A Critique of the “Research Basis” for the National Science Education Standards and the AAAS Benchmarks for Science Literacy

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ABSTRACT
Although the authors and publishers of the National Education Standards (1996) and the Benchmarks for Science Literacy (1993) claim that their recommendations are based on sound, extensive research about the way children learn, in fact the evidence is generally weak and unconvincing. In some cases the studies cited misstate the cohort of students whose learning was examined. In others, the studies were based on relatively small groups of students, and in still others, the students whose learning was examined were from foreign countries whose cultural and educational backgrounds are quite different from those of American students. In many cases the papers cited were not published in peer-reviewed journals or were merely papers presented at meetings of specialists in science education.

Keywords: Education – general; education – science; education – geoscience; education – testing and evaluation.

Introduction
I am very pleased and honored to have this opportunity to speak to you today about the effects of the educational reform movement on science education in this country. My name is Stan Metzenberg, and I’m an Assistant Professor of Biology at California State University Northridge. The university is located in the San Fernando Valley and draws its student population from the greater Los Angeles area. We have a state mandate to accept the top third of graduating high school seniors, but within that population of entering freshmen, we find that two thirds are in need of immediate remedial education in mathematics or English. I have the dubious distinction of being at a second-tier institution that is shockingly low, and federal funding is helping to create an entire generation of scientific illiterates. The often quoted adage “less is more” brings little comfort. As any thinking person knows, and as the facts demonstrate, less is not more – it’s less!

Research Basis of NSES and Benchmarks
It is often said erroneously that the AAAS Benchmarks and National Science Education Standards represent the widespread consensus of scientists and educators as to what all high school graduates need to achieve reasonable literacy in science. In fact, there is no consensus. Although there are some well-meaning scientists who stand behind these documents, the documents were primarily written by education specialists rather than scientists, and the sentiment of most scientists has been one of indifference rather than consensus. Given that only about a fifth of our research grant applications are funded, there should be no surprise that scientists only grudgingly commit time to activities outside of the lab.

In addition to this misleading use of the word “consensus,” it is also said with some frequency that the National Science Education Standards and AAAS Benchmarks are based on scholarly research on how
students learn and what is developmentally appropriate for all students to learn at a given age. In the National Science Education Standards (p. 110), for example, it is stated that there exists “an obligation to develop content standards that appropriately represent the developmental and learning abilities of students.” The prevailing philosophy among education specialists is that a teacher does harm to students by introducing material that is not developmentally appropriate. I have undertaken a study of the literature cited in the AAAS Benchmarks to ask what is the research on learning abilities of students, and is it applicable to our students?

What I have found is quite disturbing. The National Science Education Standards and AAAS Benchmarks are based on the flimsiest excuse for research that I have ever encountered. Fewer than half of the papers covering student learning in physical, earth, and life sciences are in peer-reviewed publications. In fact, quite a few of the references are unpublished talks that were presented at education meetings. This is certainly the lowest form of review, since you and I can’t read what was said or even know if the audience clapped politely after the speaker had finished. There are numerous instances where the AAAS Benchmarks misstate the methodology or findings in a paper, claiming that the study was performed on high school students for example, when the paper indicates it was performed on college students.

Most of the peer-reviewed research was not done in the United States at all, but rather in countries such as England, Australia, Germany, and Israel. The AAAS Benchmarks and National Science Education Standards make a tremendous leap of faith in assuming that children in different countries have similar learning stages. Many of the cited papers represent studies conducted on small numbers of students, on the order of 30 to 100, who in many cases were not chosen randomly from an age cohort. It is often the case that the very conclusions of the paper hinge on the responses of a dozen or fewer students who had not even received formal instruction in the material upon which they were being questioned. It is a sobering thought that educational policy in the United States could be influenced by a few seven year olds growing up in another country, but this is in fact what has happened.

I will cite three specific example from the AAAS Benchmarks research base, reflecting either a poor research methodology, a possible lack of scientific understanding on the part of the educational researcher, or a significant anti-science bias. There are, in total, only forty-three peer-reviewed papers cited in the physical, earth, and life-sciences sections of the AAAS Benchmarks, and I have managed to obtain and read about thirty-five of them. The three papers I will cite are fairly typical examples.

Children’s Understanding of Inherited Traits

In discussing children’s understanding of inherited traits, the following statements are presented in the two national standards documents:

...students might hold some naive thoughts about inheritance, including the belief that traits are inherited from only one parent... (NSES p. 128)

Some students believe that traits are inherited from only one of the parents...It may not be until the end of the 5th grade that some students can use arguments based on chance to predict the outcome of inherited characteristics from observing those characteristics in the parents. (AAAS Benchmarks p. 341)

What is the research that would support such a statement? The cited paper by (Kargbo and others, 1980) reports on the results of half-hour interviews with 32 Canadian students, with ages ranging from seven to thirteen. Twelve of the subjects were under the age of ten, and it’s astonishing that such a small group could serve as the basis for the aforementioned statement in the AAAS Benchmarks on the cognitive limitations of students before the end of fifth grade.

Students were asked the following question (Kargbo and others, 1980, Table 4, p. 142): “If a white male dog and a black female dog have six puppies, what color would the puppies be?” First of all, geneticists know that this is a question that is impossible to answer with the information provided. The students nonetheless gamely answer, guessing that the puppies would be black or some combination of black and white. None of the younger students guessed that the puppies would be all white, which may indicate that they thought the black pigment in the mothers’ coat would overcome in some way the absence of pigment in the father’s coat. It’s a good guess.

The next question in the interview was, “Which one of the parent dogs do you think will give more colour to the puppies?” Most young students said the mother dog, remembering perhaps that the father dog was white and had no color. The authors concluded from these interviews that it was clear “...that a large number of the children thought the mother would contribute more to the genetic make-up of the offspring than the father” (Kargbo and others, p. 142). This is obviously not a fair conclusion, given the context: the students were presented with a black mother dog and white father dog and asked which would contribute more color.

This is an example of poor research design. I wish I could say it was unusual, but in fact this type of error is present in nearly every cited paper. What is most harmful in this example is the statement in the Benchmarks about what children cannot understand before the end of the fifth grade. Learning follows from instruction, after all. The fact that children have misconceptions prior to instruction should not be surprising, nor should it prevent us from attempting to teach them the concepts. The Benchmarks and National Science Standards are full of unscholarly admonishments about what children cannot learn at an early age. By thoughtlessly building national policy around research of this type, we have tremendously underestimated our children’s capacity to learn.
Children’s Understanding of Cooling Objects.

My second example, on children’s understanding of cooling objects, illustrates a case where the students being interviewed appeared to know more about the science than they are being given credit for. Kesidou and Duit (1993) conducted interviews with 34 German students in Grade ten, who had previously received four years of physics instruction. The students were asked questions based on a scenario having to do with the cooling of a hot piece of metal. The authors express concern at one point that:

Some students appeared to be unaware that every cooling process requires an interaction partner. It appears that they held the idea that bodies may cool spontaneously without other (colder) bodies being involved. (Kesidou and Duit, p. 97)

In reading the background of the German students, it’s no wonder that they thought bodies could cool spontaneously – they learned about heat radiation in the seventh grade. As I’m sure you all know, hot objects can become cooler by emitting infrared radiation, and do not need to interact with other objects to do so. This error is repeated in the AAAS Benchmarks (p. 337) which state:

Middle- and high-school students do not always explain heat-exchange phenomena as interactions. For example, students often think objects cool down or release heat spontaneously – that is, without being in contact with a cooler object.

The paper by Kesidou and Duit has been favorably cited in a recent letter from Bruce Alberts, President of the National Academy of Sciences (Alberts, 1998). Dr. Alberts is an outstanding scientist, but he may be unaware that this paper contains an egregious error. I am compelled to ask why, for all the millions of dollars that have been spent, our students are being so poorly served by these national standards documents? I wish I could say that this was the only example of a paper in which the authors make a mistake about the science. Unfortunately, it is a common finding.

Children’s Perceptions of the Shape of the Earth.

My final example of citations in the AAAS Benchmarks is representative of a school of thought called “post-modernism,” in which what is generally called scientific fact is taken to be merely a “belief system.” In the first printing in 1992 of a National Research Council document discussing the intellectual foundations of the National Science Standards, it was stated that the standards would reflect the “postmodernist view of science” that “questions the objectivity of observations and the truth of scientific knowledge.” The National Science Education Standards themselves state a vision that there should be less emphasis on “knowing scientific facts and information,” less emphasis on “activities that demonstrate and verify science content,” and less emphasis on “getting an answer” (NSES p. 113).

In the cited paper Vosniadou and Brewer (1992) report the mental models children hold of the shape of the earth. These authors conducted interviews on 60 students between the ages of six and eleven, and evaluated artwork they drew of the earth situated in space. Their rubric for scoring these children’s drawings was complicated. If, for example, a child drew the earth as a circle surrounded by stars in space, that was taken to be an indication that the earth was a sphere. If the stars appear on only one side of the earth, it was assumed that the student believed the earth is flat. What is even more appalling than the research methodology is the language used by the authors:

The purpose of the present study was to further investigate the nature of children’s intuitive knowledge about the shape of the earth and to understand how this knowledge changes as children are exposed to the culturally accepted information that the earth is a sphere. (Vosniadou and Brewer, p. 541)

The authors repeat this peculiar phrase, “the culturally accepted information that the earth is a sphere,” or something similar to it, a total of four times in the paper. It is not clear from these statements whether the authors are themselves willing to commit to the proposition that the earth is round. I would merely ask: How is it possible that the AAAS, the National Academy of Sciences, and the National Science Foundation have spent so many hundreds of millions of dollars to increase the influence of this type of thought in our schools?

The vision of the national standards documents is that scientific facts have little value, and children should not learn them, and after all, cannot learn them. Depriving students of a content-rich education in science will not give them standing in the global economy.

A California Commission for the Establishment of Academic Content and Performance Standards (1998) has recently taken a different course in developing content-rich academic standards in science for the K-12 schools. A copy of these standards has been included with my written testimony. Although many documents were consulted during the writing of these standards, including the AAAS Benchmarks and National Science Education Standards, one of the primary considerations was the content knowledge expectations placed on students in other countries.

I have included in my written testimony the 1997 Indian Certificate of Secondary Education Examination (Council for the Indian School Certificate Examinations, 1994). There are several reasons for assessing our own expectations of student achievement against those of India. Their syllabus distinguishes the content knowledge that all secondary students are to learn, which is indicated in italics, from the more advanced content knowledge expected of college-bound science majors. Since much of the thrust of our own national science standards documents is to define literacy for all students, this is an important distinction.

It is clear from this syllabus that India expects significant content knowledge from all of its students. In the ninth year of schooling (Class IX), for example, all students learn about friction and lubrication,
pressure in a liquid at rest, and the effect of pressure on the boiling point of a liquid. They learn about the expansion of solids, liquids, and gases, and paths of heat conduction, convection, and radiation. The A-level students learn much more still (see non-italicized text).

Despite the problems of grinding poverty and multiple languages, India is training students to such a high level that they are rapidly becoming a world leader in the fields of information technology. We have also seen evidence in the past few months that their nuclear physicists learned a few things in school. As the late Albert Shanker, President of the American Federation of Teachers remarked (Shanker, 1994):

...when you talk about world class standards, there is a world out there.

So what are the systemic initiatives doing to help prepare our students for the global economy? I've copied three exercises from a 9th grade textbook (Issues, Evidence and You, LAB-AIDS, Inc.) being promulgated in the LA schools by the LA Urban Systemic Initiative, and have included them with my written testimony. The first activity in the book has students sipping samples of water from cups, with the challenge to attempt to reach a group consensus on which sample in the taste test might have come from bottled water. An example taken from the middle of the book has students mixing hot and cold water, and predicting the outcome (if you guessed warm water, then you must have studied in advance!). The last activity in the book has students read a short passage about the history of Easter Island, and answer questions such as, “What does this parable tell us about our own relationship to our environment?” Though these might be good exercises in the third or fourth grade, the content-knowledge expectations are shockingly low for a student in high school.

Conclusion

The educational reform movement in this country has caused us to lose our grounding and focus on what is good practice in science education. In September of last year, the House Committee on Science heard testimony from the President of the Technical Education Research Center on inquiry-based learning for the 21st century (Sampson, 1997). Among the exemplary curricula presented by this individual was an example called, “The Pringle’s Challenge,” in which students create a mailing container that is both lightweight and strong, and use that container to mail one Pringle’s potato chip to a partner school without breaking the chip. When the package arrives, the receiving school determines whether the chip is intact, measures the weight and volume of the package, and gives the package an overall score based on these three variables. Our poor showing in the 12th grade TIMSS study should come as no surprise. While our students were mailing potato chips to each other, students in other countries were hitting the science books and learning something.

References Cited

Alberts, Bruce (President of the National Academy of Sciences), letter to Chair of the California Commission for the Establishment of Academic Content and Performance Standards.


Food for Thought

The core spirit of science is to seek truths through unrelenting effort and utmost honesty and to uphold truths with courage and integrity. These are vital elements for all societies... Science also teaches people to think independently, and to question and reason objectively.


Research Basis for National Science Education Standards