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Improving Science Achievement Through Changes in Education Policy

The author reviews current science education policies in the United States and offers perspectives about ways that these policies can be changed to improve student science achievement.

Concerns over science education in the United States continue to grow due to the increasing global demands and competitiveness for careers in science and technology. In addition, current education policy will be scrutinized more rigorously as the Obama administration begins to implement their vision of public education, which includes recruiting new teachers and rewarding effective teachers. The effectiveness of science teachers is often measured by the success of the students. In order to ensure student success in science, research about how students learn science and how teachers should be teaching science must be taken into account by policy makers. Accomplishing the goal of improving student science achievement in the United States is necessary in order to increase overall science literacy amongst the U.S. population and ensure preparedness for the growing science and technology demands of the 21st century.

The current education policy in the United States is strongly influenced by the No Child Left Behind Act of 2001. One of the primary goals of No Child Left Behind (NCLB) is stronger accountability for results (U.S. Department of Education, 2004), and, consequently, schools are now being held responsible for the quality of education they provide to students. In order to ensure accountability and higher performance of students, NCLB required states to implement a method of assessing student knowledge of the core content areas. Although not mandatory, most states have opted to use a multiple-choice, standardized test, because this type of assessment is most cost effective to administer and score (Wenning, Herdman, Smith, McMahon, & Washington, 2003).

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This type of large-scale, high-stakes testing is now taking place in all fifty states and is administered to all high school students between the tenth and twelfth grades. The assessments are termed "high-stakes" because the results are used to determine which students will graduate from high school. Students must pass the test by the end of their senior year in order to receive a diploma.

These statewide test results have also become the basis for holding schools accountable and forming funding and policy decisions. States use data from the test results to determine if schools and districts are meeting their established achievement goals. If schools and districts fail to meet these goals, they can face sanctions that include reduced funding, mandatory reallocation of funds, and vast overhauls of curriculum (Wenning, et al., 2003).

While NCLB was passed by the Bush administration under a republican-led Congress, new controversies over the policy are emerging under the new Obama administration and a democratic-led Congress. Current education policy in the U.S. and the effectiveness of NCLB is a hot topic for debate among politicians and the general public. NCLB has significantly influenced state policy, and this, in turn, has affected what is being taught in the classroom. NCLB calls on states to implement a more rigorous science curriculum that is more closely aligned with national and state standards for science education. The goal is to prepare students for success beyond high school (U.S. Department of Education, 2004).

As states attempt to make their science curriculum more rigorous in compliance with NCLB, state and national science standards call for students to learn a vast amount of scientific information, and this knowledge is assessed during the statewide tests. As a consequence, teachers have been forced to alter their methods of instruction to conform to the assessment. Teaching to the test has become more commonplace as pressures mount on teachers to ensure they cover everything that their students need to know in order to succeed on the state test. The pace at which content is covered has been accelerated to an extent that permits only superficial coverage of topics with little regard to student comprehension or depth of knowledge. Effective teaching strategies are giving way to quicker, fact-based instruction due to reductions in the amount of time allotted for each topic to be covered.

While national and state standards call for inquiry-based science instruction, teachers are finding it increasingly difficult to meet this expectation and still expose students to all of the content they need to know to succeed on the state test. Furthermore, short-term assessments are geared more towards preparing students with questions that are similar in structure to those on the statewide test. All of these factors combine to demonstrate a clear discrepancy between the national and state expectations of quality science instruction and what is actually happening in science classrooms across the United States.

Some may argue that perhaps students are not really underachieving in science, and it is actually the method of assessment that is inherently flawed. Most states use standardized, mostly multiple-choice tests to assess student proficiency in science. It could be argued that these types of tests do not accurately assess student knowledge about science because they are not aligned with the ways in which students are being taught. While these arguments are compelling, the validity of the NCLB mandated statewide tests and national assessments of student proficiency in science is an issue that extends beyond the scope of this article. However, even under the constraints of NCLB and our current methods of assessment, efforts can be made to improve overall understanding of science, which should translate into improvements in science achievement.

How do we measure achievement?

While NCLB calls for accountability for results, results are not easily identifiable under our current system. Individual states have the flexibility to develop their own science curriculum, their own assessment, and set their own performance standards for proficiency in science (Wenning, et al., 2003). Proficiency in science is defined as a threshold of performance on the state test, but with each state having a different curriculum, a different test, and a different set of criteria to measure proficiency, comparisons of proficiency from state to state are meaningless. For this reason, the national assessment results are used to discuss science achievement among U.S. students. At the national level, the National Assessment of Educational Progress (NAEP) defines proficiency in science to be a raw score of 178 out of a possible 300 points on the national assessment. The NAEP includes not only multiple-choice and constructed response questions but also assesses students as they engage in actual science investigations. (Loomis & Bourque, 2001). Nationally, only eighteen percent of twelfth graders performed at or above the proficient level on the 2005 NAEP science test, which is static from the 2000 results and demonstrates a decrease in performance from 1996. (Grigg, Lauko, & Brockway, 2006).

Another method for measuring student science achievement is to compare U.S. students with students from other countries around the world. The Third International Mathematics and Science Study (TIMSS) is an assessment of both science and mathematics achievement in fourth and eighth grade students from various countries. The study has been conducted four times since 1995, with the most recent assessment occurring in 2007. Results from TIMSS showed that U.S. students performed at the same level or below students of other developed nations (Stigler & Hiebert, 1999). The situation has not improved in recent years. Results from the 2007 TIMSS shows that the United States falls behind 9 other countries in science achievement among other 4th graders, and ranks 11th in 8th grade science achievement (Martin, et. al., 2008). Countries outperforming U.S. students in science are primarily Asian nations, including Singapore, China, and Japan. Furthermore, these results reflect no measurable improvement in U.S. student science achievement since 1995 and illustrate that there is a decline in U.S. student performance in science between the fourth and eight grades in comparison with other countries (Martin, Mullis, & Foy, 2008).

There are several possibilities as to why students are not demonstrating improvements in science achievement. One theory is that our system of education ignores the research about how students learn science. A second theory is that teachers are aware of the research but, for various reasons, are unable to implement these practices in their classrooms. This may be related to another theory, which purports that our current system of education, including standards, curriculum, and education policy as a whole, is not conducive to effective science instruction. Whatever the reason, the results of the national and international assessments of student achievement in science demonstrate the need for a re-evaluation of the ways that students learn science and ways that we should be teaching science content in order to increase student achievement.

How Do Students Learn Science?

Students learn science in many different ways. Some students are able to learn from reading about science concepts while other students are auditory learners. Other students may learn better when given opportunities to move and manipulate objects, or see concepts represented visually. Students come to the classroom with different skills, ways of thinking, and learning styles. For this reason, there is not one set way that all students learn science. However, current research into science learning has identified several widely accepted ways in which students come to understand science.

Inquiry

One of the most important things to consider when examining how students learn science is that students learn science by doing science. This means that students learn when they engage in the process of science. The process of science involves prediction, observation, collecting evidence, using evidence to develop explanations, and repeating investigations and revising explanations. Science learning through doing has been termed "inquiry" and has been recognized as important for student learning of science since the 1960s (Gallagher, 2007). Inquiry is also emphasized by the *National Science Education Standards* (2003). According to the *Standards*, learning science is an active process, and students should be participants in the learning process rather passive recipients of knowledge. While engaging in the scientific process, students are required to use critical thinking to come up with explanations that aid in the development of student understanding of science. Overwhelmingly, educational research supports the idea that engaging in inquiry is one of the most important components to learning science.

Peer-to-peer interactions

Students also learn science when they discuss their ideas with their peers. Since communication is a main component of the scientific process, and research has shown that engaging in science as a process aids in learning science, it stands to reason that students must also engage in communication as one of the most important aspects of the scientific process. When students work in groups to formulate explanations and reach a consensus, they are doing what scientists do. In addition, peer-to-peer communications can help clear up misunderstandings. Since students relate to one another on a more equal level, peers can explain complex ideas to one another in a way that may have more meaning (Moreno & Tharp, 2006).

Incorporation of prior knowledge and connection of ideas

Students also learn science when they are able to make meaningful connections. When students are able to connect new information with something they already know, the new knowledge becomes much more meaningful and easier to incorporate into their current knowledge framework. Students come to the classroom with prior knowledge about how the world works. This knowledge is formed by students' experiences in the world. Based on their prior experiences, students come to the classroom with their own, although sometimes faulty, explanations for scientific phenomena. A student's prior knowledge can be deeply ingrained and very difficult to change. Students can only learn science when their prior knowledge is considered and integrated into the learning of new concepts. If presented with observations or data that is consistent with their prior ideas, the students' current knowledge framework is reinforced. However, if presented with new experiences that are contrary to their prior ideas, students' will have to either explain the new information within their current framework, or alter their knowledge framework to incorporate the new information (Moreno & Tharp, 2006). Students also learn science when they apply new knowledge to new situations, develop their own explanations for science phenomena, and reflect on their own learning.

Knowing how students come to learn and understand science is important. However, for this knowledge to be useful, it needs to be applied to classroom instruction. In other words, the way science is taught in the classroom needs to be reflective of the ways in which students learn in order for the instruction to be truly effective.

How should science be taught?

Teachers are undeniably crucial to student learning. Teachers set the tone of for the learning environment. Teachers that have a positive, enthusiastic attitude towards science are more successful in helping their students learn (Moreno & Tharp, 2006). Creating an open, student-centered learning environment that encourages curiosity and exploration is more conducive to learning science than the traditional teacher-centered approach to instruction.

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In addition to creating an environment suitable for learning science, accomplished science teachers use a variety of instructional approaches to guide learners toward knowledge about science. There is no cookie-cutter strategy of teaching that reaches all students all of the time. Therefore, it is important to use a variety of instructional strategies to address the unique needs and interests of individual students. Utilization of a variety of teaching techniques provides students with the most opportunities to learn and refine their conceptual framework.

Introducing science content in a way that engages students is one key strategy that helps students learn. Relating science content to students' real life experiences can be very effective in motivating learning. This can be accomplished by developing analogies between new science ideas and concepts with which students are more familiar as a result of their own experiences. Student interest can also be piqued by posing intriguing problems and challenging students to come up with solutions to the problem. In addition, using open-ended questioning rather than soliciting simple one-word, right or wrong answers requires students to use higher level thinking strategies instead of simple, rote memorization, and this leads to a deeper conceptual understanding (Moreno & Tharp, 2006).

Using guided inquiry as a method of instruction has been shown to be an effective teaching strategy. In this teaching method, the teacher establishes guidelines for a scientific investigation. Guidance can be very direct, such as posing the problem to be solved in the investigation, or very limited, such as simply helping students select a topic of appropriate scope for an investigation. As students gain the skills necessary to do scientific investigations, the teacher's role can become increasingly more limited. In the process of guided inquiry, students improve their problem-solving skills and their abilities to use evidence to formulate explanations. In addition, the inquiry process provides students with the opportunity to work together and share ideas with one another, all of which leads to greater conceptual knowledge about science concepts (Moreno & Tharp, 2006).

In scientific inquiry, students need to be given opportunities to engage in discourse with one another. Because science is a social endeavor, it involves consensus building, peer review, and communication in many forms. Verbal and written discourse is crucial to developing scientific knowledge. Students should be given opportunities to work in groups to conduct investigations, evaluate evidence, and formulate explanations. Having students develop their own explanations of scientific events helps them to integrate new knowledge with existing knowledge and make connections between science concepts.

Implications for Science Education and Policy

Teaching

The most immediate application of science education research can occur at the classroom level. In Teaching Science in the 21st Century, Bybee states that "… how much students learn is directly influenced by how they are taught" (2006, p. 25). Therefore, if teachers implement effective teaching strategies that correlate with the ways in which students learn, performance on assessments should naturally improve, because students will have a deeper understanding of the fundamentals of science (Gallagher, 2007). Although teachers can adjust their teaching methods to promote student understanding of science, there are limitations to how much they can do under the constraints of the educational system in which they teach, including the curriculum and the amount of content they are required to cover.

Teacher education

In order to deliver the best science education, teachers need to be trained to provide excellent education to students. Both pre-service and inservice teacher training should be geared towards development of science content knowledge and effective teaching strategies.

However, as Banilower, Heck, and Weiss (2007) point out, particularly in grades K-8, science education tends to be a low priority. This is partially due to the emphasis placed on mathematics and reading because of high-stakes testing in those two subject areas in the elementary grades. This is problematic, because NCLB holds schools accountable for student achievement in science during the high school years. Therefore, the foundations of a solid science education must be established earlier in the student's career, and the value of science education at the elementary level must be reinforced.

In addition, teachers need to be given more opportunities to observe modeling of effective science teaching techniques so that they can be implemented in the classroom. This can be accomplished during undergraduate teacher education or through professional development programs.

Increasing pedagogical content knowledge will help science teachers of all grade levels refine and enhance their teaching methods, which will lead to more effective instruction and, ultimately, result in greater science literacy among students. To provide the most effective science instruction, teachers need to be educated about how students learn so that they can adjust their teaching strategies to achieve greater student understanding.

Standards and curriculum reform

More significant advancements in science achievement can be made through fundamental changes to our current science standards and science curriculum. National and state science curricula too often place greater importance on quantity of knowledge than the quality of knowledge. Students are encouraged to memorize and learn scientific facts rather than explore and engage in science as a process (National Research Council, 2007).

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In accordance with researched-based understanding about how students learn and how science should be taught, the scope of the science standards needs to be reduced to allow for more in depth treatment of core scientific concepts. In addition, emphasis needs to be placed on connections between core concepts and the building of science knowledge over all grade levels. In order to provide the time needed to explore science and acquire essential knowledge and skills, the sheer amount of material that today's science curriculum includes must be significantly reduced. The focus needs to be on the big ideas of science rather than the minute details of every concept in science. To improve science achievement in the U.S., the curriculum should focus more on the progression of learning and making connections between concepts and less on covering a wide range of individual topics. Learning should follow a logical, coherent progression (National Research Council, 2007). Teaching should be designed to assist students in understanding these core concepts and the relationships between them. Students should have the opportunity to experience a variety of learning activities and develop meaningful science understanding. However, engaging in a variety of application and problem-solving experiences takes time. Furthermore, the teaching materials and resources used in the classroom are also limited, which further supports the idea of limiting the number of topics covered and, instead, focusing on depth of coverage.

In formulating science education policies and curriculum, much can be gained by looking towards the practices of countries that are having greater success in their science education programs. Our current science curriculum focuses too heavily on breadth of content and not enough on depth, development, and the connections between concepts in science. The Third International Math and Science Study (TIMSS) found that U.S. students were outperformed in science (Stigler & Hiebert, 1997). Valverde and Schmidt (1997) analyzed the results of TIMSS by comparing the science curriculum in the U.S. with that of the 10 highest-achieving countries in science and found profound differences between them. U.S. science curricula tend to focus on broad coverage of science topics and shallow depth, and connections between concepts are given little attention (National Research Council, 2007).

Current research and examples of effective science instruction from high-achieving countries should be used to shape U.S. education policy and curriculum. As Vitale and Romance point out in their analysis of TIMSS, "… the curricula of high-achieving countries was characterized as focused around big ideas, conceptually coherent, and carefully articulated across grade levels. In contrast, the curricula in low-achieving countries (including the U.S.) emphasized superficial, highly-fragmented coverage of a wide range of topics with little conceptual emphasis or depth" (2006, p. 336).

However, changes such as these must begin in the earlier grades. Student achievement in science amongst fourth graders is on par with other higher achieving countries. However, as students progress in the U.S. education system, the discrepancy between U.S. students and their foreign counterparts become more glaring. One explanation for this is that up until the fourth grade, expectations for student learning are similar between the United States and other countries. However, as students in the U.S. progress through the upper grades, more time is spent on repeating previously learned concepts instead of providing in depth coverage of new concepts. As a result, the list of topics that need to be covered at subsequent grade levels continues to grow (Valverde & Schmidt, 1997).

Interestingly, as a part of NCLB, programs of instruction and teaching practices are supposed to be aligned with research about effective instruction (Mundry, 2006). While NCLB calls for the use of research in making decisions about science education, it does not provide any recommendations about ways that this research can be practically applied in the classroom. One way to incorporate current research into teaching science is to revise and restructure curricula. Because science education research is ongoing, so is the pursuit of a more effective curriculum. This process has to begin at the national level with reform of our education policies.

In addition, while our current system of education allows each state to individually develop standards, curriculum, and assessments, countries like Japan that have high-achievement in science have a national science curriculum (Stigler & Hiebert, 1993). A more nationalized approach to science education would eliminate the inconsistencies in expectations and execution of science education throughout the nation. With this approach, new research about student learning or effective teaching practices could be implemented on a much broader scale, since the curriculum would be consistent throughout the entire country. A national proficiency test for scientific literacy that is aligned with revised national standards should be developed and used in place of the statewide tests. A national test that could be administered in schools nationwide would give educators and policy makers better data with which to make comparisons between states or regions of the country and make it easier to identify areas which need improvement. A nationalized approach to science education would also help to alleviate some of the problems that arise when students move into different school districts, because the expectations would be the same regardless of the school being attended.

Implications for development of a national science curriculum are wide-reaching. *The Benchmarks for Science Literacy* is a great resource in developing a national science curriculum, because it describes levels of understanding and abilities expected at each grade level. The focus of *Benchmarks* is on science literacy, which is considered to be as a broad base of scientific knowledge and understanding rather than detailed factual knowledge about specific science disciplines (American Association for the Advancement in Science, 1993). For this reason, *Benchmarks* offers good guidelines for the creation of effective national science curriculum programs that address the interconnectedness of knowledge and ways to build upon that knowledge across grade levels. New curriculum programs should be changed to reduce the amount of content and emphasize core concepts and the connections between them across grade-levels and disciplines. Connections between concepts need to be identified and explicitly outlined and mapped in curriculum programs.

Conclusion

In conclusion, educators in the United States must look for ways to increase science proficiency and overall science literacy. Research about how students learn science should be used to develop teaching strategies that facilitate student learning. With better teaching methods and improvements in science instruction, students will develop deeper understanding of science concepts, which should translate into better performance on assessments (Gallaher, 2007).

Higher levels of science achievement can be attained through an understanding of how students learn science, as well as development and implementation of more effective instruction. It is also known that learning science is a progression throughout the years and that a more thorough understanding of science concepts occurs when depth is emphasized over breadth of content. In addition, the content must be organized in a conceptual framework that allows for the retrieval and application of scientific knowledge. This needs to begin in the early stages of science education and not just at the secondary education level.

The subject of improving student achievement in science is becoming increasingly important, because districts and schools are now being held accountable for student success under NCLB. Students are also feeling the pressure to achieve as they are faced with passing a large-scale, high-stakes science assessment in order to graduate from high school. Our current science education policy may have put the cart before the horse by expecting results without allowing time to institute changes in practice. Instituting even a few of the proposed changes to our current system of education could have significant impacts on student learning and achievement in science. However, it will take time to implement such changes, and the results may not become apparent for many years. Nonetheless, policy makers need to review the current research in science education and assist educators in acquiring tools to help our students achieve success in science, which will, in the long run, benefit not only individual students, but our communities and our country as well by preparing our youth to compete in the global economy.

Finally, science educators have the responsibility to provide the most effective science education possible to our students so that they have the skills necessary to be successful adults. As the 21st century economy becomes more global, American students need to be more competitive with their foreign counterparts and in order to accomplish this, they must have the scientific knowledge necessary to secure work in the growing fields of science, engineering, and technology.

References

American Association for the Advancement of Science (1993). *Benchmarks for science literacy: Project 2061*. New York: Oxford University Press.

Banilower, E.R., Heck, D.J., & Weiss, I.R. (2007). *Can professional development make the vision of the Standards a reality? The impact of the National Science Foundation's local systematic change through Teacher Enhancement Initiative*. Journal of Research in Science Teaching, 44(3), 375-395.

Bybee, R.W. (2006). *The science curriculum: Trends and issues*. In Rhoton, J. & Shane, P. (Eds.). (2006). *Teaching science in the 21st century* (pp. 21-37). Washington, D. C.: NSTA Press.

Gallagher, J.J. (2007). *Teaching science for understanding: A practical guide for middle and high school teachers*. Upper Saddle River, NJ: Pearson Education, Inc.

Grigg, W.S., Lauko, M.A., & Brockway, D.M. (2006). *The nation's report card: Science 2005*. Washington, DC: U.S. Government Printing Office.

Loomis, S.C. & and Bourque, M.L. (Eds.). (2001). *National assessment of educational progress achievement levels, 1992-1998 for Science*. Washington, DC: National Assessment Governing Board.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, D. C.: National Academy Press.

Martin, M.O., Mullis, I.V.S., and Foy, P. (2008). TIMSS 2007 International Science Report: Findings From IEA's Trends in International Mathematics and Science Study at the Eighth and Fourth Grades. Chestnut Hill, MA: Boston College.

Moreno, N.P. & Tharp, B.Z. (2006). *How do students learn science?* In Rhoton, J. & Shane, P. (Eds.). (2006). *Teaching science in the 21st century* (pp. 291-305). Washington, D. C.: NSTA Press.

Mundry, S. (2006). *No child left behind: Implications for science education*. In Rhoton, J. & Shane, P. (Eds.). (2006). *Teaching science in the 21st century* (pp. 243-255). Washington, D. C.: NSTA Press.

Stigler, J.W. & Hiebert, J. (1999). *The teaching gap*. New York, NY: The Free Press.

U.S. Department of Education. (2004). Four pillars of NCLB. Retrieved June 11, 2008, from No Child Left Behind Web site: <http://www.ed.gov/nclb/overview/intro/4pillars.html>.

Valverde, G.A., and Schmidt, W.H. (1997). *Refocusing U.S. math and science education*. Issues in Science and Technology, 14(2), 60-66.

Vitale, M.R. & Romance, M.R. (2006). *Research in science education: An interdisciplinary perspective*. In Rhoton, J. & Shane, P. (Eds.). (2006). *Teaching science in the 21st century* (pp. 329-351). Washington, D. C.: NSTA Press.

Wenning, R., Herdman, P.A., Smith, N., McMahon, N., & Washington, K. (2003). *No child left behind: Testing, reporting, and accountability. ERIC Digest*. New York, NY: Eric Clearinghouse on Urban Education.

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