new scientific knowledge requires only the coordination of planning among teachers, and the introduction of science-based topics for writing assignments in classes that normally sidestep scientific material.

Inside the science classroom, applying scientific concepts to new contexts conjures up images of Science projects designed for annual science fairs around the country. One nonprofit developer of software, Science Buddies, found that students had much more difficulty selecting a topic and doing the background research than they had with formulating hypotheses, designing experiments, and analyzing data (Hess, Corda, & Lanese, 2011). With personalized learning tools and over 15,000 pages of content, Science Buddies matches students with information that interests them and answers their questions by connecting them to an online community of scientists. This "recommender" system allows students to converse online and understand how scientists work (only 18% of Americans have ever actually met a working scientist) and thus become a part of a learning community outside of the school setting. As with the Bugscope project, students become inspired by contact with real scientists probing meaningful questions about nature and actual problems, not just concepts in a textbook.

The fifth, and last principle for engaging students in scientific inquiry is the richest opportunity yet for collaboration between science and English teachers: engaging students in the construction of arguments and explanations. These tasks have traditionally been the province of the English teacher, especially persuasive arguments. Arguing, however, is also a core competency of scientific inquiry (Osborne, 2010). Scientists dispute the methods of collecting and interpreting data, as well as the theories resulting from interpretations. They argue in small meetings, at conventions, and in peer reviewing each other's research. It is really within this crucible of attempting to find weaknesses in a hypothesis or the data supporting it that a consensus is forged among scientists. Science would not be as objective, and as trusted without argument—yet, as a review of science texts will verify, the controversies surrounding scientific theories receives very little attention in science texts used in our schools. Densely-packed facts are presented for test preparation, at the expense of revealing the history of how we came to know what we know about consensually agreed upon theories, even relatively recent ones such as plate tectonics, for example.

By teaching the tools of rhetorical analysis, English teachers are already preparing their students to test the reliability of evidence and the validity of assumptions underpinning the claims made in new theories they will examine in science class. An analysis of 18 studies grouping learning activities into three categories (Chi, 2009) found that the "Interactive" model (based on discussion and argumentation) produced more effective learning than either a "Constructive" model (based on producing a written essay or lab report), or an "Active" model (focused on experimentation). Very surprisingly, the "Active" model produced the least effective results. Collaborative effort will always be required, however, between teachers to help students, especially younger students, to determine the reliability and relevance of evidence.

This cross-fertilization of ideas about science concepts can help our schools achieve the goals set forth in the recently released report from the National Academies, *A Framework for K-12 Science Education*, which suggests that students return to science concepts in increasing depth as they get older, and placing problem-solving skills for real-world problems on a level with the inquiry method currently taught (Mervis, 2011). When students discuss in an English class or a social studies class the implications and effects of the concepts discovered in science class, they are spiraling back to lessons from earlier in the day, and increasingly looking at concepts from earlier grade levels with more sophistication and deeper appreciation for their significance.

The other half of the fifth principle, engaging students in the construction of explanations for new science material using their own language, creates an opportunity for English teachers to demonstrate the practical application of analogies and metaphors. And here great benefits have to be weighed against the danger of misconceptions from poor choices by teachers who cling to outdated or unfamiliar analogies, especially with younger students. Often, a student's understanding of a concept derives from the popular metaphors used to create quick, shorthand descriptions. For instance, the term "DNA fingerprint" frequently appears in news stories about forensic science's ability to solve murders and paternity suits, or to identify the remains of accident victims. Interviews with both elementary and secondary students (Venville, Gribble, & Donovan, 2010) reveal the confusion that can result. One ten-year old student thought that DNA was "pieces of the body used to identify things," and is located "outside of the body, like hair, fingerprints, footprints." (Venville, Gribble, & Donovan, 2010). So the phrase "DNA fingerprint" became "DNA=fingerprint" in the minds of young students untrained in the use of representational language. And science teachers, who expend a great deal of energy and care to teach a concept, may not realize that memorable catchphrases carry inseparable associations for students struggling to incorporate new material.

Proper training in analogy construction involves a thorough examination of the features of both the analog and the target concept. In collaboration with the science teacher, the English teacher must examine those features shared by the new material being taught and the familiar analog, as well as those features they do not share. While the "perfect" teacher-constructed analogy may not exist, the chosen analog can serve as a point of departure, from which students venture forth to construct an analogy of their own choosing. And in the process of mapping the features of the target idea to a self-generated analog, critical thinking and enhanced understanding ensue.

B. Informal Learning.

The five enumerated principles for improving student engagement with science in the classroom respond to the needs identified with the first meaning of the term "science literacy": the quest to understand the language and the texts used in scientific inquiry. The classroom activities discussed in this paper can lead to greater student involvement, and thus greater comprehension of scientific concepts. Comprehension, however, is only part of the problem. America's economic leadership depends upon more young people choosing science careers, which pertains more to the second meaning of "science literacy": the movement toward greater interaction with the natural world to illustrate scientific concepts. Recent research, based on over forty years of research on "free choice" or complementary learning, has focused attention away from school as the primary determinant of career choice, and toward the out-of-school learning that has a major impact on children's educational achievement (Falk & Dierking, 2010).

The anxiety over the performance of U.S. middle school and high school students needs to be balanced with the surprising results of other age groups in this country. Over the last ten years, elementary students in the U.S. have consistently outperformed most other children in the world on such standardized tests as the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA). And for over twenty years U.S. adults have outperformed the rest of the world (except Sweden) , according to the 2005 Survey of Civic Science Literacy conducted in 34 countries. The U.S. ranked second with over 27% of the population deemed to be scientifically literate. Although taking college-level courses undoubtedly improves literacy, only 30% of American adults have ever taken even one science course in college. Instead, the fact that the U.S. scores well, apart from those years when most classroom science instruction takes place, suggests that our rich variety of free-choice sources of exposure to science and the natural world has a significant impact. From jogging through the woods, or visiting science museums, national parks, science centers, botanical gardens, and the multiple online and media-centered sources, to having science-related hobbies such as gardening or astronomy, to encountering real-life dilemmas such as disease, pollution, or the effects of climate change that provoke a powerful need-to-know in a population with these ample science-based resources, our country has the capacity, outside of the classroom, to influence interest in science.

A recent study by the National Educational Longitudinal Study (NELS) cited attitudes formed in early adolescence, primarily from out-of-school experiences, as the single most important influence on the choice of a science career (Falk & Dierking, 2010). Free-choice science activities also increase comprehension, and so appear to be a better predictor of science achievement—even more so than math scores.

V. Conclusion.

This research describes educational challenges balanced with rich resources, both within our school systems and outside in our communities. The innovations described in this paper have significant implications for the teaching methodology in our secondary education programs around the country. Surely, interdisciplinary approaches deserve immediate support.

As a nation we can choose to mobilize our increasingly limited educational resources through teacher collaboration to increase engagement with text-based science, and at the same time we must realize that our surest path leading to greater interest in science careers is probably the path just outside our back doors, the one that brings our children into contact with the natural world—the original source for all science, the original hands-on approach to learning.

References

Atkinson, R., & Mayo, M. (2010). Refueling the U.S. innovation economy: Fresh approaches to science, technology, engineering and mathematics (STEM) education. *The Information Technology and Innovation Foundation.* Retrieved from http://www.itif.org/files/2010-refueling-innovation-economy.pdf

Brown, A. (2009). What engineering shortages? *The Bent of Tau Beta,* Summer, 21-25.

Chi, M. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science, 1*(1), 73-105.

Dorph, R., Goldstein, D., Lee, S., Lepori, K., Schneider, S., & Venkatesan, S. (2007). The status of science education in bay area: Research brief. *Lawrence Hall of Science. University of California Berkeley, California.* Retrieved from http://lawrencehallofscience.org/rea/bayareastudy/index.html.

Falk, J., & Dierking, L. (2010). The 95% solution. *American Scientist, 98,* 486-493.

Hess, K., Corda, C., & Lanese, K. (2011). Science buddies: Advancing informal science education. *Science, 332,* 550-551.

Korb, M., & Thakkar, U. (2011). Facilitating scientific investigations and training data scientists. *Science, 333,* 534-535.

Krajcik, J., & Sutherland, L. (2010). Supporting students in developing literacy in science. *Science, 328,* 456-459.

Lorch, R., Lorch, E., & Inman, W. (1993). Effects of signaling topic structure on text recall. *Journal of Educational Psychology, 85*(2), 281-290.

McGonigal, J. (2011). *Reality Is Broken.* New York: The Penguin Press.

Medina, J., (2008). *Brain Rules: 12 Principles for Surviving and Thriving at Work, Home And School.* Seattle: Pear Press.

Mervis, J. (2011). Report alters definition of what students should learn. *Science, 333*, 510.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science, 328,* 463-466.

Palinscar, A., & Magnusson, S. (2001). *Cognition and Instruction: Twenty-Five Years of Progress.* Mahwah: Earlbaum.

Pearson, P., Moje, E., & Greenleaf, C. (2010). Literary and science: Each in the service of the other. *Science, 328*, 459-463.

Snow, C. (2002). Reading and Understanding: Toward a Research and Development Program in Reading Comprehension. *Rand.* Retrieved from www.rand.org/publications/MR/MR1465

Van den Broek, P. (2010). Using texts in science education: Cognitive processes and knowledge representation. *Science*, *328,* 453-456.

Venville, G., Gribble, S., & Donovan, J. (2005). An exploration of young children's understandings of genetics concepts from ontological and epistomological perspectives. *Science Education*, *89*(4), 614-633.

Witze, A. (2010). Confronting a third crisis in U.S. science education. *Science News*, *177*(11), 32.

Xie, C., Tinker, R., Tinker, B., Pallant, A., Damelin, D., & Berenfeld, B. (2011). Computational experiments for science education. *Science*, *332*, 550-551.

Yazzie-Mintz, E. (2010). *Charting the path from engagement to achievement: A report on the 2009 High School Survey of Student Engagement.* Bloomington, IN: Center for Evaluation & Education Policy.