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Program for International Student Assessment (PISA) 2006 and Scientific Literacy: A Perspective For Science Education Leaders*

This article describes the idea of scientific literacy as defined in PISA, discusses relevant results of PISA, and clarifies meaningful relationships between PISA data and scientific competencies of U.S. students. Finally, the author includes insights and recommendations for contemporary leadership in science education.

PISA's 2006 measurement of scientific literacy has connections to several themes that President Obama has included in his discussions of scientific issues and visions for science education. The President consistently includes themes of economic development, energy efficiency, environmental quality, health maintenance, and the importance of scientific knowledge in national policy. In science education, the President has indicated that, over the next decade, achievement of American students must move from the middle to the top on international assessments, including PISA. The description of scientific literacy in PISA 2006, the dismal results of U.S. students, and themes described by the current administration have clear, but challenging, implications for science education in the United States.

What Is Meant by Scientific Literacy?

Scientific literacy has become the term used to express the broad and encompassing purpose of science education. The use of the term in the U.S. most likely began with James Bryant Conant in the 1940s (Holton, 1998) and was elaborated for educators in a 1958 article by Paul DeHart Hurd entitled "Science Literacy: Its Meaning for American Schools." Hurd described the purpose of

Scientific literacy has become the term used to express the broad and encompassing purpose of science education.

scientific literacy as an understanding of science and its applications to social experience. Science had such a prominent role in society, Hurd argued, that economic, political, and personal decisions could not be made without some consideration of the science and technology involved (Hurd, 1958). Hurd made a clear connection between science and citizenship; yet, even today most school science programs emphasize content and methods that represent preparation for a professional career in science. In contrast, scientific literacy as it should be manifest in educational policies, programs, and practices has the explicit goal of preparing students for life and work—as citizens.

The historical perspective of scientific literacy, however, is not the reality of contemporary science education. Academic researchers

* Portions of this article were presented in March 2008 at an Education Reform International Symposium organized by the National Institute for Educational Policy (NIER), Tokyo, Japan and in June 2009 at a National Center for Education Statistics PISA Research Conference, Washington, DC, USA.

debate the real meaning of the term, classroom teachers claim their students are attaining scientific literacy, and national and international assessments provide evidence that, somewhere between the abstract purpose and concrete practice, the science education community has failed to achieve this goal.

Students with a more developed scientific literacy demonstrate the ability to use conceptual models to explain natural phenomena, to formulate alternative explanations of the same phenomena, and to communicate explanations with precision.

Several authors have clarified the curricular orientation and instructional emphasis of scientific literacy as a purpose of science education. George DeBoer (2000) has provided an excellent historical and contemporary review of scientific literacy. Robin Millar (2006) addressed historic and definitional issues of the term before outlining the role of scientific literacy in a contemporary curriculum—*Twenty First Century Science*.

Two other essays stand out when discussions turn to contemporary science education and the challenges of attaining higher levels of scientific literacy in the U.S. In “Science Education for the Twenty First Century,” Jonathan Osborne (2007) makes a clear case that although scientific literacy is stated as a goal,

contemporary science education is primarily “foundationalist” in that it emphasizes educating for future scientists more than educating future citizens. Douglas Roberts published a chapter on scientific literacy in the *Handbook of Research on Science Education* (Abell & Lederman, 2007). Roberts describes a long history of political and intellectual tension between scientific literacy and foundational science. The two politically conflicting emphases can be stated in a question: Should curriculum emphasize science subject matter itself, or should it emphasize science in life situations in which science plays a key role? Curriculum designed to answer the former, Roberts refers to as Vision I, and the latter he refers to as Vision II. Vision I looks within science, while Vision II uses external contexts that students are likely to encounter as citizens. These two visions of science are evident in contemporary discussions of core content for national standards for science.

How Is Scientific Literacy Defined in PISA 2006?

In PISA 2006, scientific literacy referred to four interrelated features that involve:

- Scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues;
- Understanding of the characteristic features of science as a form of human knowledge and inquiry;
- Awareness of how science and technology shape our material,

intellectual, and cultural environments; and

- Willingness to engage in science-related issues, and with the ideas of science, as a constructive, concerned, and reflective citizen (Organization for Economic Co-operation and Development [OECD], 2006).

In PISA 2006, scientific literacy was perceived as a continuum from less developed to more developed scientific competencies that include levels of proficiency. So, for example, the student with less developed scientific literacy might be able to recall simple scientific factual knowledge about a physical system and to use common science terms in stating a conclusion. Students with a more developed scientific literacy demonstrate the ability to use conceptual models to explain natural phenomena, to formulate explanations, to evaluate alternative explanations of the same phenomena, and to communicate explanations with precision.

How Was Scientific Literacy Assessed in PISA 2006?

PISA 2006 situated its definition of *scientific literacy* and its science assessment questions within a framework that used the following categories: *scientific contexts* (i.e., life situations involving science and technology), the *scientific competencies* (i.e., identifying scientific issues, explaining phenomena scientifically, and using scientific evidence), the domains of *scientific knowledge* (i.e., understanding of scientific concepts and the nature of science), and *attitudes toward science* (i.e., interest in science, support for scientific inquiry, and responsibility

toward resources and environments). These four aspects of the PISA 2006 conception of scientific literacy are illustrated in Table 1.

The *scientific contexts* align with various issues citizens confront. PISA 2006 Science items were framed within a wide variety of life situations involving science and technology, primarily: “health,” “natural resources,” “environmental quality,” “hazards,” and “frontiers of science and technology.”

The PISA 2006 *science competencies* required students to identify scientific issues, explain phenomena scientifically, and use

scientific evidence. These three key scientific competencies were selected because of their relationship to the practice of science and their connection to key abilities such as inductive/deductive reasoning, systems-based thinking, critical decision making, transformation of data into tables, construction of arguments and explanations based on data, thinking in terms of models, and use of mathematics. Table 2 describes the features of the three competencies.

The scientific competencies can be illustrated with a contemporary example. Global climate change has

become one of the most talked about and threatening global issues. As people read or hear about climate change, they must separate the scientific reasons for a response from economic, political, and social issues. Scientists explain, for example, the origins and material consequences of releasing carbon dioxide into the Earth’s atmosphere. This scientific perspective has been countered with an economic argument for continued use of carbon-based fuels and against reduction of greenhouse gases. Citizens should recognize the difference between scientific and economic positions. Further, as people are presented with more, and

Table 1: Framework for PISA 2006 Science Assessment

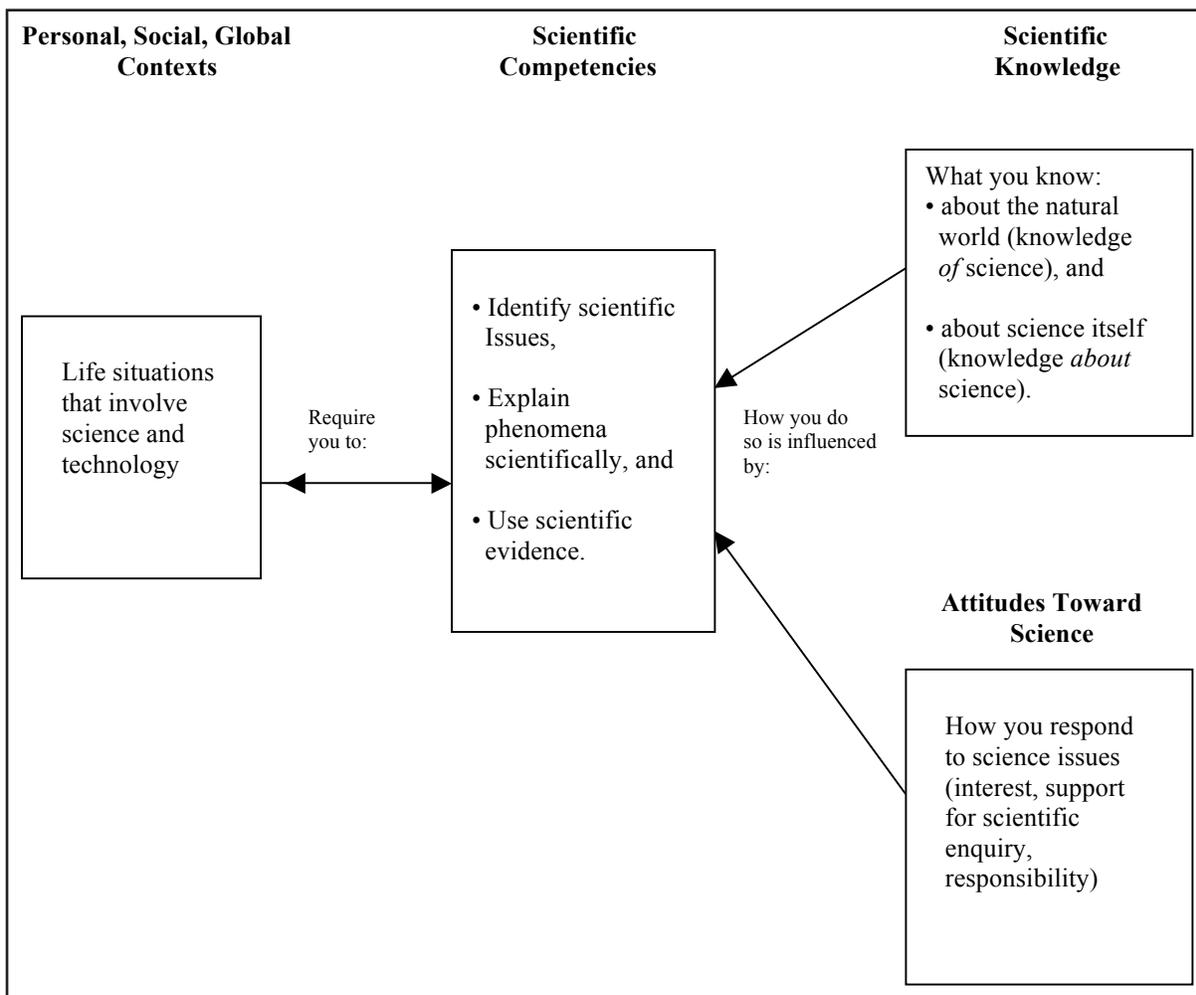


Table 2: PISA 2006 Scientific Competencies

<p><i>Identifying scientific issues</i></p> <ul style="list-style-type: none"> • Recognizing issues that are possible to investigate scientifically • Identifying keywords to search for scientific information • Recognizing the key features of a scientific investigation
<p><i>Explaining phenomena scientifically</i></p> <ul style="list-style-type: none"> • Applying knowledge of science in a given situation • Describing or interpreting phenomena scientifically and predicting changes • Identifying appropriate descriptions, explanations, and predictions
<p><i>Using scientific evidence</i></p> <ul style="list-style-type: none"> • Interpreting scientific evidence and making and communicating conclusions • Identifying the assumptions, evidence, and reasoning behind conclusions • Reflecting on the societal implications of science and technological developments

sometimes conflicting, information about phenomena, such as climate change, they need to be able to access collective scientific knowledge and understand, for example, the scientific basis for evaluations by bodies such as the Intergovernmental Panel on Climate Change (IPCC) versus the basis for perspectives by individuals representing oil, gas, or coal companies. Finally, citizens should be able to use the results of scientific reports and recommendations about issues such as health, prescription drugs, and safety to formulate arguments supporting their decisions about scientific issues of personal, social, and global consequence.

In PISA 2006 Science, *scientific literacy* also encompassed both *knowledge of science* and *knowledge about science* itself. The former includes understanding fundamental scientific concepts; the latter includes understanding inquiry and the nature of science. Because PISA describes the extent to which students can apply their knowledge in contexts relevant to their lives, assessment material was selected from the major domains of physical, life, Earth, and technology

systems. Knowledge of science is required by adults for understanding the natural world and for making sense of experiences in the *personal, social, and global* contexts.

PISA 2006 Science used two categories for *knowledge about science*: “scientific inquiry,” which centers on inquiry as the central process of science, and “scientific explanations,” which are the results of scientific inquiry. Inquiry is the means of science (how scientists get evidence) and explanations are the goals of science (how scientists use evidence).

The U.S. trend in science should be a great concern to those in leadership positions.

Finally, *attitudes toward science* underlie an individual’s interest in, attention to, and response to science and technology. The inclusion of attitudes and the specific areas of attitudes selected for PISA 2006 Science is

supported by and builds upon reviews of attitudinal research (OECD, 2006). The PISA 2006 Science assessment evaluated students’ attitudes in three areas: *interest in science, support for scientific inquiry, and responsibility towards resources and environment.*

How Did U.S. Students Do On PISA 2006 Science?

The PISA 2006 Science survey provided an opportunity to compare U.S. students’ scientific literacy with that of students in other countries, both our economic competitors in the Organization for Economic Cooperation and Development (OECD) and twenty-seven other countries. This discussion begins with a summary of the U.S. position among OECD countries and other non-OECD countries that participated in PISA 2006 Science. The discussion continues with a review of student performance on the proficiency levels used to clarify degrees of scientific literacy.

The United States was one of 57 countries participating in PISA 2006 Science. This number includes 30 OECD countries and 27 partner countries. Students in the U.S. scored an average of 489 points, which is 11 points below the OECD average of 500 points. U.S. students ranked 17th among other industrialized (OECD) countries.

The U.S. trend in science should be a great concern to those in leadership positions. The U.S. dropped from 14th in science on PISA 2000 to 19th in 2003 and to 21st in 2006. These results provide a reason to address the general scientific literacy in the U.S. In practical terms, the U.S. scientific literacy translates to the supply of scientists and engineers, skilled workers, and technological

Table 3: PISA 2006 Science Survey: OECD Jurisdictions

PISA Results	Science
	OECD average score.....500
	OECD Jurisdictions
Average is measurably higher than the U.S. average	Finland..... 563 Canada..... 534 Japan..... 531 New Zealand..... 530 Australia..... 527 Netherlands..... 525 South Korea..... 522 Germany..... 516 United Kingdom..... 515 Czech Republic..... 513 Switzerland..... 512 Austria..... 511 Belgium..... 510 Ireland..... 508 Hungary..... 504 Sweden..... 503
Average is not measurably higher or lower than U.S.	Poland..... 498 Denmark..... 496 France..... 495 Iceland..... 491 UNITED STATES..... 489 Slovak Republic..... 488 Spain..... 488 Norway..... 487 Luxembourg..... 486
Average is measurably lower than the U.S. average	Italy..... 475 Portugal..... 474 Greece..... 473 Turkey..... 424 Mexico..... 410

innovation, as well as to economic growth in general.

Overall U.S. performance. To say the least, U.S. results on PISA 2006 Science were disappointing. U.S. 15-year-olds lag behind the majority of developed nations that participated in the survey. Out of 30 OECD countries participating, 16 countries' average score was significantly higher than the U.S. average (See Table 3). The average score for Finland, the highest achieving country, was 74 points above the U.S. Other high achieving countries

included Canada, Japan, New Zealand, and Australia. Among non-OECD countries, six countries' average scores were significantly higher than the U.S. Those countries were: Hong Kong-China, Chinese Taipei, Estonia, Liechtenstein, Slovenia, and Macao-China (see Table 4).

Science literacy scores for racial/ethnic groups. On the combined science literacy scale, Black students and Hispanic students scored significantly lower, 409 and 439 respectively, than the OECD average (500) and lower

than White (523), Asian (499), and students of more than one race (501). This pattern of performance for racial and ethnic groups was similar to that reported by PISA in 2000 and 2003 (Baldi, Jin, Skemer, Green & Herget, 2007; Lempke et al., 2001; Lempke et al., 2004).

Proficiency levels for scientific literacy. In PISA 2006 Science, performance levels were defined for the purpose of describing in greater detail the scientific competencies and overall scientific literacy. Student scores in science were grouped into six proficiency levels. Level 6 represents the most difficult tasks, and Level 1 represents the least difficult tasks. The grouping into proficiency levels was undertaken on the basis of combining scientific knowledge and abilities underlying scientific competencies. Proficiency at each of the six levels can be understood in relation to descriptions of the kind of scientific competencies that students need to attain the respective levels. Table 5 summarizes the levels and represents a synthesis of individual competencies for overall *science literacy*. The percentage of OECD students and the percentage of U.S. students at the respective levels also are displayed in Table 5.

U.S. students at higher levels of proficiency. At Level 6, for example, students can consistently identify, explain, and apply both knowledge of science and knowledge about science in a variety of complex situations involving science. For OECD countries, 1.3% of students perform at Level 6 on the science literacy scale. In the U.S., 1.5% reach Level 6. If we consider both Level 5 and 6, the U.S. is the same as the OECD average—9.0%. This is the good news. However, other countries have much

Table 4: PISA 2006 Science Survey: Non-OECD Jurisdictions

PISA Results	Science
	OECD average score.....500
	Non-OECD Jurisdictions
Average is measurably higher than the U.S. average	Hong Kong 542 Chinese Taipei 532 Estonia..... 531 Liechtenstein 522 Slovenia..... 519 Macao..... 511
Average is not measurably higher or lower than U.S.	Croatia..... 493 Latvia..... 490 *United States 489 Lithuania..... 488 Russia..... 479
Average is measurably lower than the U.S. average	Israel..... 454 Chile 438 Serbia 436 Bulgaria 434 Uruguay 428 Jordan 422 Thailand..... 421 Romania 418 Montenegro..... 412 Indonesia..... 393 Argentina 391 Brazil..... 390 Colombia..... 388 Tunisia 386 Azerbaijan..... 382 Qatar..... 349 Kyrgyz Republic 322
* The United States is an OECD country. It has been included in this table for comparison purposes.	

higher percentages at Levels 5 and 6; for example, Finland (20.9%), New Zealand (17.6%), and Japan (15.1%). These countries have a very high potential for creating scientists and engineers and promoting scientific literacy among all citizens.

U.S. students at lower levels of proficiency. In PISA 2006 Science, Level 2 was designated as the baseline for the competencies. This is the level at which students begin to demonstrate science competencies that

will allow them to participate actively as citizens. Students at Level 2 can identify key features of a scientific investigation, recall concepts, and use results of an investigation represented in a data table to support a personal decision. Across the OECD, 19.2% of students are categorized as below the baseline, Level 2. For the U.S. this average is 24.5%. Below Level 2, students may confuse key features of an investigation, apply incorrect scientific information, and confound

scientific evidence with personal opinions and beliefs. These results indicate that about one quarter (24.5%) of U.S. students do not demonstrate the competencies that will allow them to productively engage in science and technology related life situations. *Science proficiency levels for racial and ethnic groups.* Black, Hispanic, and American Indian/Native Alaskan students scored below the OECD average. Scores for White students were above the OECD average. On average, the mean scores for White, Asian, and students of more than one race were in Proficiency Level 3; the mean scores of Hispanic, American Indian/Native Alaskan, and Native Hawaiian/Other Pacific Islander students were in Proficiency Level 2; and the average mean score for Black students was at the top of Proficiency Level 1 (Baldi, et al, 2007).

U.S. students and science competencies. Among the unique insights gained from PISA 2006 Science is information on student performance on three scientific competencies: *identifying scientific issues, explaining phenomena scientifically, and using scientific evidence.* Examining the scientific competencies individually suggests possible areas to emphasize in school science programs. One way to think of the science competencies is in terms of a sequence that individuals might go through as they encounter and solve science-related problems. First, they must identify the scientific aspects of a problem, then apply appropriate scientific knowledge to that problem, and, finally, they have to interpret and make sense of their findings and use them to support a decision or recommendation. Traditional science courses in the U.S. tend to concentrate on the middle segment—explaining

Table 5: Summary Descriptions for the Six Levels of Proficiency on the Combined Science Scale

Level	What students can typically do at each level	Percentage of all students across OECD who can perform tasks at least at this level	Percentage of U.S. students who can perform tasks at least at this level
6	At Level 6, students can consistently identify, explain, and apply scientific knowledge and <i>knowledge about science</i> in a variety of complex life situations. They can link different information sources and explanations and use evidence from those sources to justify decisions. They clearly and consistently demonstrate advanced scientific thinking and reasoning, and they use their scientific understanding in support of solutions to unfamiliar scientific and technological situations. Students at this level can use scientific knowledge and develop arguments in support of recommendations and decisions that center on personal, social, or global situations.	1.3%	1.5%
5	At level 5, students can identify the scientific components of many complex life situations, apply both scientific concepts and <i>knowledge about science</i> to these situations, and can compare, select, and evaluate appropriate scientific evidence when responding to life situations. Students at this level can use well-developed inquiry abilities, link knowledge appropriately, and bring critical insights to these situations. They can construct evidence-based explanations and arguments based on their critical analysis.	9.0%	9.0%
4	At Level 4, students can work effectively with situations and issues that may involve explicit phenomena that require them to make inferences about the role of science and technology. They can select and integrate explanations from different disciplines of science or technology and link those explanations directly to aspects of life situations. Students at this level can reflect on their actions and they can communicate decisions using scientific knowledge and evidence.	29.3%	27.3%
3	At Level 3, students can identify clearly described scientific issues in a range of contexts. They can select facts and knowledge to explain phenomena and apply simple models or inquiry strategies. Students at this level can interpret and use scientific concepts from different disciplines and can apply them directly. They can develop short statements using facts and make decisions based on scientific knowledge.	56.7%	51.3%
2	At Level 2, students have adequate scientific knowledge to provide possible explanations in familiar contexts or draw conclusions based on simple investigations. They are capable of direct reasoning and making literal interpretations of the results of scientific inquiry or technological problem solving.	80.8%	75.5%
1	At Level 1, students have such a limited scientific knowledge that it can only be applied to a few, familiar situations. They can present scientific explanations that are obvious and follow explicitly from given evidence.	94.8%	92.3%
	Below Level 1	5.2%	7.6%

Table 6: Identifying Scientific Issues: *Summary Descriptions of the Six Proficiency Levels*

Level	Proficiency at each level	Percentage of all students across OECD who can perform tasks at this level	Percentage of U.S. students who can perform tasks at this level
6	Students at this level demonstrate an ability to understand and articulate the complex modelling inherent in the design of an investigation.	1.3%	1.2%
5	Students at this level understand the essential elements of a scientific investigation and, thus, can determine if scientific methods can be applied in a variety of quite complex, and often abstract, contexts. Alternatively, by analyzing a given experiment, students can identify the question being investigated and explain how the methodology relates to that question.	8.4%	8.1%
4	Students at this level can identify the change and measured variables in an investigation and at least one variable that is being controlled. They can suggest appropriate ways of controlling that variable. The question being investigated in straightforward investigations can be articulated.	28.4%	26.5%
3	Students at this level are able to make judgments about whether an issue is open to scientific measurement and, consequently, to scientific investigation. Given a description of an investigation, students can identify the change and measured variables.	56.7%	53.2%
2	Students at this level can determine if scientific measurements can be applied to a given variable in an investigation. They can recognize the variable being manipulated (changed) by the investigator. Students can appreciate the relationship between a simple model and the phenomenon it is modelling. When researching topics, students can select appropriate key words for a search.	81.3%	78.4%
1	Students at this level can suggest appropriate sources of information on scientific topics. They can identify a quantity that is undergoing variation in an experiment. In specific contexts, they can recognize whether that variable can be measured using familiar measuring tools or not.	94.9%	94.4%
	Below Level 1	5.1%	5.6%

Table 7: Explaining Phenomena Scientifically: Summary Description for the Six Proficiency Levels

Level	Proficiency at each level	Percentage of all students across OECD who can perform tasks at this level	Percentage of all U.S. students who can perform tasks at this level
6	Students at this level draw on a range of abstract scientific knowledge and concepts and the relationships between these to develop explanations of processes within systems.	1.8%	2.0%
5	Students at this level draw on knowledge of two or three scientific concepts and identify the relationship between them to develop an explanation of a contextual phenomenon.	9.8%	9.8%
4	Students at this level have an understanding of scientific ideas, including scientific models, with a significant level of abstraction. They can apply a general, scientific concept containing such ideas in the development of an explanation of a phenomenon.	29.4%	26.7%
3	Students at this level can apply one or more concrete or tangible scientific ideas/concepts in the development of an explanation of a phenomenon. This is enhanced when there are specific cues given or options available from which to choose. When developing an explanation, cause and effect relationships are recognized and simple, explicit scientific models may be drawn upon.	56.4%	50.1%
2	Students at this level can recall an appropriate, tangible scientific fact applicable in a simple and straightforward context and can use it to explain or predict an outcome.	80.4%	73.7%
1	Students at this level can recognize simple cause and effect relationships given relevant cues. The knowledge drawn upon is a singular scientific fact that is drawn from experience or has widespread popular currency.	94.6%	91.7%
	Below Level 1	5.4%	8.4%

phenomena scientifically—and give much less emphasis to identifying scientific issues and using scientific evidence.

On identifying scientific issues, U.S. students ranked 15th among OECD countries, which was not statistically significantly different from the OECD average. U.S. students were statistically significantly below the OECD average on explaining phenomena scientifically and using scientific evidence. There were gender differences in that girls performed better on identifying scientific issues and using scientific evidence and boys performed better on explaining phenomena scientifically. This finding was consistent with performance by other OECD countries.

U.S. students performing at the highest levels, 5 and 6, were about equal to the percentage of all OECD students, 9.7% for OECD students, and 9.3% for U.S. students. Below the baseline, the U.S. had 21.6% on identifying scientific issues. (See Table 6.)

On explaining phenomena scientifically, the U.S. had slightly more students in the upper two levels of proficiency, 11.8% (U.S.) and 11.6% (OECD). However, the U.S. had 26.3% of students below the baseline. (See Table 7.)

Finally, for using scientific evidence, 13.7% of U.S. students did well by achieving at the top levels on this proficiency. However, this percentage was lower than the percentage of OECD students (14.2%). The disappointing result was at the lower level. Twenty-six percent of U.S. students were below the baseline. This is compared to 21.9% of all OECD students (see Table 8).

Selected Implications of PISA for Science Education Leaders

This concluding section presents implications of PISA for science education in general and several themes emphasized by President Obama in his clearest discussion of science and science education, the 27 April 2009 remarks at the National Academy of Sciences.

Fostering scientific literacy. In the United States, most school science programs do not emphasize scientific literacy as described in PISA 2006. Consistently, the term scientific literacy is stated as the purpose of science education, but school programs primarily emphasize facts, information, and knowledge of the science disciplines and only secondarily emphasize the applications of science related to citizens' life situations. The distinction may seem subtle, but it is basic and essential to understand the difference as it relates directly to curriculum, instruction, and assessments at local, state, and national levels.

A critical challenge for science education leaders centers on the difference between the two perspectives of science curriculum and teaching described earlier. One perspective is the fundamentalist and *internal* to science itself. This is the perspective currently emphasized in most state standards, assessments, and school science programs. In this perspective, educational policies, programs, or practices center on questions such as: What knowledge of science and its processes should students have? What facts and concepts from physics, chemistry, biology, and the Earth sciences should be the basis for

school science programs? In contrast, there is the *external* perspective that begins with science-related situations that citizens might encounter. When thinking about educational policies, programs, and practices from this perspective, questions center on: What science should students know and be able to do as future citizens? What contexts could be the basis for introducing science and technology? The difference between these two perspectives is significant, because the emphasis of curricula, selection of instructional strategies, design of assessments, and professional education of teachers differ depending on the perspective.

Based on this discussion of PISA 2006, I point out what is perhaps the single most significant challenge facing leaders who wish to foster scientific literacy in the U.S. Most science educators hold the internalist perspective that school science programs should first, foremost, and exclusively emphasize the basic knowledge and processes of science and secondarily and incidentally make some links to social issues such as health, environment, resources, and energy efficiency. If time and opportunity permit—which usually they do not—the science-related social issues might be taught.

If the United States wants to foster higher levels of scientific literacy, then it is essential to begin recognizing the perspective that includes science-related social issues and accept the importance of incorporating scientific literacy into standards, assessments, and school programs for science.

In order to realize the President's vision, science and scientific literacy must be added to initiatives being undertaken by the National Governors

Table 8: Using Scientific Evidence: *Summary Descriptions for the Six Levels of Proficiency Levels*

Level	Proficiency at each level	Percentage of all students across OECD who can perform tasks at this level	Percentage of all U.S. students who can perform tasks at this level
6	Students at this level demonstrate an ability to compare and differentiate among competing explanations by examining supporting evidence. They can formulate arguments by synthesizing evidence from multiple sources.	2.4%	2.5%
5	Students at this level are able to interpret data from related datasets presented in various formats. They can identify and explain differences and similarities in the datasets and draw conclusions based on the combined evidence presented in those datasets.	11.8%	11.2%
4	Students at this level can interpret a dataset expressed in a number of formats, such as tabular, graphic, and diagrammatic, by summarizing the data and explaining relevant patterns. They can use the data to draw relevant conclusions. Students can also determine whether the data support assertions about a phenomenon.	31.6%	29.0%
3	Students at this level are able to select a piece of relevant information from data in answering a question or in providing support for or against a given conclusion. They can draw a conclusion from an uncomplicated or simple pattern in a dataset. Students can also determine, in simple cases, if enough information is present to support a given conclusion.	56.3%	51.8%
2	Students at this level are able to recognize the general features of a graph if they are given appropriate cues and can point to an obvious feature in a graph or simple table in support of a given statement. They are able to recognize if a set of given characteristics apply to the function of everyday artifacts when making choices about their use.	78.1%	73.9%
1	In response to a question, students at this level can extract information from a fact sheet or diagram pertinent to a common context. They can extract information from bar graphs where the requirement is simple comparisons of bar heights. In common, experienced contexts, students at this level can attribute an effect to a cause.	92.1%	90.0%
	Below Level 1	7.9%	10.0%

Association, the Council of Chief State School Officers, and Achieve (2008), as well as those initiated by the National Research Council, National Science Teachers Association, and others so that core standards and assessments can be revised and improved upon. By clearly identifying the ability to apply science to social issues as a goal of basic science education, we can move towards the goal of achieving higher levels of science understanding for all citizens of our nation.

If the United States wants to foster higher levels of scientific literacy, then it is essential to begin recognizing the perspective that includes science-related social issues and accept the importance of incorporating scientific literacy into standards, assessments, and school programs for science.

Socioeconomics and science achievement. One major insight from PISA 2006 Science is the fact that poverty had a greater affect on science scores in the U.S. than in other nations. Socioeconomic background accounted for an 18% variation on U.S. student achievement. This finding should cause alarm about the importance of scientific literacy as it relates to social inequities and the connections between social inequities and racial and ethnic groups. It is clear that students of lower socioeconomic status do not have the same opportunities to learn science as students in higher socioeconomic groups. The U.S. system of education does not provide underprivileged

students with demanding science curricula, high quality science teachers, and other resources, such as well equipped modern science laboratories. To place this in contemporary terms, in spite of the No Child Left Behind legislation, we are leaving some children behind, and they tend to be the less privileged.

The difficulty with the socioeconomic problem is that it is a huge, complex social issue. Schools can only contribute to changes in the larger social problem, but policy makers and educators can respond to inequities within the educational system. I refer to those mentioned above: curriculum, instruction, teachers, and the allocation of resources. The current administration has proposed to allocate \$5 billion for states that make a commitment to improve math and science achievement. States are competing for these funds under an initiative titled "Race to the Top." The double entendre of this title should not be lost in discussions that center on competitions with other countries and educational standards, curriculum, and teacher education. Reducing the discrepancies of achievement among racial and ethnic groups must be a part of contemporary reform in the U.S.

A new generation of science curricula. Assuming that the themes related to scientific literacy, such as "science in personal and social perspectives" (National Research Council, 1996), are included in standards, then it is clear there is a need for instructional materials aligned to the standards. This new generation of curriculum materials for grades K-12 could include strategies that help students develop 21st century workforce skills and abilities in modernized laboratories for science and technology.

Let me be very clear about this implication. I propose that this new generation of curriculum materials be designed, developed, and implemented as a complement to current programs. Rather than a complete reform of the current fundamental curriculum, the proposed new generation would account for 4-6 weeks of activities in the school year. These activities would give students opportunities to apply their scientific knowledge to local, national, and global problems of energy, environment, resources, and health while developing 21st century skills and abilities.

In conclusion, I have used my perspective of PISA 2006 Science to provide both an orientation and rationale for reinvigorating American science education. The President has indicated that a decade is a reasonable amount of time within which to realize this reform. The results from PISA 2015, when science will again be emphasized, represent a reasonable benchmark for U.S. progress in our race from the middle to the top. The stage has been set. We have clear indications of our standing as a nation, and we have clearly defined measures of success. We have identified problems with the way science is currently being taught, and solutions to resolve those problems have been proposed, as has funding to implement those solutions. Now we must take action.

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Opening the Classroom Door: Professional Learning Communities In the Math and Science Partnership Program

This article highlights examples of professional learning communities (PLCs) in the National Science Foundation (NSF) Math and Science Partnership program.

Students come marching into the classroom and take their seats ... the bell rings ... the teacher closes the door and thinks, “This is my time with the kids. I have a lesson plan that I prepared, and they’ll learn what I have to offer.” The teacher never talks to other teachers about what to teach or how to teach, and the only time that anyone visits the classroom is when an administrator comes to evaluate the teacher once a year.

Although such a reality typified many classrooms in the 20th century, in the 1990s and the first decade of this 21st century, a new exemplar of K-12 teacher professional development has evolved—the professional learning community (PLC). This paper looks at how PLCs have become an operational approach for professional development with potential to de-isolate the teaching experience in the fields of science, technology, engineering, and mathematics (STEM). We offer a short synopsis of the intellectual origins of PLCs, provide multiple examples of PLCs employed in projects funded by the National Science Foundation

Learning organizations were characterized by a shared vision among employees and management with team learning through group discussion of goals and problems.

(NSF) through its Math and Science Partnership (MSP) program, and consider benefits for varied aspects of the teaching and learning environment.

Origins

Much has been written about PLCs. Fuller histories are available elsewhere (e.g., see Feger & Arruda, 2008), and countless articles and synopses are found online. The term ‘learning community’ began to enter the educational vernacular broadly in the early 1990s, following the publication of Peter Senge’s book *The Fifth Discipline* (1990). Senge’s philosophy called for a radical restructuring of business management strategies. The purpose

of this restructuring was to transform corporations into *learning organizations*. Learning organizations were characterized by a shared vision among employees and management with team learning through group discussion of goals and problems. The concept of an environment in which “people are continually learning how to learn together” (Senge, 1990, p. 3) caught fire in the educational world.

Soon, the term was modified to ‘learning communities’ as educational practitioners and researchers began to create a collection of literature on this topic (Hord, 1997a, 1997b; Senge et al., 2000). In this period, Richard DuFour and Rebecca DuFour, along with an array of collaborators, became broadly influential as they popularized the term ‘professional learning communities’ and edited the seminal book *On Common Ground: The Power of Professional Learning Communities* (DuFour, Eaker & DuFour, 2005). Today, PLCs are used to describe a variety of circumstances that include bringing administrators and teachers together into discussion groups, en-

visioning the classroom environment as a community, and enhancing the classroom experience by including the broader community. Moreover, STEM educators have not been absent from the work with PLCs, and this is captured well in a recent volume edited by Mundry and Stiles (2009).

While educators in the United States exhibit a growing enthusiasm for participating in PLCs, it is interesting to recognize that educators across the globe already identify collaboration with peers as a common mode of practice (Wong, Britton & Ganser, 2005). Perhaps the strongest example of a learning community is the cultural norm among Japanese teachers to participate in lesson study groups as described, for example, by Stigler and Hiebert in *The Teaching Gap* (1999). Acculturating new teachers into learning communities is also well-developed in nations outside of the United States. As Britton notes, "Although all teachers in Shanghai and Japan participate in learning communities, beginning teachers receive particularly essential help from participating in them at the outset of their practice ... What we observed in Shanghai and Japan contrasts with what we saw generally in the U.S. We have noticed places where lesson study groups exist as professional development for experienced teachers, but beginning teachers often are omitted" (2007, p. 9). To overcome this reticence on the part of American educators, the National Commission on Teaching and America's Future (Fulton, Yoon & Lee, 2005) has adopted recommendations that new teachers become deeply engaged in learning communities during the induction phase of their careers. Such efforts are meant to address the observation noted by Wong, Britton, and Ganser that "isolation is

the common thread and complaint among new teachers in U.S. schools. New teachers want more than a job. They want to contribute to a group" (2005, p. 384).

As the notion of PLCs has entered the mainstream, concerns about the fundamental definition of the term have emerged. DuFour notes that "the term has been used so ubiquitously that it is in danger of losing all meaning. The professional learning community model has now reached a critical juncture, one well known to those who have witnessed the fate of other well-intentioned school reform efforts. In this all-too-familiar cycle, initial enthusiasm gives way to confusion about the fundamental concepts driving the initiative, followed by inevitable implementation problems, the conclusion that the reform has failed to bring about the desired results, abandonment of the reform, and the launch of a new search for the next promising initiative" (2004, p. 6). Michael Fullan identifies several "reasons to be worried about the spread of professional learning communities. First, the term travels faster and better than the concept. Thus we have many examples of superficial PLCs—educators simply calling what they are doing professional learning communities without going very deep into learning and without realizing they are not going deep ... Second, people make the mistake of treating professional learning communities as the latest innovation. Of course in a technical sense it is an innovation to the people first using it, but the moment you treat it as a program innovation, you run two risks. One is that people will see it as one innovation among many—perhaps the flavor of the year, which means it can be easily discarded once the going gets rough and as other

innovations come along the following year" (2006, p. 10).

The Math and Science Partnership program

Launched in 2002, the Math and Science Partnership program at the National Science Foundation is a research and development effort to build capacity and integrate the work of higher education, especially its STEM disciplinary faculty, with that of K-12 to strengthen and reform mathematics and science education. Ultimately, the MSP program seeks to improve student achievement in mathematics and science for all students, at all K-12 levels. MSP projects are expected to incorporate creative, strategic actions that extend beyond commonplace approaches in order to improve the depth and quality of K-12 mathematics and science education. A primary goal of MSP projects is to develop and embellish strategies that deal with issues of teacher quality, quantity, and diversity. Because the preparation and diversity of future teachers is also of concern, many MSP projects strive to improve undergraduate and graduate education for those seeking to enter the teaching profession.

The first call for proposals, MSP Solicitation 02-061, remarked that "teachers require support throughout the professional education continuum from recruitment, through preparation, induction and continued professional development in order to create and sustain an excellent teaching force" (NSF, 2002). Proposals were encouraged to offer solutions that would "[s]trengthen the mathematics and science teaching profession, especially in underserved areas, through (a) recruitment of qualified individuals to become teachers, (b) preparation of future teachers in significant

content and pedagogy, (c) support of the teacher certification process, (d) policies that impact where teachers are employed, (e) induction into the field, and (f) continuing professional development.” It is noteworthy that in 2002, and even in later years, PLCs were emphasized as a significant strategy for engaging K-12 teachers and higher education faculty in only a few proposals, including those that succeeded through the merit review process and thus were awarded funding. This has been true even though the intent of the MSP program is to forge partnerships among individuals and institutions.

However, as MSP-funded projects began to unfold and add to their repertoire of strategic interventions, it became clear at conferences of the MSP community and in early pre-publications from project investigators that PLCs have become a relatively common vehicle for professional development. Most often, PLCs have been implemented as school-based communities of teachers with a common purpose for their professional development, and they often also include higher education STEM and education faculty. PLCs occur in many of both the mathematics-focused and the science-focused projects of the MSP program, and with well over 100 MSP projects awarded to date, it is clear that STEM PLCs are new exemplars of professional development in the lives of thousands of teachers. This article discusses several examples—made available by investigators and staff—of science-focused MSP projects from across the nation.

North Cascades and Olympic Science Partnership (NCOSP), led by Western Washington University

During the first three years of the project (2003-2006), the NCOSP focused on developing a highly competent cadre of approximately 160 teacher leaders by increasing their knowledge and skills concerning: (a) science content, (b) considerations related to effective science teaching and learning (Bransford, Brown & Cocking, 1999), (c) tools for effectively structuring collaborations among teachers that aid in improving student learning (such as Lesson Study, Curriculum Topic Study, Formative Assessment Probes, and Looking at Student Work Protocols), and (d) strategies to develop effective professional learning communities (Garmston & Wellman, 1999). The teacher leaders were given opportunities to practice leadership through presenting, facilitating, coaching, and consulting with teachers.

Subsequently, in Summer 2007, 105 out of the 160 NCOSP teacher leaders involved in the project expanded the scope of the partnership by developing PLCs within their respective schools. Each teacher leader collaborated with higher education faculty and other teacher leaders for one week in July to develop three-day professional development activities that met the initial needs of his/her school-based PLC. Using what they had learned during their first three years with NCOSP, the teacher leaders focused their initial three-day professional development events on developing teachers’ science content knowledge and understanding of the ways in which people learn. During the 2007-08 school year,

most of the PLCs used Curriculum Topic Study, Formative Assessment Probes, and Looking at Student Work Protocols in a coherent sequence to better understand students’ thinking and determine ways to improve classroom instruction and student learning in science. In the Summer of 2008, the teachers from the PLCs attended a week-long content immersion in physical science while their teacher leaders and administrators worked on developing an action plan to guide the work of the PLCs during the 2008-09 school year.

NCOSP examined the PLCs’ working processes and impacts on teachers in order to obtain formative and summative evaluation data that the partnership could use to make programmatic decisions and that the PLCs could use to improve their foci and practices. Multiple methods were developed and used, including a *Professional Learning Community Observation Protocol* and a *School Capacity for Improvement—Survey of Science*.

A case study of one of the NCOSP schools illustrates the process through which a PLC became a key school advisory board. During the 2007-08 school year, the NCOSP teacher leader “Conny” provided leadership for the science PLC at an elementary school in rural northwest Washington State. The PLC included one teacher representative from each grade of the K-5 school. The principal participated in a few PLC meetings but mainly supported the work of the PLC by providing the teachers time to meet as a group. During the initial three-day professional development event that Conny developed and led for the teachers in the PLC in August 2007,

she shared NCOSP tools and resources, made the case for science reform with a Minds of Our Own video, discussed the research on *How People Learn*, and had the teachers participate in a one-day content immersion on light. During this first professional development event and over the course of the school year, the PLC teachers were very willing to explore new content and their own misconceptions in order to develop further their content knowledge in science. They quickly determined their goals for the year and initially focused on overcoming the limited amount of science being taught at the school.

Because the preparation and diversity of future teachers is also of concern, many MSP projects strive to improve undergraduate and graduate education for those seeking to enter the teaching profession.

The school already had FOSS science kits (see <www.fossweb.com>) available at each grade level, so the PLC recommended to the principal that science be reintegrated in the school by requiring that each K-5 teacher implement one FOSS kit per year. Conny, as the school's science specialist, would teach a second FOSS kit at each grade every year. As the FOSS kits began to be used fully, thus increasing the amount of time devoted to teaching science, the PLC shifted its focus to work on improving classroom assessment and grading in science, and began exploring ways to improve teachers' ability to assess students' understand-

ing through the use of science notebooks, formative assessment probes, and questions similar to those on the statewide assessment that would better prepare students for these exams. In the spring of 2008, the school decided to deepen its emphasis in science by having a building-wide science fair in which the lower elementary students presented their results from whole class science projects and the upper elementary students shared their individual or group science projects. This inaugural science fair brought together teachers, students, parents, and community members at the school one evening in May. By this time, science appeared to permeate all aspects of the school. As the principal wrote in a school newsletter to all staff and parents, "I am not kidding when I say science is the bedrock subject that we hang all of our teaching on, we know science rules and we want our children to think like scientists."

The PLC had become a key advisory body in the school because they had the support of the principal and had structured the PLC so that each grade was represented and the role of each teacher representative was to facilitate the sharing of information between the PLC and the grade level teams. The group had made a lot of progress in increasing the amount of science instruction. Although it is difficult to make a direct attribution, the percentage of 5th grade students proficient on the state science assessment increased by 19.6% following the increase in science instruction that took place during the 2007-08 school year. This finding encourages the continued use of PLCs to increase emphasis on and awareness of teachers' roles in teaching and assessing science.

Boston Science Partnership (BSP), led by the University of Massachusetts - Boston

The BSP employs a professional learning community model called Collaborative Coaching and Learning in Science (CCLS). CCLS is adapted from a model originally developed for the Boston Public Schools to support teaching of literacy. In the CCLS model, a group of 3-8 science teachers in a building meets once or twice per week for an 8-16 session cycle. Each group is led by a teacher and supported by an "apprentice facilitator," both of whom receive training from the Boston Public Schools Science Department. A full CCLS cycle includes a course of study about science teaching and learning chosen by the participants, research, observations and debriefs, a review of student work, and reflective documentation. Recent topics have included writing in science, using notebooks, assessing student understanding, using evidence to support claims, student misconceptions, and analyzing standardized test results. CCLS groups were designed to have a greatly reduced dependence on external staff resources than the groups in the original Boston literacy model. To accomplish this, Boston Public Schools Science Department staff members spend much of their time providing specific on-site support to CCLS groups as needed, including co-facilitating and/or providing quarterly training sessions for teacher facilitators. Three part-time staff members support 30-35 CCLS groups each year. As a result of these efforts, some CCLS groups have successfully become independent, self-sustaining communities.

CCLS is an extremely flexible and adaptable model that includes the ability to address a particular mission of the school or district. CCLS has changed the nature of how teachers teach and reflect on teaching and learning science. This was accomplished by providing a context and culture that supports on-going, research-informed, in-depth conversations about science teaching and learning. The external evaluation, which consisted of observations, surveys, and interviews of participants, administrators, and district staff, found changes in teachers' feelings about their effectiveness in the classroom as well as a change to the overall community of science teachers across Boston. CCLS was shown to expand teachers' knowledge of the science curriculum, advance an atmosphere of professionalism, and raise awareness among teachers and administrators of the resources available from the district's science department. Teachers also reported learning about and implementing new teaching strategies, focusing more on student success and student understanding, and gaining content knowledge. By the spring of 2010, the BSP will have findings that look at student outcomes as a function of teacher participation in CCLS; however, the formative evaluations, feedback from participants, and informal observations indicate that there have been important changes to the community of science teachers in Boston. Teachers feel they have support and connections across the district. They are familiar with their peers' teaching and are known by their peers. They have a structured format in which to talk about teaching and learning in science. Teachers at all stages of the professional continuum can participate equally. Furthermore,

opportunities for professional growth and recognition, such as the facilitator and apprentice facilitator positions, are made convenient through the training and support. Participation in the BSP (CCLS and other programs) is a statistically significant contributor to teacher retention. CCLS provides an incentive to remain in Boston by supporting a vibrant community of practice. A core group of teacher leaders in the district, many of whom were first recruited through CCLS, even formed a monthly science social rotation that is hosted each month by teachers from a different school. The socials have continued for two years now, and 50 to 100 science teachers from across the district, as well as STEM faculty and BSP project staff, typically attend each social. Teachers credit their desire to remain in the school district to the professional atmospheres of their schools and the cohesive learning communities they have formed.

BSP evaluators have found that there are several characteristics common to successful CCLS groups. These include: 1) support by school administrators, 2) a course of study chosen by the teachers participating in the CCLS group and alignment of that course of study with the school's mission, 3) a sincere desire by teachers to participate and development of trust among the teachers in a CCLS group, 4) effective facilitation and clear structure in CCLS meetings, 5) authentic feedback offered by peers that includes both praise and challenges with discussions that focus on improving teaching practice, and 6) recognition by participants of connections between the chosen course of study and the lessons observed. Implementation of CCLS has also included challenges that mirror

most of the common characteristics. Three key contextual considerations emerged as the most critical factors necessary for successful implementation of CCLS: 1) at least a minimal level of administrative support, 2) a trained facilitator with the ability to effectively lead a CCLS group, and 3) the prior existence of a moderately well functioning science program in the school. Lastly, it is critical that someone with an understanding of high-quality instruction is a facilitator or participant in the group in order for high quality and productive conversations to occur.

Institute for Chemistry Literacy through Computational Science (ICLCS), led by the University of Illinois - Urbana-Champaign

A significant component of ICLCS, which is now entering its fourth year, has been the use of the *Virtual Professional Learning Community (VPLC)* to support rural high school chemistry teachers who reside in different geographic areas across Illinois. Among the ICLCS Fellows, i.e., the teachers participating in ICLCS institutes, 24% are the only science teacher in their small district. The project has used Moodle, an open-source course management application, as a platform for a vibrant, active learning community in which the emphasis is on learning and the purpose of professional development is student achievement. ICLCS Fellows partner with University of Illinois faculty, students, and researchers as equals to improve student achievement. The total of 44,712 logins (June 2007-May 2009) and 16,428 postings among 100 Fellows, faculty, and ICLCS staff shows that the VPLC has become a powerful tool in the continued

professional development of ICLCS Fellows.

The flexibility in time and space provided by the asynchronous communication of the VPLC is important, because it 1) allows for in-depth investigation and analysis of discussion topics, which promotes deep thinking/learning, and 2) creates opportunities for more teachers and faculty to participate in the same discussion session, which enhances collaboration and social interaction. It also effectively creates a network of experts and peers who communicate regularly. Through the use of social network analyses, the interwoven web of communication is being further studied over the remaining years of the project as ICLCS continues to gather longitudinal data on the VPLC. However, there are definite indications of early success. As one Fellow noted, “[t]he networking with others in my field has meant a great deal to me. I have taught chemistry in Illinois for over twenty years and knew virtually no other chemistry teachers. Now I have a HUGE network of fellow teachers I can use for support and resources.”

The project implemented a randomized selection research design to measure the impact of ICLCS strategies on students in participant classrooms. Over the past two years, ICLCS has observed a significant difference in achievement between students of Cadre I teachers (treatment group) and those of the control group (Cadre II). The Cadre I Fellows had completed a full year of professional development, including participation in the VPLC. In the following year, using an American Chemical Society standardized test, ICLCS found that students of Cadre I teachers had a 45% greater gain in terms of content acquisition than students of the Cadre II teachers.

ICLCS staff is continuing to examine these trends and the VPLC at large in order to understand the impact of its interventions on teacher learning and student achievement.

Project Pathways, led by Arizona State University

In their original design, Pathways staff included PLCs as part of the intended plan. However, the project team initially underestimated the support that teachers in PLCs would need to shift their instruction to have a primary focus on student thinking and learning while utilizing inquiry as a primary mode of instruction. Pathways also did not anticipate the many school-based obstacles that emerged during its effort to establish PLCs in the schools. Over the past four years, the Pathways PLC research team has utilized qualitative methods to code videos of PLC meetings in order to identify the essential attributes of highly effective content-based PLCs.

The Pathways PLCs are composed of 3-7 teachers who teach the same course. These teachers meet weekly to discuss issues of knowing, learning, and teaching the ideas that are central to that course. The PLCs are initially structured with an agenda that aids the facilitator in promoting meaningful reflection and discourse among all members of the PLC. In the absence of a PLC facilitator who holds teachers to high standards for verbalizing the processes involved in knowing, learning, and teaching content, Pathways research has revealed that PLC discussions tend to be superficial and teachers make little progress in shifting their classroom practices (Carlson, Moore, Bowling & Ortiz, 2007). As a result, Pathways PLCs currently designate a lead teacher to serve as a facilitator. All facilitators within a school attend a

four-day facilitator training workshop and weekly coaching meetings that are designed to support them in learning to guide the PLC conversations so as to assure that teachers “speak meaningfully” about the processes involved in knowing and learning the content (Clark, Carlson & Moore, 2007). If a teacher is vague in expressing what it means to understand, learn, or teach an idea, the facilitator is responsible for posing questions that will encourage members of the PLC to express clearly ideas about the issue under discussion. A good facilitator must have strong content knowledge about the subject area that is the focus of the PLC. The facilitator must also be interested and able to inquire into the thinking of other members of the PLC. This requires the facilitator to be a good listener who is able to make sense of the meanings conveyed by others (Carlson, Moore, Bowling & Ortiz, 2007).

Pathways researchers have found that before teachers are ready to develop new lessons to improve the teaching of specific ideas, they must first inquire into: 1) student thinking relative to these specific ideas, 2) the processes involved in learning the specific ideas, and 3) the degree to which their students are currently learning about the specific ideas. In the most recent iteration, Pathways found that after one year of meeting weekly in PLCs that emphasized content, the teachers were ready for extended work in the summer that prepared them to make substantive shifts in their curriculum, assessments, and pedagogical approaches. At this stage of their development, the teachers also express willingness to videotape their new lessons and present video clips from their classrooms as artifacts for discussion with other members of their PLC.

Additionally, the Pathways team has found that the school principal and STEM department chairs are critical to the institutionalization of PLCs within a school. For the purposes of institutionalizing PLCs, desirable qualities of a principal include: 1) willingness to rearrange schedules to accommodate content-focused, school-based PLCs for one hour during the work week, 2) support of inquiry-based and conceptually-oriented teaching, and 3) willingness to work through logistical obstacles to facilitate participation by all teachers' in the workshop or course and weekly PLC meetings. The researchers have concluded that shifts in secondary mathematics and science teaching practice are achieved when teachers have opportunities to re-conceptualize and revise their curriculum and instructional practices to align with inquiry-based instruction. Research on the practices of secondary mathematics and science teachers has revealed that teachers' images of teaching and curriculum are deeply rooted in their experiences and that often these experiences have been predominately stand-and-deliver, procedurally-oriented instruction. Because of their deep rooted beliefs about teaching and learning and previous experiences, teachers typically need an external support system in addition to more developed content knowledge in order to realize substantive shifts in their classroom practices¹.

Vertically Integrated Partnerships K-16 (VIP K-16), led by the University System of Maryland

VIP K-16 has brought together several Maryland institutions of higher education and high schools in

the Montgomery County (Maryland) Public Schools district in order to promote inquiry-based learning in the sciences, both in high schools and at the undergraduate level. Learning communities became the commonly accepted strategy for teachers and faculty to exchange information, interact and observe instruction, share research endeavors, reflect on teaching practices, and reform curriculum at all levels. Although several PLCs included only faculty or only high school teachers (usually because of geographical limitations), several had participants from across the K-16 spectrum.

In one example of developing PLCs, project leaders at the University of Maryland, Baltimore County developed bi-annual colloquia that brought faculty, graduate students, and high school teachers together to explore inquiry instruction in science. Nearly 80 people were involved in three colloquia. At the first such colloquium, participants self-selected into smaller, sustained PLCs that met as small groups (of 1-2 faculty and 1-3 teachers) throughout the year. Ultimately, 7 faculty and 10 teachers participated in these groups. The PLCs designed inquiry-based lesson plans for high-school and undergraduate courses, and some teachers and faculty spent time visiting each others' classes. One PLC contributed to the development of a graduate teaching assistant training program for the mathematics department.

Another type of PLC was designed by project leaders at the University of Maryland Biotechnology Institute. Over a four-year period, the program placed nearly 40 high-school

teachers (8-10 each year) in research laboratories during the summer and supplemented their experience with a pedagogical learning community that was established to help teachers translate their laboratory experiences into inquiry lessons in the classrooms. During the summer and in follow-up meetings during the academic year, the teachers and faculty (in science and in science education) met regularly to talk about and challenge their own notions of scientific inquiry and redesign their instructional practices in response to those discussions. Survey instruments and learning-community observations were employed as well as an inquiry-teaching rubric modified from Llewellyn (2002). The results indicate significant increases in teachers' understanding and use of inquiry instruction over the course of the year. This strategy, dubbed "ExPERT" (Extended Professional Experiences in Research for Teachers), was one of the most successful learning community strands in the project.

Measuring PLCs

Implicit in the design of MSP projects offering professional development for teachers is the belief that these projects will result in new learning among the teachers, which will then translate into improved learning opportunities for students. How do investigators know that creating PLCs results in new and meaningful interactions among teachers or that PLCs result in changes in classroom practice that benefit students? As part of a national research and development effort, MSP projects are expected to collect data to document their work and use that data to inform future

1. In the Pathways project, teachers either enrolled in a two sequence graduate course or attended 8 half day workshops that were focused on improving teachers' content knowledge for teaching.

directions and provide insights to the field on methods of analysis that are effective at measuring indicators of success. Rigorous assessment of the impact that professional development has on teachers and their students requires the development of tools and instruments accompanied by piloting, revision, and field-testing.

Two of the projects discussed above have developed instruments for observing PLCs. In NCOSP, the investigators developed and used the *Professional Learning Community Observation Protocol*, which is an instrument structured around the project values that had been identified as key elements of an effective PLC: Shared Vision and Ways of Working, Collaboration, and Reflective Dialogue. These three elements combine to help foster open communication among group members so that they develop common norms, vision, and goals. The two main purposes of this protocol are to: 1) build and deepen a shared understanding of what it means to work effectively as a PLC, and 2) provide a meaningful tool for self-monitoring a PLC's development.

Project Pathways researchers are currently refining its *Learning Community Observation Protocol (LCOP)*, which is a tool used by project staff to determine the degree to which a PLC is engaging in genuine inquiry and meaningful conversations about knowing, learning, and teaching specific content (Sutor, Oehrtman & Carlson, in preparation). The LCOP is being designed to determine if PLC members are "productively engaged" during sessions and if group members reflect on and discuss problems related to student thinking and understanding, problems of teaching practice, ways to unpack mathematical or scientific

ideas, and/or problems related to communication with peers. The Pathways team has found that productive engagement in PLCs is characterized by PLC members contributing to the discussion in meaningful ways, and encouraging others to do the same, with the group engaged in a reflective rather than routine way, and the group taking important issues as problematic. In contrast, unproductive characteristics appear when the PLC group works routinely through the agenda without reflective engagement with the material, allowing a) some members not to be engaged in the intended activity of the group, b) exclusion of some members of the group by more engaged members, c) an excess of time to be spent on extraneous discussion, and/or d) a failure of the group to value the time spent in the learning community.

Other projects funded by the MSP program have developed additional methods to measure impacts of PLCs, and it is anticipated that this research, such as the two examples that follow, will be made available to others across the nation who are interested in assessing the effects of professional development.

Partnership for Reform in Science and Mathematics (PRISM), led by the University System of Georgia

PRISM is a large-scale project with state and regional partners. The state partners include the University System of Georgia, which is the public higher education state agency, and the Georgia Department of Education, which is the K-12 state agency. Four regional P-16 ('P' is for preKindergarten) partnerships include at least one institution of higher education (IHE) and one K-12 system, which results

in a total of 6 IHEs and 15 school districts participating in PRISM. In order to increase the quality of science and mathematics teaching and learning in Georgia, PRISM initiated 10 focal strategies. One of the strategies is to "engage higher education and P-12 faculty in learning communities" (see <<http://www.gaprisim.org/about/strategies.phtml>>). Over multiple years, PRISM has developed evidence showing consistent, positive effects of PLCs on teaching and learning practices (Monsaas, 2006; Hessinger, 2009).

To provide evidence about the impact of PLCs, PRISM has used the *Inventory of Teaching and Learning (ITAL)*, which is a self-report survey that was developed by a team of PRISM evaluators to assess teachers' reported emphasis on reformed teaching and learning practices (Ellett & Monsaas, 2007). Reformed teaching was characterized as primarily learner-centered, whereas more traditional teaching was characterized as primarily teacher-centered. The inquiry questions on the ITAL were derived from the observation categories and assessment indicators of the Reformed Teaching Observation Protocol (RTOP) developed at Arizona State University (Sawada et al., 2000). Additional items were developed to assess teachers' reported use of standards-based teaching and learning practices and traditional practices. The inquiry items reflected reformed teaching and learning activities (e.g., encouraging students to evaluate their own thinking throughout the lesson) and the traditional scale reflected more traditional teaching practices (e.g., evaluating learning and performance on the basis of right and wrong answers). Teachers used a six-point

scale ranging from 1=No Emphasis to 6=Very Strong Emphasis to rate the extent to which they emphasized each ITAL teaching and learning activity in their classrooms. Principal components analyses supported three subscales of the ITAL: Inquiry-Based Teaching and Learning (30 items), Standards-Based Teaching and Learning (10 items), and Traditional Teaching and Learning (12 items) (Ellett & Monsaas, 2007). In addition to the ITAL questions about teaching and learning practices, several demographic questions (e.g., grade level and science and/or mathematics courses taught) and questions about participation in PRISM activities were asked, including if the responding teacher participated in a PRISM learning community and if a higher education faculty member participated in the PLC.

The ITAL has been given to thousands of teachers across Georgia, including those who participated in PRISM PLCs and those who did not, and statistical analyses were run separately in the Springs of 2006, 2007, 2008 and 2009. The dependent variables were the three subscales of the ITAL and the independent variable was participation in a PRISM PLC. The results were consistent over the four collection times and showed that participation in a PRISM LC is associated with greater emphasis on standards-based teaching and learning practices in both mathematics and science K-12 classrooms. Moreover, the PRISM team also found that participation of an IHE faculty member has an additional, positive impact on teachers' reported use of inquiry-based teaching and learning.

Developing Distributed Leadership, led by Northwestern University in collaboration with

the Math in the Middle Institute Partnership of the University of Nebraska - Lincoln

This collaboration between an MSP-funded research project and a partnership project (entitled Math in the Middle) focuses on PLCs for mathematics education (see Pustejovsky, Spillane, Heaton & Lewis, 2008) that examining different dimensions of middle school mathematics by comparing them to other subjects (e.g., Language Arts). One component of this work explored the validity of a social network instrument (the *Social Network Survey*) for studying subject-specific leadership and social influence in schools, with particular attention to question-order effects (Pustejovsky & Spillane, 2008; Pitts & Spillane, 2009).

The Social Network Survey was administered to all certified staff in each of the ten middle schools in the partnership. School-level response rates ranged from 70% to 94% for teaching staff and were slightly lower for administrators and other certified staff. The survey collected data on different dimensions of the PLC. Seven sets of measures, comprised of 46 items in total, measured teachers' views on the social norms within their school, including:

- Trust among teachers (6 items)
- Trust between teachers and the Principal (8 items)
- Teachers' evaluation of the Principal's instructional leadership (7 items)
- Collective responsibility for student learning: peer-assessed (7 items)
- Collective responsibility for student learning: self-assessed (7 items)

- Teachers' control over classroom practice (5 items)
- Openness to innovation (6 items)

Network data were collected in order to measure the structural and content aspects of the PLC, and network ties (i.e., linkages between individuals) were measured by asking respondents to list the people "to whom they go for advice and information" about several topics. All teachers were asked about mathematics and reading/writing/language arts. Additionally, all subject-specific teachers were asked about their primary subject. For each tie listed by a respondent, data was collected on the tie's designated role, the frequency of contact between respondent and advisor, the influence of the advisor on the respondent's practice, and the content of the interaction between respondent and advisor. Content was measured along five dimensions: deepening content knowledge, planning or selecting course content and materials, approaches for teaching content to students, strategies specifically aimed at assisting low-performing students, and assessing students' understanding of the subject.

The collaboration's ongoing analyses suggest that there is considerable variation across schools in the structure of the PLCs, even though the norms and substance of PLCs appear to be relatively homogeneous across schools (e.g., regarding norms, between-school variation ranges from only 2% for teacher control over classroom practice to 7% for instructional leadership). Although school-level averages do not vary greatly, there do appear to be differences in the homogeneity of attitudes within each school; respondents in some schools have a high level of agreement about

the principal's instructional leadership, while respondents in other schools show a much greater range of opinions. There is also considerable variation in terms of the structure of PLCs, both by school and across subject-areas. Schools varied in the degree to which the subject-specific networks spanned the formal organization of the school and the degree to which teachers' networks reached outside the school to access advice and information. Schools and subject-areas also varied in their network concentration. For example, math networks generally appeared more concentrated than reading/writing/language arts. Finally, the researchers observed that Math in the Middle associates are prominent brokers of information both within schools and between schools and their environment. The associates tended to be named as advisors by more individuals within their schools as compared to other teachers in similar roles. Moreover, associates sought advice from more sources outside of their schools, compared to their colleagues, and many of their external ties were with other Math in the Middle associates at different schools. All in all, this work on PLCs in schools shows great promise. The collaboration of the research and partnership projects is now exploring relationships between teacher networks and student achievement.

Conclusion

Over the past decade, professional learning communities have been identified by many schools as an effective approach to increasing collaboration among educators. As such, PLCs challenge the stereotype that teachers work in isolation and, instead, open the classroom door wide so that teachers can discover ways to improve their

craft through group effort, discuss with others ways to improve the education of all students, and generally create a culture of mutual support within school walls. A literature on PLCs in science education has begun to appear, and the projects of the National Science Foundation's MSP program, which emphasizes partnerships within and across schools as well as with institutions outside of schools such as colleges and universities, have become especially fruitful sources of new experiments with PLCs in varied manifestations. With the development of new tools and instruments to measure their impact, MSP projects anticipate identifying additional outcomes from their work and, thus, will inform the decisions that all educators must make to improve teaching and, ultimately, learning.

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3D Multi-User Virtual Environments: Promising Directions for Science Education

Centered on the theme of scientific inquiry, this article describes a number of 3D multi-user virtual environment programs and their potential for improving science learning.

Our nation's students fall short in science. The Department of Education's 2000 National Assessment of Education Progress (NAEP), also known as "The Nation's Report Card," showed no improvement in student science performance between 1996 and 2000 in grades four and eight, and a slight decline in performance by twelfth-graders. While results from the 2005 NEAP indicated improvement for elementary school students in science achievement over the last decade, middle school scores have remained flat, and high school scores have continued to decline since 1996, in sharp contrast to the large gains in math, and slower but still significant gains in reading (National Assessment of Educational Progress, 2005). A recent report from the National Center for Education Statistics revealed that American students scored below average on science literacy in the 2006 Program for International Student Assessment (PISA), trailing their peers in 16 of 30 industrialized countries (National Center for Education Statistics, 2007).

Lamenting the "statistically and morally significant" fall in science results, Rod Paige, former Education

Secretary, warned that "(e)veryone should be concerned—82% of our high school seniors are not performing at the proficient level in science," (Leath, 2001) which could threaten the country's economic future and damage national security in the long run. In reaction to U.S. students' science performance in 2006 PISA, Senta Raizen, Director of WestEd's National Center for Improving Science Education, pointed out that U.S. students "seem to lack a strong grasp of the nature of science, and of science's important role in society" (Cavanagh, 2007).

Leveraged by federal support to address the critical crisis in science education, scientists, science education researchers, and school teachers have started to join efforts to explore how to maximize the use of emerging technologies to improve science teaching and learning.

What obstacles have hindered U.S. students' performance in science? While studies have identified a number of factors that have contributed to the decline of science education, such as shortage of highly qualified teachers and inadequate support from the public system and community, two pressing issues are in need of a rapid response. First, compared to reading and math, which by law are the nation's educational priority, much less attention and thus relatively limited time are devoted to science teaching, especially in elementary schools. The results of the *National Survey of Science and Mathematics Education: Trends from 1977 to 2000* showed that, while mathematics continues to be taught virtually every day in grades 1-12, only about 70 percent of elementary classrooms receive science instruction every day (Smith, Banilower, McMahon, & Weiss, 2002). A more recent study investigated the status of science education in California Bay Area elementary schools, which is home to much U.S. innovation in science and technology, but which ranked 2nd lowest of all states in 2005 NAEP in science. This study showed a diminishing amount

of time spent on science since the enactment of No Child Left Behind, and schools in program improvement status reported that little to no time was being spent on science at all because of their need to show improvements in the tested subjects of language arts and mathematics (Dorph, Goldstein, Lee, Lepori, Schneider, & Venkatesan, 2007).

Parallel to the time constraints, the dominant science instruction pedagogy is problematic. Heavily influenced by the high-stake tests and standards-based curriculum and exacerbated by time constraints, science teachers have focused primarily on delivering the outcomes of science to their students, as opposed to engaging them in the inquiry process. This deviates from the nature of science learning. Compared to their peers in high-achieving countries (such as Japan, Australia, and the Netherlands), U.S. science teachers tend to present science content as a collection of discrete facts, definitions, and algorithms rather than as a connected set of ideas, and high-interest activities and real-life issues are usually designed and introduced as a side-bar to motivate and engage students, rather than being used as tools for developing concepts (Roth & Garnier, 2007). The National Science Education Standards emphasize that scientific inquiry is at the heart of science and science education (National Research Council, 1996); the National Science Teachers Association (2004) suggests that all K-16 teachers embrace scientific inquiry. Although inquiry has a decade-long history of strongly supported recommendation as a best practice in science education, its implementation in the classroom is, unfortunately, misguided. Many teachers, unclear about how to implement inquiry in the classroom,

substitute real scientific inquiry with traditional “cookbook” experiments (Wallace & Louden, 2002).

Exemplary 3D Multi-User Virtual Environments for Science Education

Leveraged by federal support to address the critical crisis in science education, scientists, science education researchers, and school teachers have started to join efforts to explore how to maximize the use of emerging technologies to improve science teaching and learning. There has been a surge of interest in the use of emerging 3 dimensional (3D) multi-user virtual environment (MUVE) technology to engage and motivate learners, support authentic scientific inquiry, and facilitate students’ construction of science knowledge and development of inquiry skills in a socially situated and distributed environment. Made popular by SecondLife, the 3DMUVE is an immersive 3D virtual space where people, entering the space via avatars, meet and interact with one another and learn in the multi-user environment in real time. A variety of 3DMUVE programs has rapidly burst into the limelight in science education, including Harvard University’s River City, Indiana University’s Quest Atlantis, Cornell University’s SciCentr, and North Dakota State University’s Geology Explorer and Virtual Cell.

River City

River City, funded by the National Science Foundation and developed by the Graduate School of Education at Harvard University, is a scientific inquiry-based 3D MUVE that targets middle school students. Adopting a storyline—a familiar game design scheme among mainstream games—

River City is set in a 19th-century city with a river running through it, and its citizens face a chronic illness. The students’ task is to find out why the residents of River City are getting sick and what can be done to help them. The problems are interdisciplinary and integrate aspects of science, history, and social studies, allowing students to experience real world inquiry skills that are required when disentangling multi-causal problems in a complex environment.

Centered on the scientific inquiry skills and on the content in biology and ecology that are embedded within historical, social, and geographical contexts, River City guides students through making observations, posing questions, developing hypotheses, investigating, explaining, predicting, proposing answers, and communicating the results in the form of a letter to the Mayor of River City. River City has been implemented successfully in twelve states in the U.S., and has involved approximately 100 teachers and over 5,000 students in 2007-2008 (Harvard University, 2008).

Quest Atlantis

Quest Atlantis, funded by the National Science Foundation and MacArthur Foundation and developed by the Center for Research on Learning & Technology at Indiana University, is another widely cited innovative science learning program. Similar to River City, Quest Atlantis is a 3D multi-user online learning community intended to engage children ages 9-12 in science learning. Its legend is that the people of “Atlantis” face an impending disaster; their world is slowly being destroyed through environmental, moral, and social decay. The task of the project is to save Atlantis. Leveraging 3D technologies and game-based

methodologies, the problems are presented in an interactive narrative in which the “reader” has agency in co-determining how the story unfolds (Barab, Sadler, Heiselt, Hickey, & Zuiker, 2007).

To echo the national call for inquiry-based math and science learning, Quest Atlantis has been designed to support children’s learning and thinking through the use of scientific inquiry. Its inquiry-based activities begin with an interesting problem that is grounded in real-world issues. Students are involved in refining questions, gathering data, evaluating information, developing plausible interpretations, and reflecting on their findings. Similar to other multi-user virtual worlds, Quest Atlantis is a globally distributed community with more than 20,000 participants from four continents (Barab, Arici, & Jackson, 2005).

SciCentr

SciCentr, an outreach program of Cornell University’s Cornell Theory Center, is a 3D multi-user chat-enabled online museum developed to engage young people in science, technology, engineering, and mathematics subjects. As opposed to River City and Quest Atlantis, which focus on the guided inquiry method of learning, SciCentr is based on constructivism in that it promotes children’s exploration of scientific topics of their own choice and provides a virtual platform for them to share their passion and knowledge of a particular topic with the science community.

Since 2001, SciFair, a portion of the online SciCentr museum, has involved more than 1,000 middle school students and teachers annually. Participants build their own virtual knowledge spaces that combine science

exhibitions with game interactions. SciFair was designed to target a wide variety of settings, especially in terms of cultural diversity, that include underserved, rural, and minority communities. For example, SciFair has been successfully implemented as a science communication program with Native American students in Washington and urban middle school students in New York and Virginia (Corbit, Bernstein, Kolodziej, & McIntyre, 2006).

Geology Explorer and Virtual Cell

Developed by North Dakota State University’s World Wide Web Instructional Committee, Geology Explorer is a multi-user role-playing virtual environment that provides secondary and post-secondary students the means and equipment to carry out geologic investigation of a mythical planet called “Planet Oit”. This planet is described as similar to Earth, but it is directly opposite of the Sun from Earth. In a role-based “learn by doing” environment, students take on the role of a geologist and learn fundamental concepts of geology and inquiry strategies used by geologists through exploration, experimentation, and guided collaboration.

Along with Geology Explorer, Virtual Cell is a similar 3D MUVE for learning fundamental concepts of cell biology and strategies for diagnostic problem-solving. Similar to Geology Explorer, the pedagogical approaches are to provide students with authentic problem solving experiences that include elements of practical experimental design and decision making, while learning science content at the same time (Slator & Beckwith, 2006). These two programs have significantly facilitated

science students’ learning of abstract concepts in geology and cell biology via 3D visualization and modeling.

Promising Directions for Science Education

As evidenced in these pioneering 3D MUVE programs for science education, this emerging technology holds great promise and opportunities for improving science learning and is potentially a viable solution to the pressing issues facing science education in schools.

1. Platform for Scientific Inquiry

The 3D MUVE provides a viable platform to support the authentic scientific inquiry process and help learners acquire inquiry skills defined by the National Science Education Standards (1996). As in River City and Quest Atlantis, the scientific inquiry process and skills are seamlessly embedded in the immersive probing environments. In such environments, students are first exposed to a complex, authentic problem, such as finding solutions to save Atlantis from problems similar to those being faced on Earth. In order to disentangle the complex multi-causal problems, students need to go through the process of making observations, refining questions, gathering data, evaluating information, developing plausible interpretations, and reflecting on their findings—a set of inquiry activities that are at the heart of science and science education. Additionally, the science content and skills specified in the curriculum are embedded in the inquiry activities, which provides an opportunity for the assessment of students’ mastery of these contents and skills.

The unique technological affordances of 3D MUVE offer

a variety of tools for conducting scientific inquiry. One of 3D MUVE's salient features is its ability to construct a virtual space that can not only resemble but go beyond the real world, and provide an experience that is not accessible, possible, or practical in reality. In *Geology Explorer*, for example, students are able to access and examine almost 100 different rocks and minerals that are normally not readily available, and use nearly 40 scientific instruments and geology tools (e.g., "streak," "scratch," "hit," "view," "taste," and "touch," etc). This greatly enhances students' inquiry experiences by providing exploration opportunities similar to those of a real geologist. In addition, in most 3D MUVEs, students can teleport instantly from one place to another, "physically" (via avatar) visiting a place thousands of miles away or even on the other side of the globe and meeting and chatting with people and content experts from around the world. These capabilities can create a profound sense of motivation and engagement conducive to a rich and deep inquiry experience.

2. Gateway to Engaged Learning

Our schools are faced with the challenge of engaging this generation of students in formal learning in the classroom. Studies over a span of two decades reveal a consistently low level of engagement in the classroom, which has resulted in widely reported boredom and an escalated high school drop-out rate. One reason may be related to the widening gap between the tech-savvy students and the print-centric schools. Children today are growing up in a rapidly evolving digital media environment where using cutting-edge gadgets has become an integral and important part of their

growing and learning experience. Despite children's massive use of digital technologies outside of the classroom, schools still continue to operate within a print-based cultural logic.

Yet as revealed by studies on the above-discussed programs, the 3D MUVE is a motivationally rich gadget that deeply engages students in an enjoyable and fervent game-like environment. Results from the implementations of *River City* in public school classrooms indicate that students, both boys and girls, are highly motivated by the 3D MUVE program, with students reporting that they "felt like a scientist for the first time" (Clarke & Dede, 2004). Similarly, students in *SciCentr* rate their learning experience in 3D MUVE significantly higher than in a traditional science teaching environment, stating that they have more fun and have learned more (Norton, Corbit, & Ormaechea, 2008). Moreover, *SciCentr* appears to have the greatest impact on students who begin with neutral or negative attitudes toward science. This echoes the results of *River City*, which showed a greater impact on learning for low achieving students in inner-city schools (Dede & Ketelhut, 2003). These findings make it obvious that, if well designed and wisely used, the 3D MUVE would be a viable platform to increase student engagement, which is important to students' achievement and to their social and cognitive development.

3. Bridge between Formal and Informal Science Learning

As discussed previously, science learning in a school setting is subject to time constraints, in addition to the added complexity of classroom management introduced by technology. The 3D MUVE appears to be an

ideal supplemental tool that connects formal science learning in class and learning in an informal setting, such as after-school programs, or leisure time playing at home. A consistent theme among the existing 3D MUVE science programs is that they are being implemented with great success in the informal setting, as teaching aids or supplemental activities in K-12 science classes.

Except for the above mentioned exemplary 3D MUVE science programs, there have been few efforts to leverage the energy, passion, and engagement children show for the 3D game world in their time outside of school. Children's enthusiasm with 3D MUVE should be harnessed and linked to the science content and inquiry skills required in the curriculum. Instead of grouching and competing with reading and math for a share of the limited amount of time available in school, science educators should make the most of the 3D MUVE's abundant features and popularity, and connect it with in-school activities. By building a continuum between classroom instruction and after-school or at-home activities in 3D MUVE, the passion and informal learning that occur in the 3D game-playing environment will transfer into the classroom and significantly increase student engagement in the formal learning setting.

Conclusions

The fact that it is a multi-billion dollar industry that rivals Hollywood's cultural influence shows that digital games are now a dominant play culture, and they are increasingly affecting kids' development and informal learning outside school. It is becoming ever more evident that technologies make access to children's

interests, passion, and preferred learning styles quick and easy. To harness the power of 3D MUVE and leverage the passion and energy children have with this media, schools need to consider seriously the role of 3D MUVE in science education. As we have seen in the pioneering 3D MUVE science programs designed by forward-thinking science education researchers, the 3D MUVE definitely holds great potential and opportunities for improving science learning and points to a new, promising direction for science education. It is a viable platform for conducting scientific inquiry, a gateway to an engaging, socially distributed learning environment, and a bridge to connect and blend formal and informal science learning. After efforts of more than a decade in science education reform with marginal results, it may be time to sit down and watch how our children play and learn with the new media, experience their enthusiasm and creativity in the digital world, and ask ourselves how we can make this happen in the classroom.

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Analysis of Student Responses to Peer-Instruction Conceptual Questions Answered Using an Electronic Response System: Trends by Gender and Ethnicity

This descriptive study investigated students' answers to geoscience conceptual questions answered using electronic personal response systems. Answer patterns were examined to evaluate the peer-instruction pedagogical approach in a large general education classroom setting.

Over the past decade, it has become apparent that effective learning occurs in Science, Technology, Engineering and Mathematics (STEM) classrooms that use student-centered, active approaches that allow interactive exchange between and amongst students and instructors (American Geophysical Union, 1994; National Research Council, 1997, 2000; National Science Foundation, 1996). Such exchanges are facilitated when students use electronic personal response systems to answer conceptual multiple choice questions, called *conceptests* by Mazur (1997) and referred to as *think-pair-share* exercises in some disciplines (McTighe & Lyman, 1988). Conceptests are repetitive measures designed to explore student depth of understanding (both individual and group), and they often include answers with known preconceptions. Students consider the question and respond individually. Crouch and Mazur (2001) suggest that an initial correct response rate of 35%

- 70% is optimal for these questions. Peer instruction is a practice in which students work together in pairs and small groups to discuss and defend their responses (Mazur, 1997), and this discussion may be followed by a second round of student responses. The use of conceptests is formative, because they provide timely feedback that the instructor and student can use to improve their performance. Much has been written about the ways in which this technique can be used by faculty (Cox & Junkin, 2002; Crouch & Mazur, 2001; Green, 2003; Hake, 1998; Mazur, 1997; McConnell, Steer, Owens & Knight, 2006; Pilzer, 2001;

Responses were analyzed for predictability, construct validity and gender reliability assuming a statistically normal response distribution.

Rao & DiCarlo, 2000; Sokoloff & Thornton, 1997). The evidence is also compelling that this technique improves student learning from a course perspective (Crouch & Mazur, 2001; King & Joshi, 2008; Lasry, Maur, & Watkins, 2008; Smith et al., 2009) and that the technology is well received by students (MacGeorge et al., 2008a). Less is known about the impact this technique has on subpopulations of students based on gender and race.

The conceptests used in this study were taken from a large database of questions for the geosciences that were developed by more than 30 geoscience faculty members with multiple years of experience teaching introductory courses in a variety of settings (e.g. community college, small 4-year, and public universities). Those faculty members used their personal experiences and a review of the published literature to develop lists of geoscience concepts that are difficult for students to grasp and are discussed

in most typical introductory geoscience courses for non-majors. Some of these concepts include plate tectonics, geologic time, the rock cycle, and the water cycle. The conceptests were generated according to good practices for writing multiple choice questions (Haladyna, Downing, & Rodriguez, 2002) by focusing on a single concept, using simple language or graphics, and including 3-4 short answers that require few or no calculations. The distracters (incorrect answers) also include alternative conceptions, misconceptions, or incorrect intuitive responses. The conceptests probe student understanding at various cognitive levels and emphasize the comprehension and application (“understanding” and “applying” levels in Anderson and Krathwohl [2001]) through analysis and evaluation levels of cognitive processing (Bloom, 1956).

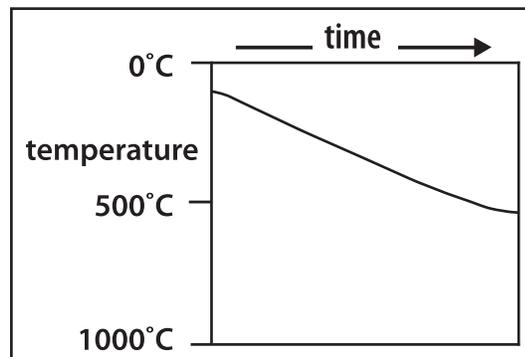
This study focuses explicitly on conceptual questions at the *understanding*, *applying*, and *analyzing* cognitive levels (Anderson & Krathwohl, 2001), because these are the most appropriate levels to assess using multiple-choice formats. The questions are posed as text-, diagram-, or graph-based problems, and they are similar to questions on the summative exams. At the *understanding* level, students demonstrate they are able to convert concepts learned as text to an illustration or vice versa. Students are also asked to compare and contrast objects or concepts, select reasons, compare solutions, or make predictions (see Figure 1). At the *applying* level, students apply rules or principles to new situations, use known procedures to solve problems, or demonstrate that they know how to do something. When working at the *analyzing* level, students select answers that

explain how something works or distinguish fact from opinion. Questions that require students to scrutinize graphical data or images are interpreted as analysis questions, especially if the students have not previously seen the graph (see Figure 2).

In the landscape pictured, how would the amount of rainfall change at location X if the mountain eroded down to the dashed line?

- a) Rainfall would increase
- b) Rainfall would decrease
- c) Rainfall would stay the same

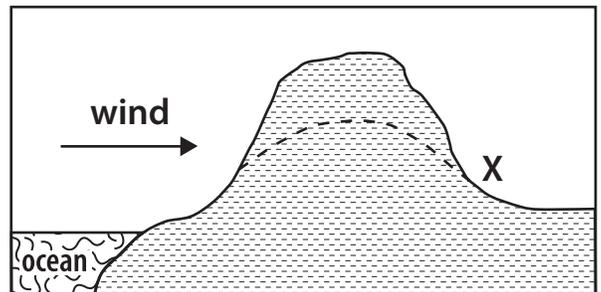
Figure 2: Example of a graph-based, analysis-level conceptest related to the rock cycle.



The graph illustrates how the temperature changed with time for part of the rock cycle. Which of the following is best represented by the graph?

- a) Sand is lithified to form sandstone
- b) Limestone is metamorphosed to form marble**
- c) Marble is uplifted to Earth’s surface
- d) Magma cools to form granite
- e) Shale is heated and converted to magma

Figure 1: Example of a diagram-based-based, understand-level conceptest related to the orographic lifting of air.



Methods

The data used for this study represents 4712 responses to conceptests collected from 242 students enrolled in four earth science classes for non-science majors and one physical geology class at a community college. These classes were taught

by three instructors, each with over five years of teaching experience using active learning strategies. In addition to incorporating conceptests using peer instruction (Mazur, 1997; McConnell, Steer, Owens, & Knight, 2006), classes were taught using a variety of learner-centered activities including the use of student-manipulated physical models (Gilbert & Ireton, 2002), lecture tutorials (Kortz, Smay, & Murray, 2008), and predictive demonstrations (Sokoloff & Thornton, 1997). Students earned participation points for responding to conceptests, regardless of whether the answers were correct or incorrect. Three classes occurred in spring 2008, and two classes occurred in fall 2008.

This study reports conceptest response trends for paired answers from students who answered from 10-26 questions each over the course of the semester. The questions are assumed to be valid for content since they were

developed by geoscience educators and have been reviewed for content validity by 12 experts across multiple institutions. Reliability and validity testing was completed for the questions using responses collected in spring 2006 from a large-format, general education introductory earth science class (155 students). Responses were analyzed for predictability, construct validity and gender reliability assuming a statistically normal response distribution. Correct response rates for the questions as a whole were not gender biased ($p > 0.35$, $n = 55$). Three individual questions appeared to show bias even after addition of response data for the same questions from fall 2005. As a set, the 52 remaining conceptest questions used in this study met predictive validity requirements. The percentage of students correctly responding to comprehension-, application- and analysis-level questions decreased with increasing question cognitive level ($p < 0.0001$; 67%, 52% and 36% respectively).

Student responses from conceptests answered during lessons that used the peer instruction technique were scored using a rubric (Table 1). Those scores were used to evaluate the efficacy of this pedagogical technique for various populations (male, female, Caucasian, and minority). Students in selected courses completed a 15 question, Geoscience Concept Inventory (GCI) test (Libarkin & Anderson, 2005) as an independent assessment of geoscience conceptual understanding. The GCI is a valid and reliable assessment designed to assist geoscience faculty in evaluating teaching and learning (Libarkin & Anderson, 2005). Its purpose and design are similar to the Force Concept Inventory (Hestenes,

Wells, & Swackhammer, 1992) that is widely used in physics education.

Note that, as averaged over all questions, 33% of students recorded incorrect responses after peer instruction, and the remainder recorded a correct answer on the second attempt.

Student engagement was determined by dividing the number of student answers to conceptests by the total number of questions posed. For example, a score of 70% on student engagement was recorded by a student who answered 70% of the conceptests analyzed in the study. These scores were a proxy indicator of attendance. Average conceptest scores were calculated by dividing the number of correct answers by the number of questions asked, and no deduction was made for unanswered questions. Individual student response rates for each question category (Table 1) were calculated by dividing the number of responses in a category by the total number of questions answered by that student. Final course grades and post-course GCI scores were also used as summative assessments of student success. Response data were grouped by gender and ethnicity for analyses. African American, Asian, Pacific Islander, and Hispanic were combined under the 'minority' classification.

Table 1: Scoring rubric for student responses to conceptest questions.

Pre-Discussion Answer	Post-Discussion Answer	Score	% of Responses
Correct	Incorrect	1	5%
Incorrect	Incorrect	2	28%
Incorrect	Correct	3	26%
Correct	Correct	4	41%

Note that, as averaged over all questions, 33% of students recorded incorrect responses after peer instruction, and the remainder recorded a correct answer on the second attempt.

All data fields were not available for all students (due to student absence during administration of the GCI, missing self-reported data, failure to complete the course, etc.). In all, five variables (pre-GCI, post-GCI, final grades, average proportion of correct answers on conceptests, and engagement) were analyzed for each of the four populations (minority male, minority female, Caucasian male, Caucasian female). Pearson's correlation coefficients ($\bar{\rho}$) were calculated for the 20x20 matrix with values of 0.1-0.3 considered of small significance, 0.3-0.5 moderate, and 0.5-1.0 large. Comparisons between larger populations (male-female, minority-Caucasian) were also completed using ANOVA or statistical T-tests using Cohen's d values for effect sizes, and values of $p < 0.05$ were considered significant.

Data

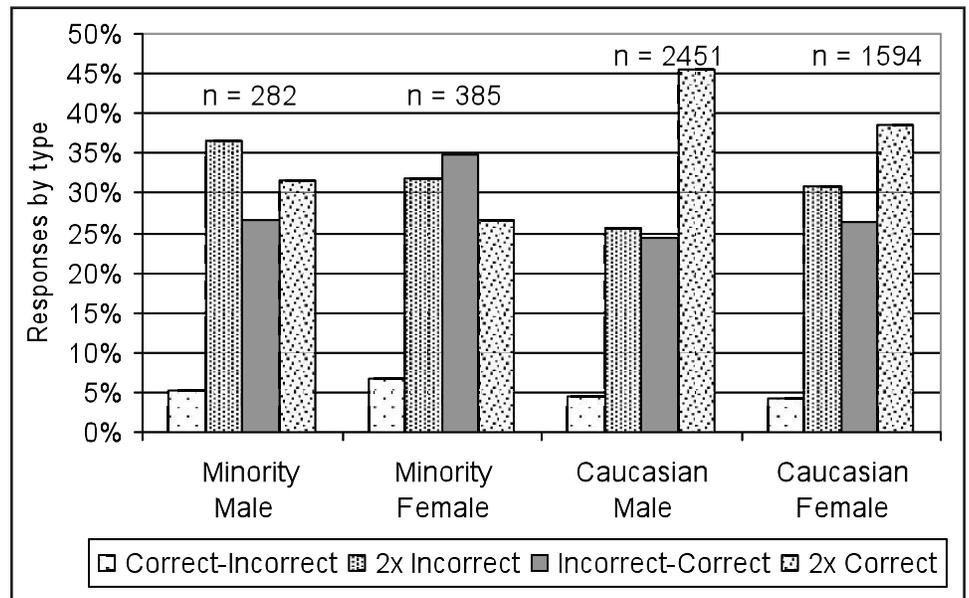
Data were sorted by both gender and race (Figure 3) to show how student responses were distributed in the four paired-response categories (correct-incorrect, twice incorrect, incorrect-correct, twice correct; see Table 1). The total response database included 6% minority male ($n = 282$), 8% minority female ($n = 385$), 52% Caucasian male ($n = 2451$), and 34% Caucasian female ($n = 1594$) responses.

Correct-Incorrect: Overall, approximately 5% of responses showed students answered concepttest questions correctly the first time the question was posed and incorrectly on the second attempt (Table 1; Figure 3). There were not enough responses in this answer category for meaningful analyses between population groups.

Twice-Incorrect: About 28% of all responses were incorrect on both attempts (Table 1; Figure 3). As a percentage of their responses, male minority students were most likely to answer in this way (over 36% of their responses, Figure 3). Female students of both demographic groups answered in this fashion in approximately equal proportions (32%), and Caucasian males answered twice incorrect 26% of the time. Comparisons in twice incorrect response rates between minority populations and for Caucasian females compared to other populations showed small effect sizes ($d = 0.0$ to 0.3). There were moderate effect sizes when comparing male Caucasian response rates in the twice incorrect category to minority males and females ($d = 0.5$ and 0.6).

Twice Correct: The largest differences between populations were noted when analyzing the 41% of twice-correct responses (Table 1: score 4; Figure 3). Caucasian male students were most likely to answer correctly both times (45% of responses). Their female counterparts answered in this fashion about 39% of the time. Female minority students were least likely to answer twice correct (26% of responses), and minority males answered in this way 32% of the time. Effect sizes were small to moderate when comparing female Caucasian students to males ($d = 0.3$ for minority

Figure 3: Percent of student concepttest responses by demographic group.



males; 0.4 for Caucasian males) and when comparing minority males and females ($d = 0.4$). Effect sizes were larger when analyzing Caucasian males to both minority populations ($d = 0.6$ for males; 1.3 for females) and when comparing female populations ($d = 0.9$).

Incorrect-Correct: Overall, 26% of the responses were incorrect on the first attempt, but correct after peer instruction (Table 1: score 3). At this level, minority females fared better than their minority male peers (35% versus 27% of responses) and slightly better than Caucasian students (26% for Caucasian females and 24% for males). Effect sizes were small when comparing minority males to both Caucasian populations ($d = 0.0$ for males; 0.2 for females). All other response rate comparisons in the incorrect-correct category displayed moderate effect sizes ($d = 0.5$ to 0.7).

Combined Responses: When average response rates for individual students by demographic group were

compared to other course variables (pre- and post-GCI, final grades, concepttest average, and engagement), several trends appeared (Table 2).

Male minority students: Minority male concepttest averages were strongly correlated with post-course GCI scores ($\bar{\rho} = 0.9$; Table 2: row D, column B) and moderately correlated with final grades ($\bar{\rho} = 0.5$; Table 2: row D, column C). Pre-course GCI scores (Table 2: column A) were strongly correlated to final grades (Table 2: row C) and post GCI scores (Table 2: row B) for this population ($\bar{\rho} = 0.6$ and 0.7). Engagement (Table 2: row E) displayed a moderately negative correlation with post-GCI scores (Table 2: column B) and moderately positive correlations to final grades and average concepttest scores ($\bar{\rho} = 0.4$; Table 2: columns C and D).

Female minority students: Minority female average concepttest responses (Table 2, row I) displayed a strong negative correlation with pre-GCI scores ($\bar{\rho} = -0.6$; Table 2: column F). Final course grades (Table 2: row H)

Table 2: Pearson's correlation coefficients for studied populations

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
A: Pre GCI Male Minority	1.0																			
B: Post GCI Male Minority	0.7	1.0																		
C: Final Grade Male Minority	0.6	0.5	1.0																	
D: CT Avg Male Minority	0.0	0.9	0.5	1.0																
E: Engage Male Minority	-0.3	-0.4	0.4	0.4	1.0															
F: Pre-GCI Female Minority	0.5					1.0														
G: Post-GCI Female Minority		-0.4				0.2	1.0													
H: Final Grade Female Minority			0.0			0.5	0.2	1.0												
I: CT Avg Female Minority				-0.2		-0.6	0.3	0.1	1.0											
J: Engage Female Minority					-0.1	-0.1	0.2	0.5	0.3	1.0										
K: Pre-GCI Male Caucasian	0.0					0.4					1.0									
L: Post-GCI Male Caucasian		-0.3					0.1				0.4	1.0								
M: Final Grade Male Caucasian			-0.3					0.0			0.0	0.1	1.0							
N: CT Avg Male Caucasian				0.2					-0.1		0.2	0.4	0.2	1.0						
O: Engage Male Caucasian					-0.2					-0.3	-0.2	-0.1	0.5	0.2	1.0					
P: Pre-GCI Female Caucasian	0.3					0.5					0.4					1.0				
Q: Post-GCI Female Caucasian		-0.4					-0.3					0.1				0.3	1.0			
R: Final Grade Female Caucasian			-0.1					0.2					-0.1			0.1	0.1	1.0		
S: CT Avg Female Caucasian				-0.3					-0.3					0.0		0.3	0.0	0.3	1.0	
T: Engage Female Caucasian					0.3					-0.1				0.0	0.2	0.3	0.6	0.2	1.0	

Between populations (Note: Correlations for unrelated variables are removed from the table)

were moderately correlated ($\bar{\delta}=0.5$) to pre-GCI scores (Table 2: column F) and engagement (Table 2: row J, column H).

Male Caucasian students: Male Caucasian students recorded moderately correlated engagement and final course grades ($\bar{\delta}=0.5$; Table 2: row O, column M). Pre- and post course GCI scores (Table 2: row L, column K) were also moderately correlated to post GCI results ($\bar{\delta}=0.4$; Table 2: column L), as were average conceptest scores (Table 2: row N).

Female Caucasian students: Female Caucasian student data showed only one strong correlation ($\bar{\delta}=0.6$), and that was between engagement (Table 2: row T) and final grades (Table 2: column R). All other within-group correlations were small or insignificant.

Between Group Correlations: Moderately significant correlations were found when variables were compared between population groups.

Male and female minority student pre-GCI scores were correlated ($\bar{\delta}=0.5$; Table 2: row F, column A), and male minority post-GCI scores (Table 2: column B) were negatively correlated with post-GCI scores of all other demographic groups. Pre-GCI scores for female minority students (Table 2: column F) were correlated with both Caucasian males and females ($\bar{\delta}=0.4$ and 0.5). Other correlations between groups were either between variables that had no practical relationship and were not shown (e.g. minority male pre-GCI scores and minority female post-GCI scores) or were of little or no significance.

Interpretation and Discussion

Correct/Incorrect Responses: We considered an initial correct response followed by an incorrect answer choice to be the least desirable response sequence. The 5% of responses for which students answered correctly

initially but changed to an incorrect response following peer instruction was similar to the 6% rate reported by Crouch and Mazur (2001). These data suggest that such responses should be expected regardless of ethnicity or gender (Figure 3). The 5% rate closely matches a four-answer multiple choice question occurrence probability of 6% for random guessing on two identical questions (probability increases to about 10% for a three answer question). Since students were awarded credit for answering the questions (whether correct or incorrect), it is possible that some students were simply guessing or answering randomly to fulfill course requirements (King & Joshi, 2008). It is also possible some of these responses simply represent input error. Such an error was possible, because the electronic response software provided signals when student responses were received, but did not display individual responses. However, ineffectual peer instruction also can not be ruled out. If

guessing and input error accounted for most correct-incorrect responses, those answers provided little information relevant to student assessment or teaching. Additional studies are necessary to determine if correct-incorrect responses are important indicators of student learning when using this technology.

Correct/Correct Responses: A twice-correct answer was considered a positive result, because such a response suggested students initially understood the concepts and then validated that understanding by answering correctly a second time. The overall twice-correct answer rates found here closely matched the 40% rate reported by Crouch and Mazur (2001) and played a major role in understanding similarities and differences between populations. Since Caucasian male and female students were more likely to answer twice correct, their other major answer categories had proportionally fewer responses than those of minority students (Figure 3). Such an observation supports the contention that differences within diverse populations can be more important than differences between populations (Harper, 2009). When student data were sorted into two groups (>40% and <40% of responses twice correct), there was a strong correlation between engagement and final grade for both the high- and low-performing groups ($\bar{\rho}=0.6$). Such a finding was not surprising, because engagement is a proxy for attendance, which has been previously correlated to course success (Newman-Ford, Fitzgibbon, Lloyd & Thomas, 2008; Scott, 2000).

Incorrect/Incorrect: As with the correct-incorrect answer, a twice incorrect response was considered a negative outcome, because it

This is the first study to examine the contrasts in student performance by both gender and ethnicity using electronic response systems in large classes.

suggests the peer-learning technique was not effective for the students that answered in this fashion. The 28% overall response rate for twice-incorrect questions was higher than was reported for physics (22% in Crouch & Mazur, 2001). The finding that over one quarter of all responses were incorrect after peer discussion was particularly troubling in light of the fact that 40% of responses were twice correct, because this suggests that more correct responses result from other learning than from peer instruction. Students were randomly organized into four-person learning teams to encourage in-class discussion during the peer instruction phase of the class. The correct answer for most of the conceptests was also the most popular answer when students were polled on the first attempt. Armed with that information and group discussion support, such a high level of twice incorrect answers was considered problematic. ANOVA and correlation analyses showed that there were indistinguishable differences ($p > 0.05$) and correlations ($-0.2 \leq \bar{\rho} \leq 0.2$) between students who frequently answered in this fashion (>25% of registered twice incorrect responses) as compared to those who did so less often (< 25%) for all analysis variables. If a significant number of students in these classes were not actually discussing answers, there may have been little propensity

for students to change their answers. Perhaps students simply failed to change answers to questions if they did not understand the concepts and dialog was not effective enough to clarify understanding. Additional research that focuses on group interactions during peer discussion is necessary to determine the extent to which group communication affects twice incorrect response patterns.

Incorrect/Correct Responses: The type of response sought when using conceptests with peer instruction was that of changing from an incorrect to a correct response (Table 1: score 3). Approximately 26% of student responses in this study were of this type, which is lower than the 32% reported by Crouch and Mazur (2001). These data suggest that peer instruction was nearly equally effective for all populations, but perhaps slightly more so for female minority students (who were ~7% more likely than any other demographic group to answer this way). Since minority students were more likely to miss these questions on the first attempt than Caucasian students, they were in a better position to benefit from this approach.

Overall Responses: Combined analyses of all the response data suggested that there were similarities and differences in the ways that diverse populations respond when using this technology and pedagogical approach. When comparing males and females, all meaningful variable correlations were small or insignificant, which supports the suggestion made by King and Joshi (2008) that electronic response systems did not significantly hinder male or female student success in engineering. Within the male population, moderate correlations between pre- versus post-GCI scores, engagement versus final course grades,

and concept averages versus post-GCI scores were again identified. Within the female population, engagement was strongly correlated to final grades ($\delta=0.6$), and other variables correlated poorly. When the responses of all minority students were compared to the responses of all non-minority students, all meaningful variable correlations related to performance were insignificant or small, which suggests that this pedagogy provided an inclusive approach to formative assessment. Strong to medium correlations related to GCI scores and engagement suggest that prior knowledge and attendance played the most important role in minority students' course success. This finding supports the use of this technology with these populations if doing so encourages attendance, as has been noted in previous studies (MacGeorge et al., 2008b).

All populations could benefit if twice incorrect responses were minimized. This pedagogy relies on the positive group synergies known to be generated when learning with peers in a low-stakes environment (Mazur, 1997). Students placed in groups working toward a common goal, as is implicit in peer learning, provides a pseudo-organizational structure with social norms. Because of this, organizational learning theory (Argyris & Schön, 1996) may be an appropriate lens through which to view student response patterns. Central to such learning is the ability to detect errors (wrong answers) and take appropriate action (select correct answers) when responding to future opportunities (questions). This requires that members of the learning team work effectively and that the culture of the group be conducive to constructive dialog

between all members of the team (Bensimon, 2005). An environment that is conducive to constructive dialogue is one in which all students are comfortable asking questions of their group members when they are not certain of the correct answer or when they consistently answer twice incorrect. The social dialog presumed to occur during peer instruction is known to result in successful performance among minority students (Quaye, Tambascia, & Talesh, 2009). However, the twice incorrect data presented here suggest that the optimal type of dialog was not occurring as often as desired for all populations. Clearly, all student groups have high and low performers. More detailed observations of student discussions are needed to better understand the dynamics and implications of dialog occurring in these groups and the impact of those peer discussions on response distributions.

This is the first study to examine the contrasts in student performance by both gender and ethnicity using electronic response systems in large classes. Given the ubiquity of this technology on college campuses, these data are available in electronic archives for a wide range of classes. We encourage others to analyze their data to determine if the trends reported here apply more widely.

Conclusions

The similarities and differences in concept response patterns found here illustrate how data from electronic response systems can be used to evaluate a pedagogical technique such as peer-instruction. The relatively small percentage of correct-to-incorrect responses may simply be a function of operator error or lack of interest in the class activity.

As a percentage of all responses within populations, males' and females' answers show very similar distributions, which implies that the pedagogical technique is gender neutral. Furthermore, the distribution for answer changes from incorrect to correct suggests that all demographic groups benefit nearly equally from peer discussions. Perhaps as expected, students who answer conceptual questions correctly the most often tend to score highest in course grades, and correct response rates are a moderate function of prior knowledge and attendance. However, the consistently high rate of twice incorrect answers for all groups, and particularly among minority males, is cause for concern. Better dialog within groups appears to be necessary for diverse student populations to benefit most effectively from this intervention.

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No Child Left Behind and High School Astronomy

This article examines the impact of the No Child Left Behind Act on the high school astronomy course.

Astronomy was a required subject in the first American secondary level schools, the academies of the 18th century. When these were supplanted a century later by public high schools, astronomy still was often required, subsumed into courses of Natural Philosophy. Reasons given at that time to support astronomy as a part of general education include “training of minds,” “mental discipline,” and the practical aspects of geography, commerce, navigation and the refinement of a civilized person (Bishop, 1977).

The “Committee of Ten” changed this situation in 1892 by changing college admission standards to no longer consider the study of astronomy as favorable. By 1930, only 0.06% of all students in the whole country would take an astronomy class (Bishop, 1980). The launch of Sputnik I in 1957 created a brief renaissance of astronomy education, but eventually enrollment slipped back down to 1% in the 1980s, which was when the last significant nationwide examination of high school astronomy was done through Philip Sadler’s 1986 survey (Sadler, 1992).

After Sadler, an era of budget cutbacks and increases in high stakes standardized testing began, and this became a dominating influence in 2001 with No Child Left Behind

(NCLB) and its emphasis on reading and mathematics. Today astronomy is taken by about 4% of all high school students (Krumenaker, 2008). Despite the meager growth that this enrollment represents, it remains important to re-examine the subject of high school astronomy as well as the effects that NCLB has had on the availability and quality of these courses.

The results indicate that high school astronomy courses are far more affected by NCLB indirectly than directly.

This mixed-methods study looked at fully independent, self-contained astronomy courses available to students in grades 9-12. Therefore, courses, such as physics or earth science, that contain some astronomy units were not considered in this study. The data came from high school astronomy teachers via a survey available to them on a Webpage and as a Word file. (See Appendix A for an overview of the research procedures.) The study mirrored but greatly enlarged the scope of the Sadler study. Quantitative and categorical questions included diverse topics such as instructors’ back-

grounds, planetarium and telescope availability, financial support, course content, student demographics, school AYP status, and other items. Also included were open-ended survey questions, such as requests for recommendations about ways to go about starting a course, and these responses were coded and treated with qualitative or quasi-quantitative analyses. A detailed quantitative summary can be read in Krumenaker (2009a).

With an initial estimate of between 2500 and 3000 possible teachers derived from a national listing called the National Registry of Teachers supplied by the National Science Teachers Association, our initial survey sample of about 600 teachers represents 20-25% of the astronomy teacher population. In order for a sample of a small population to be considered reliable, Tuckman (1999) claims that it must consist of at least 10% of the target population, and this data exceeds that standard.

The survey had an overall response rate of about 40%, and out of this initial sample 237 surveys were deemed usable.

Additionally, in the Fall of 2007 the same questionnaire was sent in a second survey by postal mail, and this generated numerically half as many responses. All of these results

are essentially identical to the larger, first survey, which strengthens the conclusions and removes concerns relating to possible selection effects arising from the methods of solicitation and response (Krumenaker, 2009b).

Schools' AYP Status and Sizes

This article concerns itself with the part of the study that deals with the perceived effects that the No Child Left Behind Act may have had on high school astronomy courses. One key parameter to investigate is the AYP status of each school. AYP stands for Adequate Yearly Progress and is a measure of compliance with NCLB that relies mostly on high stakes testing scores. Filtering the results to include only currently employed public school teachers yielded 114 public schools with a Pass grade, 30 with a grade of Needs Improvement, and 5 with a Failing AYP, or a rate of 77% Pass, 20% Needs Improvement, and 3% Fail. The NCES (2007) values for 2005-2006 indicate the comparable national percentages were 60% Pass, 14% Needs Improvement, and 26% Fail. This shows that high schools with astronomy are more likely to be schools that Pass AYP. Needs Improvement percentages for schools with astronomy are also higher than the norm. The percentage of schools with astronomy that Failed are substantially lower than the national value.

This supports, though does not prove, studies that say that electives like astronomy are eliminated when a school does not pass AYP. Speculatively speaking, this also supports the contention that schools that pass AYP have the luxury of offering an elective like astronomy. But one must now ask: have the teachers, therefore, not felt any effects from NCLB?

Have Astronomy Courses Been Affected by NCLB?

Among the open-ended questions in the survey was "What, if any, positive or negative effects have you felt in the astronomy course from the No Child Left Behind Act? (And, why do you feel this way?)".

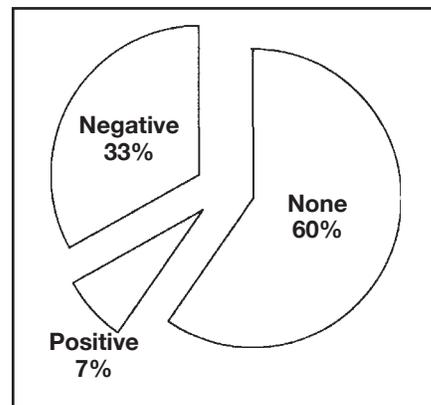
Analysis of this (and other similar questions on the survey) was done by coding the responses in a manner akin to grounded theory techniques developed by Strauss and Corbin (1997). Each sentence in an answer, regardless of grammar or size, was given a code word or phrase indicative, in this case, of the purported effect of NCLB. The sentences were sorted alphabetically by code word, then grouped under larger headings; these might include 'administration', 'justifications', 'support', and so on. No presupposed groupings were used; each grouping would appear when a 'critical mass' of similar answers was gathered. As general themes became evident, larger groups could be split into smaller ones, and smaller ones could be combined into larger groups.

In addition, simple descriptive statistics were performed on most qualitative questions by counting and comparing the sizes and numbers of groups or themes.

Out of the 237 teacher pool, 30 belong to private schools where NCLB has no effect or standing. Others did not respond at all to this question or gave answers not related to their course. Of the remaining 139 responses, 83 teachers (60%) claimed that NCLB had no effect on their course. Forty-six made statements that can be construed as negative effects. Only 10 teachers gave responses that could be construed as positive. Of those that claim some

effect from the Act, the resulting balance is clearly negative, 33%, versus 7% positive (Figure 1).

Figure 1: Teachers Reporting Effects of No Child Left Behind on Astronomy Courses



Why do so many astronomy teachers find themselves apparently immune from NCLB? One of the two most direct answers coming from survey results is that NCLB itself and the "high stakes testing" that is NCLB-inspired but directly controlled by state departments of education only apply to Math and Language Arts, not science, as of the time of this survey. The other common answer is that some states have few or no high school astronomy standards at all, such as the state of Texas' TEKS (Texas Expected Knowledge & Skills). Therefore the courses are not tested, and, consequently, they are ignored.

In the detailed discussion that will now follow, additional evidence about these perceptions, through representative quotations, will be presented. In them, a "Pass," "Passing," "Fail" or "Failing" comment indicates the school's AYP status. Numbers alone, such as "1.5K" or "1500" refer to the number of students in the school. Where the information

is not listed, either the status is unknown or not considered relevant to the discussion. Also, quotes are left intact as typed into the surveys by the respondents, including misspellings and grammatical errors.

Negative Effects

Negative effects due to NCLB, or related state high stakes testing or curriculum changes caused by NCLB pressure, manifest themselves in six areas: enrollment numbers, course cancellations, redeployment of teachers and certification issues, a change in the makeup of the courses' student bodies, loss of status as a science course, and loss of funding.

Numbers

Teachers report a decline in enrollment due to a strong and increasing emphasis on biology, chemistry, and physics. As these courses become more state-tested, and therefore more required of students, fewer students have time available for electives, and student scheduling abilities become more limited. Other studies such as Hunt (2006) indicate the same problem for other science electives. The October 2007 *NSTA Reports* found that "investment in these programs (environmental education) came to a screeching halt ..." (NewsBits, 2007). Survey responses show similar concerns.

NCLBA will cause course to be canceled after this year. School will concentrate on Biology which is the only state science test in Arizona. —Self-described pessimist, soon-to-retire Arizona teacher in a 0.6K student Passing high school whose class is open to all grade levels.

Cancellations

In addition to drops in enrollment, sometimes the courses themselves are dropped, or are expected to be dropped, for other reasons.

However, our administration has told us that IF our API scores drop in the future or we do not meet the benchmarks that have been set by the State, we will have to remediate these students somehow. That will cause the teachers of elective courses (including science electives) to become overseers of remedial courses. Regular class enrollment will drop and courses will be eliminated as we have to add remedial sections. —Teacher in a 2.2K, Passing Oklahoma high school.

Student academic levels

Teachers reported substantial increases in the numbers of students of lesser academic abilities in their classes. Comments indicated that more special education students are believed to be placed in astronomy classes, despite the fact that often there are prerequisites of passing grades in math, especially algebra, and other sciences that these students do not meet. There were more comments on the effects of inclusion than for any other individual, negative coding.

... the emphasis of inclusion has resulted less in including a few special education students into regular education classes and more in classes becoming special education. ... the math prerequisites for the astronomy course are ignored for special education students. With time, more and more students enroll in

the course without the necessary math background thereby requiring drastic alterations to the curriculum. For example, students are not proficient with measuring angles and solving one variable algebra problems. —Teacher in a 1.2K student Passing Pennsylvania high school with a planetarium.

Teaching qualifications

Another effect seen by surveyed teachers, and the only effect directly caused by NCLB, is change in, or elimination of, teaching assignments, particularly because of the 'highly qualified' specification. Some teachers wrote that they have had to make choices in what they can, or will, teach. Sometimes the change has been forced upon teachers. This particular certification issue was further and vividly exemplified in an email from a responding teacher that came just after the formal end of the survey.

Well I thought I would update you to a new road block to having astronomy in our classrooms. One of the provisions of No Child Left Behind (No Teacher Left Standing) is that a teacher must be "Highly Qualified" in every subject they teach. In most states including mine, that means you have to take a test to prove you are qualified. Having a degree no matter what your GPA doesn't count. If you haven't taken such a test you have to go through all sorts of "hoops" to earn enough points to prove you know your subject.

Since there is no Astronomy test then the process is overly complicated for any teacher to attempt starting out a new program. In my case I have both a BA and

Master of Education. Although I am considered highly qualified in Biology, a course I have never taught, I am not in Astronomy since it isn't recognized on any state list. I have taught astronomy for 27 years. Awarded [a prestigious award from a renown society but name removed to keep letter writer anonymous] ... for teaching high school astronomy but can not get the state of [omitted] to acknowledge I am highly qualified.

Loss of status

Teachers report that astronomy is being 'left behind' other sciences.

Students are required to take Biology and two other Science electives. NCLB does not emphasize the importance of taking any Earth and Space courses. Earth/Space seems to take a 'back seat' to Chemistry and Physics. —Teacher in a 1.3K Minnesota Passing high school.

Loss of funds

Financial resources are also diminished, according to some reports.

So many financial resources are directed to remediation of these that materials funding has been cut past the bone. I get about one dollar per student for the year. —An Alaska teacher at a 2K student Passing high school.

the courses have been de-emphasized by the administration because it is not testable material and uses resources better spent on improving test scores. —Self-described pessimistic former teacher from a small 400-student, Passing Wisconsin high school.

Secondary effects

There are secondary negative consequences mentioned.

Teachers can't go to a workshop if it doesn't fit NCLB. Can't make a workshop, can't write to state standards, must be federal. Attendance is down. —Former small school Maine teacher who gives workshops.

Further evidence of reduced professional development opportunities comes from Pennypacker (2008) who coordinates a global version of the Hands-On Universe (HOU) teaching training program. His chart of the number of teachers who have taken the HOU training program over the years shows a rising trend-line abruptly curtailed at the 2001 year mark, and which descends in 2004, just after the War in Iraq began (Figure 2). We can not state there is a clear cause and effect here, but clearly the HOU graph parallels similar effects reported by the surveyed teachers.

Teachers claim they can not call in as many outside resources.

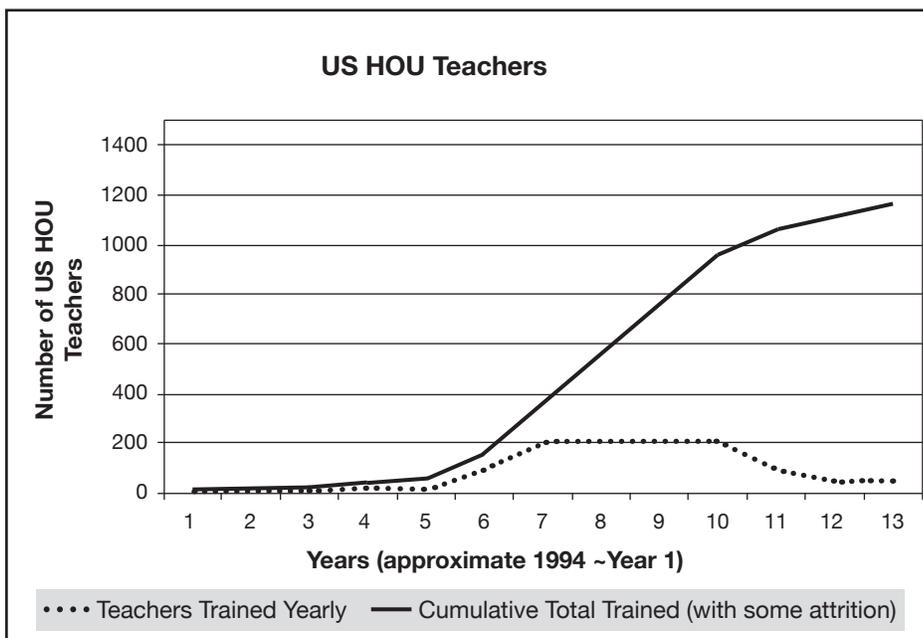
We [astronomy club members] have seen a drop off in the number of request for the club to come out to schools and put on star parties. Teachers are commenting that they are so under pressure to meet NCLB mandated standardized tests that they don't have time to cover much astronomy. —A private school teacher in Hawaii who also is in an astronomy club.

It is also reported that there are fewer opportunities for collaborations and, consequently, a purported stifling of teacher creativity.

Positive Effects

Fewer positive effects are reported than negative effects. Two of them are at odds with some previously mentioned negative effects. One positive effect is that courses are actually experiencing increased enrollments.

Figure 2: The number of teachers taking the HOU workshops, 1994-2007, from Pennypacker (2008), used with permission.



Since No Child Left Behind analyzes our failure rates, it has caused an increase in the astronomy enrollment due to students trying to make up lost science credits. —Teacher in a 2K, high minority, Needs Improvement, planetarium equipped New Mexico school.

The existence or lack of astronomy standards affects administrative perspectives about whether the course is worthy of being offered.

The other at-odds positive effect is the paradoxical increase in the amount of time spent on astronomy, but not in astronomy courses. Instead, the astronomy courses themselves are eliminated, but more astronomy is taught in geoscience courses, so the net effect is that more students, at a lower non-capstone level, are taught more astronomy than prior to NCLB.

Positive effects, besides increasing enrollment at some schools, include having more literacy work and math work included in courses that, presumably, had previously been more conceptual.

I firmly believe in the intent of No Child Left Behind. Reading and Writing in the context of Astronomy improves the students abilities in all courses. I approach the math component using the Read/Analyze/Compute/Evaluate (R.E.A.D.) method. The honors Geometry classes have visited my astronomy classes to see first hand how the fundamentals of mathematics came into being. Holding the students to a high

level is essential to improve their attitudes about learning and gives them confidence. The students will be doing several major term papers each semester. There is a rich history behind the science that helps to students see the interconnections between science in general and their other core classes. —Teacher in a 1.8K student, high minority, Needs Improvement school in New Mexico.

Why ‘No Child’ Has No Effect

The results indicate that high school astronomy courses are far more affected by NCLB indirectly than directly. Enrollments drop often, not because of a shift of student interest, but because students are channeled increasingly into the main three sciences (shades of the Committee of Ten effect) and state mandated/tested courses, leaving fewer students (or schedule time) available for students to take an astronomy course. As a result, fewer sections are offered, and this can lead to outright elimination of the course. Because NCLB does not mandate that Earth/Space Science classes be tested, funding for these courses is reduced, which in turns makes teachers unable to bring in outside resources or obtain professional development related to astronomy. Consequently, teachers report a loss of status for astronomy teachers compared to those of other sciences.

Because the existence of state standards pertaining to a specific content area often correspond to state mandated testing of student performance, another paradoxical situation arises. The existence or lack of astronomy standards affects administrative perspectives about whether the course is worthy of being

offered. Astronomy course standards may not be specified by the state, and, therefore, the courses are ignored by administrations that must be more concerned with achieving acceptable pass rates in math, language arts, and state-tested sciences like biology or physical science. However, in other schools located in states that lack astronomy standards, that situation results in the termination of the course:

They cancelled my course because it wasn't tested! —Self-described pessimistic teacher at a large 2.5K-student Passing Texas school, with a portable planetarium.

Yet, in still another paradoxical situation, this untested specification can cause an increase in enrollment, because this science is perceived (incorrectly at times) to be an easier path for students who have difficulty with the tested sciences. It also means more students are placed into these courses without sufficient academic background, which adds to the perception that these courses are less academically challenging. Astronomy course standards created using NCLB-“approved” standards (whatever they may be) can be helpful to the course’s survival. This tactic has had some positive effects, such as increasing math and literacy-based work.

However, the presence or absence of standards does not uniformly predict the existence of astronomy courses throughout the country. Because the overall survey indicated that large schools are more likely to have astronomy than small schools, size of the school may be a significant factor with regards to astronomy course availability, usually in the form of a capstone class, whether or not there are

established standards (Krumenaker, 2009a).

When all of the reasons given for the lack of direct effect on the course by NCLB are examined, it is found that, currently, astronomy hangs on primarily as a capstone course that is offered only to seniors or upper division students who have essentially passed all NCLB-created hurdles, such as graduation requirements and mandated end-of-course tests. Specifically, 75% of astronomy courses are offered exclusively to upperclassmen. These factors may be putting astronomy beyond the target range of NCLB. Should science become a factor in AYP, this relationship is likely to change, and the indirect effects would be overshadowed by direct ones.

Defending the Course

Even though quite a few teachers appear to have avoided being directly negatively impacted by NCLB, there are documented cases included in this study of courses being cancelled or curtailed. In other cases, the course has been threatened, but teachers have been able to defend the course successfully.

To find out the tactics and rationale that teachers have used (or suggest should be used) to defend the existence of the course, the following open-ended question was asked: “If you should have to defend or justify the course at some future date, what arguments would you use? Why?”

The question generated 428 responses, where ‘response’ indicates a particular defense mechanism. Six primary themes are listed in Table 1; percentages do not add up to 100 due to rounding.

By far, the largest theme is “Defending with the nature of the course.” The most common reason

Table 1: Themes Teachers Use to Defend the Course

Theme	Number	Percentage of Responses
Defending with the nature of the course	137	32
Defending with student interest	88	21
Defending with cultural linkages	78	19
Helps improves students, school, AYP	54	13
Defend with traits of science	24	6
Institutional benefits	22	5
Other	25	6

given is that astronomy, by nature, is interdisciplinary in that it involves math, other sciences, logic, history, and more. “An integrated course” is given as all or part of a response in a full one-third of all the Nature of the Course responses.

The second largest defense theme is “Defending with student interest.” The most common sub-theme is “students are interested in astronomy, often more than for any other science, so we should teach it,” and it was given by 53% of those teachers providing responses that fell within the scope of this theme of defense.

Closely following is the theme of “Defending the course with its cultural linkages.” This defense mechanism utilizes historical, sociological, and philosophical arguments and intangible connections that astronomy has with human thoughts and societies. A common sub-theme is that astronomy teaches students about their place in the universe and about the wonder of it all. The historical argument that astronomy is the first science or the foundational science is listed frequently. More tangible linkages include ways that astronomy is part of everyday life, for example, as cultural myths, the origin of the calendar, and so on.

The next largest theme is “Astronomy helps improve students, school, and AYP measures.” This

uses the defense that astronomy helps schools meet state standards, helps students pass state end-of-course and school graduation tests, and provides alternatives for students who have difficulties passing the biology, chemistry, and physics course sequence.

The last two themes are less common and roughly equally proportionate in influence. “Defending the course with traits of the science” utilizes the arguments that astronomy is physically and mentally more accessible to students and that astronomy is less static than other sciences. “The Institutional Defense” promotes the idea that astronomy courses help the school’s image and economics. Finally, there are responses that do not fit any of the stated defenses, including a few unique defense strategies that will not be discussed here.

In order that other astronomy instructors may find these useful, a discussion of each defensive argument follows.

Nature of the Course

The most common theme mentioned in the survey that is useful to defend the course from external threats is the argument that astronomy is the most integrated, interdisciplinary, multidisciplinary science course that can be offered. Astronomy involves mathematics, literacy and language,

and other sciences such as chemistry, physics, various life sciences, and geosciences. The argument is given that astronomy is the only capstone course that inherently incorporates all the listed subjects, or at least that it can, if the curriculum is designed to do so. Because a capstone course culminates a sequence, it can also reinforce prior learning.

Requires mastery of all disciplines and integrates these like no other course can. My students learn more history than in some history classes. They use trig to rediscover Kepler's laws as well as analyze many articles about current research. —Teacher in a minority, Needs Improvement, 1.7K student public high school in Georgia.

Astronomy is truly a multi-disciplinary course in which the different sciences may be blended, but also one in which students may see direct application of other course content as well. For example, math is obviously required, but government policy/legislation with respect to aerospace expenditures, aerospace spinoffs that help solve Earth-bound problems, ELA communication of important findings and discoveries to the general public, understanding the environment by working to create closed ecosystems for colonization, etc., etc., etc. Beyond all this, it is a wonderful venue for teaching problem-solving skills because space exploration is still in its infancy. —First year teacher of astronomy in a large 2.8K public high school in Texas.

Astronomy at the high school level should now integrate many other areas of science and mathematics. We can now do comparative

geologies, meteorologies, and possibly some day comparative biologies to better understand our Earth's systems. —Teacher in a 500-student Wisconsin public school.

When all of the reasons given for the lack of direct effect on the course by NCLB are examined, it is found that, currently, astronomy hangs on primarily as a capstone course that is offered only to seniors or upper division students who have essentially passed all NCLB-created hurdles, such as graduation requirements and mandated end-of-course tests.

Knowledge about the universe has changed rapidly over recent years. Consequently, the content and textbooks used in early science classes are likely to no longer be current, and the high school course may be the last chance that the education system has to correct misconceptions gained in elementary and middle schools.

Astronomy courses can incorporate many science and inquiry skills. Depending on the curriculum design, these courses can be taught from a very descriptive, low-math perspective or one that incorporates higher-level physics and math.

Astronomy has no academic level restriction.

The course was taught in an inner city school with students that had low math skills and generally were

not science kids (not also enrolled in courses like AP chem or AP Physics), yet this course got them excited and enthusiastic about science. Kids joined the astronomy club and were INTERESTED! This is/was very uncommon for the school, and definitely encouraged many minority and minority female students to take a science class and join a science club. —Former teacher from a high minority, Connecticut, 1.2K-student public high school.

Astronomy courses can be directly and concretely beneficial. For example, a Washington-state teacher made arrangements for transferable college credit. She wrote "they can get 5 University of Washington credits for taking the course (at a price of \$293) through the UW in the High School Program."

Student Interests

Astronomy courses have interest and appeal among students. Representative comments include:

- "Many students are interested in Astronomy and it therefore is an excellent medium for teaching fundamental science principals (i.e., science inquiry, nature of science, etc.)"
- "Students enjoy the course; it is sometimes the only advanced science course some students take;"

Because of this attraction, some surveyed teachers found students that normally resist science voluntarily take their class; others also found that astronomy changed students' attitudes by drawing them into the field of science and even to causing them to become scientists. Student interest in

astronomy also benefits the teacher by increasing or maintaining enrollments or keeping the course on the schedule. Additionally, the success in college of prior astronomy students is considered another top defense argument.

Cultural Linkages

Astronomy is a part of every culture, not just Western. There are sky legends from other cultures, the calendar, the way things are named for celestial objects, and more everyday connections to students' lives and backgrounds.

Astronomy also has direct relevancy to modern society. While the subject matter, unlike chemistry, physics, or earth science, may be physically distant from the students, it is still relevant to their everyday lives.

As one of the oldest sciences, astronomy has influenced our lives through use of calendars, vocabulary, and the scientific thought process. Most recently, the 'demotion' of Pluto to a dwarf planet has engendered much discussion about how science changes as improved technology brings new information to us. —Teacher in a 1K student public school in Massachusetts.

Helping with AYP Issues

With science possibly becoming a factor in determining AYP status, teachers have noted schools seem to be seeking more options.

Astronomy as an elective provides an interesting and exciting 4th year of science. Students will opt out of science if it isn't something they are interested in. —Teacher at a AYP Passing tiny 150-student Arizona public high school.

An appropriately designed astronomy course will meet a variety of states' standards and national ones as well.

Honors Astronomy involves all of the important skills that virtually all state and national teaching standards emphasize: critical thinking, application of math and computer skills, project-based learning, development of presentation skills. —Grades 10-12 astronomy course teacher at a high minority, 1.8K student Passing California public school.

We use a variety of technology (telescopes, CCD imagers, computers) and software (Hands-On-Universe, Adobe Photoshop, TheSky, Starry Night Pro) to aid the state mandate to make sure all students are technologically literate. —Teacher at a Failing school in West Virginia.

It can even substitute for some of the regular science courses; it does so in at least two states: New Mexico and Wyoming.

Administrators should find astronomy helps raise test scores in science. We note that no state reported having astronomy end-of-course tests, but many astronomy concepts do appear in other tests, including some national ones.

Kentucky's Core Content has a subsection based on astronomy. According to KSTA, the lowest scores in the state deal with the universe's formation. Since our state's test is one the engines that drives this train here at [deleted school name] this fact will always make a good case for my astronomy class. —Teacher at a 1.4K student Passing public high school.

Furthermore, AYP status depends on language arts, and astronomy can play a role in that as when "the students are required to produce research papers and other analytic essays," as exemplified by a teacher in a small Pennsylvania school.

One of the most common reasons astronomy courses are able to avoid deleterious effects is the frequency with which they are offered as capstones for seniors who have already completed the courses that are directly examined for AYP status.

Institutional Benefits

Good public relations is always a positive reason to have a course.

[When the Oregon Department of Education said schools ranked an "F" for astronomy in the state,] Our Superintendent immediately told the press/ public about our thriving Astronomy courses and his commitment to continue to teach this relevant and stimulating course. —Teacher at an Oregon public high school.

The existence of an astronomy course can be attention getting to school-shopping parents.

As a selling point to prospective students/parents. Few other schools are doing astro. —A Georgia 400-student private school teacher.

In a strictly economic sense, a very common response from one particular group of teachers—those with planetariums—is that such an

expensive resource should not be wasted.

The Science Itself

Many teachers believe that astronomy is more accessible to student minds than other sciences.

Also its one of the few courses that you can learn something that day and use that knowlege that night. —Teacher at a 1000-student, Minnesota public high school.

Astronomy is the rare science in which amateurs do make significant, valid, and valuable contributions, and this can be a real jumpstart to a college career. Students can actually contribute original research—some have discovered new asteroids, for example—to astronomy, and this allows high school students to feel an ownership of the material.

This course gives students an opportunity to contribute to the school and astronomy research. Many of my students are non-athletes who really love astronomy. They are involved in several reseach programs through NASA and get their observations publicized frequently. They have the same pride in contributing to astronomy as athletes do in sports. —Teacher at a small, 400-student Kansas public high school, with a portable planetarium and an observatory.

Conclusions

Most teachers of astronomy in American high schools claim not to have been directly affected by the No Child Left Behind Act but do say they have suffered indirectly and negatively, notably by effects of the Passing or Failing of math and language arts high stakes testing and

an emphasis on moving more students into biology, chemistry, and physics courses which have testable standards. The indirect effects include drops in course enrollment, number of courses offered, cancellation of courses, and redeployment of teachers. Loss of funds, status, and collaboration and professional development are also reported. The only major direct effect appears to be that of meeting the ‘highly qualified’ status, which is difficult to achieve because no state offers teaching certification in astronomy. A few other teachers have allowed NCLB to positively, directly affect their classes by incorporating more math and literacy exercises than before. One of the most common reasons astronomy courses are able to avoid deleterious effects is the frequency with which they are offered as capstones for seniors who have already completed the courses that are directly examined for AYP status. Additionally, in many states (but not all and not always), a lack of state standards means a lack of oversight for the course. However, sometimes that lack of standards means a course is not considered important enough to keep on the schedule, and sometimes astronomy enrollment increases only because the course is made into an alternative source of science credits for students who have difficulty passing the mandated courses.

Astronomy, if it exists, is usually in an AYP Passing school or Needs Improvement school, and schools offering astronomy are often larger than average in student body size. Furthermore, schools with astronomy generally have higher Pass and Needs Improvement status rates than the nation as a whole.

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Appendix A: Survey Procedure

The courses' teachers were gathered from announcements in such venues as the email mailing lists/discussion groups or print newsletters of astronomy and science educational associations, including the National Science Teachers Association (NSTA), the American Association of Physics Teachers (AAPT), the Astronomical Society of the Pacific (ASP), and the American Astronomical Society (AAS), as well as state and regional association discussion groups for physics, earth science, and general science teachers. Also used were other discussion mailing lists that have interested astronomy teachers, such as Dome-L for planetarium teachers,

the 200,000-subscriber newsletter for the "Starry Night" software program, and the newsletter for StarLab portable planetarium operators. Several state science coordinators and educators who work with astronomy teachers passed along our invitation in their own media, including their own discussion or 'news broadcast' lists. The "science brokers" at NASA, who work with teachers and maintained contact lists were of enormous help (sadly, after our study, the "science brokers" program was terminated). Additionally, educational personnel associated with NASA-operated missions, such as Cassini, broadcast our appeal for qualified survey respondents to the larger community, as did national observatories and other programs, including SETI and NRAO.

The teachers gathered by these means were labeled our 'hot' group, because they volunteered to take part. A voluntary response group is not necessarily the best research design, because there may be other factors at play, such as extreme views or overwillingness that may not be representative of the whole population. To counteract the non-probabilistic 'hot' group, a more randomly selected sample, which is labeled the 'cold' group, was created. These teachers were invited through our direct email solicitation. Their names and contact information were obtained

primarily either by lists given to us from personnel at astronomy-related conferences, publishers, some state departments of education, or private individuals who volunteered names. Names were also amassed through searches on the Internet, which yielded lists of planetariums and high school astronomy clubs obtained from the *Sky and Telescope* magazine website, the International Planetarian Society *Directory* (IPS, 2005), and several American regional planetarium groups. Finally, snowball sampling—having responders recommend other people to survey—was also used.

The spring 2007 survey started with over 600 names, evenly split between 'hot' and 'cold' groups. The 237 usable responses included seventy from the 'cold' group, which resulted in a response rate of about 24%. The 'hot' group responded at a 60% rate. The second, printed postal survey took place in the Fall of 2007. Participants were acquired via a 2176-piece postal mailing using primarily a mailing list from the National Registry of Teachers plus about 600 names and addresses acquired in the spring without email addresses. Eighty-five percent responded by sending the survey back via a prepaid, pre-addressed envelope, the remainder answered using a Web questionnaire as in the first survey. Response numerically was half as much as the Spring survey but proportionally much smaller.

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).

Students come to the classroom with different skills, ways of thinking, and learning styles.

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 eighth 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 than 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.

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.

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 in-

service 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).

Because science is a social endeavor, it involves consensus building, peer review, and communication in many forms.

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.

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Impact of Inquiry-Based Professional Development on Core Conceptions and Teaching Practices: A Case Study

This case study focused on changes in teachers' core conceptions and the translation of such changes to classroom practices needed to enhance students' science learning experiences.

Introduction

Teaching science through inquiry-based, student-centered instructional methods has been consistently emphasized by science education reform documents such as the National Research Council's (NRC, 1996) *National Science Education Standards* (NSES), and practically all states have adopted inquiry standards. The NSES emphasize inquiry as a content to be learned and a way to learn science. In treating inquiry as a content, the NSES encourage students' participation in activities and learning opportunities that allow them to experience the process of scientific inquiry by posing questions, developing and carrying out experiments, gathering and analyzing results, and communicating findings with their peers. Through this process, they also gain a better understanding of the nature of science and the importance of collaboration and communication in science.

As an approach to teaching and learning science, inquiry-oriented instruction, based on the constructivist theory of learning, emphasizes the active role of students in the learning process. In this model, teachers must pay attention to and access students'

prior understanding and experiences, which, in turn, should shape the direction of instruction. Furthermore, teachers need to guide and facilitate the learning experience by allowing students to take an active role in their learning and construct their own understanding through first-hand experience, discourse, and reflection. Assessment plays a critical role in an inquiry-based classroom, because it can help in diagnosing students' prior knowledge, gauging students' understanding throughout the learning experience and guiding instruction, and measuring their understanding and knowledge at the completion of the learning experience.

In order for science education reforms to succeed, it is necessary for teachers to be familiar with and utilize inquiry-based practices in their classrooms; however, this is not the case in many classrooms around the country (Weiss, Pasley, Smith, Banilower, & Heck, 2003). Although, there may be numerous explanations to account for this unfortunate phenomenon, one of the most important reasons to recognize and address is teachers' lack of familiarity with and inability to effectively employ inquiry-

based instructional methods in their classrooms. Inquiry-based teaching is simply an abstract idea to teachers who never encountered this type of teaching during their own K-16 education and did not learn to teach in this fashion as part of their teacher education training. Prior studies (e.g. Cronin-Jones, 1991; Hashweh, 1996; Keys & Bryan, 2001; Thompson & Zeuli, 1999; Wallace & Kang, 2005) have indicated that teachers' knowledge and beliefs about (1) science, (2) the learning process, (3) their students, and (4) effective teaching influence their classroom instructional practices. Hence, it is evident that instigating changes in teachers' classroom practices requires a transformation in their beliefs and understanding with regard to the abovementioned areas. Literature on professional development (PD) suggests that such changes, especially improving teachers' understanding of how science operates and use of inquiry-based teaching techniques, can be achieved through effective professional development programs (Bazler, 1991; Caton, Brewer, & Brown, 2000).

Professional development as a tool to enhance teaching is especially

stressed in science education reform documents (e.g. NSES) that emphasize inquiry teaching; however, as suggested by prior studies, not all professional development experiences can be defined as successful and fruitful. For instance, Hawley and Valli (1999) propose that short PD models that simply “teach” teachers how to teach through lecture rather than involving them as active participants in the process fail to be effective. It is recommended that PD programs be directed more by the participating teachers and based on teachers’ long-term reflections of their own conceptions and practices. Professional development programs should model inquiry-based instruction and allow teachers opportunities to experience science inquiry in an active, collaborative setting and through authentic inquiry research (Loucks-Horsley et al., 2003; Thompson & Zeuli, 1999).

Beginning in 2003, one such professional development program has allowed high school science teachers in a particular Midwestern state to have opportunities to experience science inquiry first-hand and learn about inquiry-based teaching. Several studies have focused on the participants completing this program (Bonner, Lotter, & Harwood, 2004; Lotter, Harwood, & Bonner, 2007). The case-study research by Lotter, et al. (2007) involving the three high school science teachers who participated in a two-week inquiry-based professional development workshop reported on the type and degree of change in four core conceptions: conceptions of science, conceptions of students and student learning, conceptions of effective teaching practices (esp. inquiry), and conceptions about the purpose of education (esp. science

education). It also indicated that the type and amount of inquiry instruction performed in the classrooms were both positively and negatively influenced by the participating teachers’ core conceptions. Furthermore, these findings alluded to internal and external constraints that impeded participating teachers’ implementation of inquiry-based instruction in their classrooms. Some of the key constraints, previously mentioned by Tobin and McRobbie (1996), include a perceived lack of time, the need to prepare students for state exams, and the need to cover all of the material mandated by state standards or school districts.

Purpose

The above case study focused on changes in teachers’ core conceptions and the translation of such changes to classroom practices with regard to only one specific course for each participant. The instructional practices of the study’s three cases and the core conceptions that were found to influence their instruction fell into three categories: 1) teacher-guided inquiry and few instructional changes, 2) real world inquiry-based units and reflective teaching, and 3) controlled inquiry and cautious change. It would be valuable to extend these findings by exploring other program participants’ core conceptions and instructional practices and whether they fit any of the mentioned categories. The current study focuses on a participant attending the same professional development program two years later whose teaching assignments included three different courses. The aim of the study is to explore the changes in the core conceptions and instructional practices of this teacher with regard to all three courses. Furthermore, factors that aid or inhibit the implementation

of inquiry-based teaching in these different courses are examined.

Methodology

Context of Study

Beginning in 2003, a group of science and science education faculty at a large Midwestern university took part in a collaborative effort aimed at improving K-16 science education. One component of this multi-tiered project, which was funded by a Howard Hughes Medical Institute grant, included an inquiry-oriented professional development (PD) for high-school science teachers from across the state. The PD consisted of a two-week summer workshop and three follow-up workshops during the academic year. The summer workshop was divided into morning and afternoon sessions. In the morning sessions, participants actively participated in a variety of inquiry oriented activities and discussions. The first week was devoted to teachers developing a 7-step plan aimed at solving their students’ “bottlenecks,” which refer to concepts that students have difficulty comprehending (Bonner, et al., 2004; Lotter, et al., 2006). Teachers then developed inquiry-based lessons to address their selected bottlenecks. During the second week, each participant presented their inquiry-based lesson to the rest of the group followed by a discussion in which facilitators and other participants provided feedback on the lessons and ideas about ways to improve them. Each day, participants completed readings on topics addressed in the workshop and reflected on the workshop activities as well as their own learning and beliefs. The afternoon sessions allowed teachers to work in authentic settings alongside

assigned science faculty conducting research in biology, chemistry, or physics. Participants also completed daily reflections on their experiences in the labs.

Research Design

The current study is part of a larger, ongoing study exploring the experiences of the science teachers participating in these annual workshops. Since the aim of this study is to better understand the experiences, changes in conceptions and practices, and factors influencing classroom practices of one particular teacher, a qualitative case study approach was deemed most appropriate. This approach allows for in-depth examination of data from various sources in order to provide a rich and holistic description and picture of the particular case (Merriam, 1988). These data sources included: a brief questionnaire on participants' views and instructional practices both before the workshop and during the instructional year, field observations in all three classes several times a week for a period of four weeks during the following academic year, and a semi-structured interview and several informal conversations during the observation period.

Sample

The case in focus, referred to as Seth from this point forward, was a high school science teacher in the same town as the university in which the summer workshops were held. Seth, who had been teaching for 17 years, received his undergraduate degree in geology and completed an M.A.T program majoring in biology. He was teaching College Preparatory Biology (i.e. regular biology), Life Science (remedial, lower level course), and Advanced Environmental Science

(Junior/Senior level course) in a school that was one of the few in the state to receive a distinguished Great Schools rating of 8 out of 10. The school has slightly over 1500 students, 83% of whom are white, 6% black, 4% Asian/Pacific Islander, and 2% Hispanic with 21% of the student body eligible for free/reduced lunch. The school enjoys above state average math and English scores. The classes are arranged in a Block 8 schedule with four 85 minute classes alternating every other day. Seth taught two biology and an advanced environmental science class on one day and one biology and two lower level life science classes the next day with each class consisting of 22-27 students. Seth's proximity to the University and the number of different types of courses taught were the main reasons that he was selected for this study.

Data Analysis

Interview data were analyzed using the constant comparative method (Glaser & Strauss, 1967; Denzin & Lincoln, 2000) to identify themes regarding Seth's four core conceptions as identified by Lotter, et al. (2007) and factors that influence the implementation of inquiry-based instruction. Observation logs were analyzed in order to document emergent patterns regarding Seth's instructional practices in the three courses. The process of analyzing the data involved several iterations of reading and coding as well as discussion of themes between the authors to identify patterns.

Findings and Discussion

The following sections describe 1) changes in Seth's core conceptions, 2) changes in his instructional practices, 3) factors that augmented

the implementation of inquiry-based teaching in his classroom, and 4) factors that impeded such instruction.

Conception of Science

Seth explained that, although a few of his M.A.T courses had addressed the nature of science to some degree, he had continued to view science mainly as a body of facts about the world around us. He further explained that his own experiences with learning and teaching science had left him thinking about science mainly as terminology, facts, equations, and theories he had memorized or learned superficially, and he admitted that this influenced his actions in the classroom. His main focus had always been on science as a content to be mastered. However, upon completion of the summer PD, he began to view science as more than just facts and unrelated content as described in the following quote:

I had always known that science was more than just facts, but the classes I have attended and those I taught have caused me to lose touch with many important aspects of science and to overlook them in my teaching. In my classes, facts and terminology were always emphasized, but now I see, and try to help my students see, that science is more than that. It is really about posing questions and solving problems. It is about thinking critically and trying different things and being active in the pursuit of answering questions.

Furthermore, Seth's understanding of the scientific process expanded from a simplistic, unrealistic scientific method to a more cyclical and integrated model of inquiry that involves continued iterations of posing

questions, making observations, collecting and gathering data, and analyzing and communicating results. Seth explained that he had always begun his courses by introducing the scientific method and followed that specific protocol in the few labs his students would do in class. He emphasized that, although students' thinking was of great value to him, he had, up to that point, mainly done cookbook confirmation type of labs that allowed little room for obtaining a unique answer. Seth explained:

Up to last year, my students probably could all tell you the steps of the scientific method. Sometimes I would see some of them struggle with the order of the steps or become frustrated because they did not get the "correct" answer. But now I think back, and I see that students can arrive at solutions to problems in different ways. (Pause) I had taken out the creative and imaginative aspect of science. Even though I had asked my students to always base their conclusions on evidence, I had invariably pushed them to come up with the results that confirm what I had taught them. Now I want my students to think outside the box. I want them to be able to not be scared to state that their results were inconclusive or that their results do not support their original predictions. It is still difficult for them to do that because they are not used to it, but at least now I find myself pushing for that mindset.

This indicates that after the PD, Seth had a more enhanced understanding of the nature of science and the process of scientific inquiry. As a result of PD discussions about the inaccuracy of a rigid and linear model of science

inquiry and the idea of the scientific process as fluid because each step may lead to further questions, observations, and experiments, Seth replaced his conception of the scientific method as an inflexible set of rules with a cyclical model of scientific inquiry. These changes make Seth's conceptions of science more consistent with ideas presented in science education reform documents. However, there were some minor inconsistencies in his responses that should be mentioned. Although he indicated understanding science as more than content and the importance of science process skills, he added that this was not the case in all his classes. For example, he explained that in his College Preparatory (CP) biology course he could not and did not emphasize the more accurate depictions of the nature of science and how science is done as much as in his environmental science course. He pointed to the continued importance of presenting facts and content information in that class in order to prepare students for the state exam and college. He further described the current structure of the life science course as also inconsistent with some of the changes he had mentioned. He added that he found it difficult to portray an accurate depiction of the nature and processes of science to these students, because he had not yet incorporated much change into the techniques used for this class.

Conceptions of Students

Similar to his beliefs about science, Seth's conceptions of students also underwent change as a result of the summer PD. Seth admitted that, prior to the PD, he did not take into consideration the unique needs of every group of students and taught all of his classes in the same way without

regard for the diversity of learners in his classroom. Because he had always emphasized science as facts and content to absorb and put to memory, he had not paid attention to differences in his students' abilities, learning style preferences, prior experiences, and processes of cognition. As described in the post-PD interview, he began to view students as an important variable in the equation.

I have come to realize that students are not "blank slates" to be injected with information. They come to my classes with different abilities, experiences, and levels of understanding which I need to acknowledge in my teaching. I have also come to realize how important their prior understanding and experiences are, not only to themselves, but to others in class. There have been so many instances where they have shared something that has been valuable to our class discussions and lessons. Instead of saying 'here is something new, let's learn about it', it's like 'what do we already know about this?' So it is more of an *immediate connection* to their own experiences.

He continued to explain that "students in the regular and higher level courses are capable learners who should be actively involved in their own learning and given the freedom to explore their own questions and discover content for themselves with teacher guidance." Here again, a slight point of conflict in his views was seen as he proceeded to comment: "Of course, students in the lower level classes may be able to do so too but need to be guided more and should be given the tasks to complete and the instructions to follow, because they may have difficulty otherwise." Seth indicated a lack of trust in these

students' abilities and a hesitancy to allow them more autonomy in their learning.

Conceptions of Effective Teaching

Seth's new understanding about the role of students in the learning process partly describes his newly formed beliefs about effective teaching. In reference to his old teaching methods, he described himself as "a usual lecturer with frequent worksheets and occasional labs and hands-on experience." When asked about his post-PD views on effective science instruction, he displayed plenty of enthusiasm for the inquiry-based method of instruction and mentioned that he had strayed away from traditional methods.

He also mentioned the importance of "incorporating inquiry opportunities for students to pose questions and investigate them and use science process skills and problem solving skills in order to discover more about various class topics." He placed emphasis on engaging students in the learning process by making learning personal and capturing their attention and interest early in the process. The following quote from one of the informal conversations further clarifies the change in his beliefs regarding effective teaching:

Making it personal and relevant and capturing students' attention, (pause) that was something that was modeled in a lot of the workshop sessions. Let's say we have a demo, what do we know about what's going on here? So trying to pull out from them the knowledge and you can guide that and add things to it and it becomes a teachable moment based on something they already know instead of saying 'here you

go, here is some knowledge'—I think it is more engaging to them, immediately captures their interest, makes it more personal.

He also added:

I think it's basically getting students involved in coming up with their own questions and directing their own learning and engage them more in the process of the lesson. I think that is most valuable. One aspect that I most like about it is the gathering of common knowledge, in a group. Students find that exciting and empowering a lot of times.

He continued with his emphasis on the importance of engaging students in the learning and the "mind capture" approach, as it had been referred to in the workshops. It was also clear that, in his revised view, lectures played a less important role and were to be limited to discussions that should *follow* active exploration of concepts rather than *preceding* them.

Capturing their interest is very important, (pause) get them excited about the lesson instead of just me saying, 'here, we are going to lecture on a topic and then now we are going to do a lab on it'. I had always tried to introduce an idea and then do a lab. This PD has kind of changed my idea a little bit (pause) pose a question and have the problem present itself, then do the lab, and then discuss the concept at the end"

Furthermore, he viewed inquiry-based teaching as an investigative approach and defined any learning activity in which "groups of students work as collaborative teams to explore and think through problems" as inquiry. He continued: "In an inquiry-based

classroom, students may be presented a problem or an action and be asked to figure out why." The PD workshops heavily emphasized that this type of inquiry could occur outside the walls of the laboratory.

Conception of purpose of learning

The final category of beliefs examined in this study was views about the purpose of learning. In response to questions related to the purpose of learning, Seth described how the PD had "opened my eyes" to realize how in the past he had "incorrectly viewed the purpose of teaching to be for students to gain knowledge that they can use in their future classes and careers they pursue" without much attention to anything besides content. He stated that "scientific critical thinking and problem solving are the two most important goals of science education" and added that possessing these two capabilities "applies to every student's daily life and will continue to be used in adulthood, regardless of direct involvement in science." He emphasized the importance of giving students the opportunity to "learn to do science and think in a way that scientists think—like looking at data and interpreting them without help . . . to get to a point where they make those judgment calls." Finally, Seth made a comment regarding his CP biology course that indicated he had not yet completely abandoned some of his previous ideas. He described his CP biology course as more content-driven because of the "standards and the state test." He added that it is important that "students come away from that class with knowledge of certain vocabulary, processes, and concepts that they will encounter in their lives, college, or on the state exam."

Classroom practice

The second research question is concerned with the ways in which Seth's four core conceptions translate into teaching practices in the classroom. Field observation and interview data were used to provide a rich description of his classroom practice and evaluate the extent to which his instruction was aligned with science education reform initiatives that call for inquiry-based teaching. When asked about his teaching practices since the PD, he described a continuous process of reflecting on his instruction and modifying lessons and activities to make them more inquiry-based and student-centered. He stated: "Since the workshops, I find myself constantly thinking about changes. As a teacher, I am looking at everything so differently now." Seth indicated that although unable to create changes in every aspect of his teaching or re-do everything he had done so far, he was attempting changes and thinking about aspects he might handle differently in the near future.

I can't do it (inquiry) everyday, especially with three different classes that I need to teach, but whenever I am really rethinking a lesson that's always in the back of my mind 'how can I do this in a more inquiry manner'?

Observing Seth's classrooms clarified several items. First, the rethinking and tweaking of lessons and activities Seth had mentioned were indeed occurring. Second, there were noticeable differences in Seth's instructional practices, including the incorporation of inquiry-based teaching techniques in the three classes which will be described below. The Advanced Environmental Science course, based

on Seth's own accounts and the classroom observation data, was the most inquiry-based class. Students often worked collaboratively in teams. Seth's lectures had been replaced with class discussions, video presentations, and team presentations. Students participated in projects and long-term experiments rather than occasional, brief, cookbook labs, which had been the case previously. One example of a long-term investigation that had been introduced after the PD involved the study of lemna. In previous years, Seth had merely discussed and lectured about population growth, and then the class reproduced a simple lemna population growth laboratory exercise out of the textbook. However, this year, he turned this one-time cookbook lab into a year-long investigation that spanned two semesters and addressed other topics besides population growth, including ecosystems. His description of the project follows:

This year I wanted to do something different and thought the lemna project might be the best route. First semester we explored the population growth of lemna in a more guided inquiry where I was still the one directing students' attention to the question and gave them some directions for the investigation and data collection. But they were really into it. We were able to address not only population growth but also how to make data tables and show data on graphs. It was very successful! We got some of the best growth curves I have ever seen. Then this semester I thought it would be cool to continue with the lemna population activity and allow my students more freedom this time around. So I used the previous project as a baseline study and

had my students think about how the introduction of various things into the environment might effect the population growth of lemna. It has been great! They have really surprised me.

Classroom observations coincided with the last week of the open-inquiry lemna investigation. Students were seen walking into the classroom and going straight to their stations to check on their lemna population and collect data. This time was also used to carry out routine procedures such as adding more of the "contaminant", checking temperature, and adding water. Each team was doing something different in accordance with their investigation design. Seth circulated around the classroom and observed teams at work. Occasionally, he would ask members of a particular team questions about their protocol, observations, or other matters relevant to their study. When in need of guidance, the teams would ask him questions as he listened carefully and in return Seth asked further questions to guide the students, rather than giving them the answers. Seth described his role in the classroom as such:

It (lemna activity) is an ongoing activity. So at the beginning of each class I wander around as they collect data and solve problems like 'our lemna died what we do?' I try to get them to think and redirect questions. 'OK what should we do?' They pose ideas such as 'mess w/ the concentrations? Let's try with half and see what happens?' So it takes some thinking on your part and not giving them the answer but drawing it out of them.

After their initial period of observation and data collection,

students returned to their seats and had a brief chance to discuss their findings and possible next steps with their teams. Seth continued to facilitate discussions. Afterwards, he asked them to begin thinking about how to analyze their data and present their findings to the class. Students worked in their teams to draw graphs, check journal articles for prior studies similar to their own, and discuss conclusions and the implications of their study. Several days were spent on this phase of the project, and then several class sessions were devoted to presentations of the individual projects. Each presentation was followed with a question and answer session in which the audience would pose questions or make suggestions for improving the study, and this would develop into whole class discussions on the implications of the findings. This project was extremely student-driven and engaging. Students were constantly active in exploration, discussion, analysis of data, collaboration, and communication.

Seth also described another project he had developed for this course that had taken place prior to the observation period. He had reflected on and modified the recipe-type forest density lab and created a more student-centered investigation of the successional stages of trees. He describes the forest ecology investigation in this way:

I had always done the lab in the book, and, although students used to have fun going outside and looking at the trees, I did not think they were thinking much (pause). This time we went out there, and we said ‘ok let’s pose a problem—how can we figure out what’s going on here? Who are the dominant species?’ Got some of their ideas, we came back

and talked and shared those ideas and came up with pros and cons of each. Came up with ideas that were pretty similar to what we’ve done in the past, but I felt this year they had a better understanding of what they were doing—whereas in the past they were plugging in numbers into equations and not really understanding what those equations were.

It was evident from the interview and observation data that the most changes had occurred in this class. Seth described his interest in making learning relevant to students and allowing them to experience science firsthand. He also described courses such as environmental science as his “favorite” and “ideal,” because they gave him plenty of flexibility to teach in this fashion.

My ideal classroom would be outside. In some ways my environmental science I tried to make my ideal class. Part of it is because there are not set standard. I try to take them outside and with field trips and look at local resources and ecosystems to make it more applicable and conducive to their lives.

In his biology classrooms, the tweaking and slow process of change and reflection he referred to in his interview were evident during the observation period as well. This class consisted of some inquiry-oriented activities, but Seth mentioned that he had not yet dramatically changed any lab, activity, or unit in this classroom. When asked why he had not yet taken steps to modify this class in the same manner as the advanced environmental science course, he identified the quantity of content material that

needed to be covered as the chief factor preventing the more immediate implementation of change.

With bio you need to cover. So much of it is just vocabulary and the concepts behind the vocab. There is a time limit. Not easy to do long-term experiments. You feel like you *have* to cruise through the material/units quickly, so you have to modify the inquiry.

This is not to say that he did not reflect on or change his instruction at all. Instead of large, sweeping changes, Seth had resorted to changing small components of the course, such as doing more class discussions in place of lectures, using attention-grabbing demonstrations or discrepant events, posing problems to engage students in the learning, and asking more questions during activities and class discussion. As he put it, “a lot of it is not changing the lab, but how I *present* the lesson and the topic—for example, brainstorm before we start. Regular lesson, but *they* introduce it.” Although there were greater instances of teacher-directed instruction in this class, Seth attempted to maintain his facilitator role during student activities. He also gave students the opportunity to share and discuss the results of the labs and activities instead of simply doing the activities and moving on.

As for Seth’s third course, there were little to no changes in the life science classes. There was little inquiry-based learning occurring in this class, and it continued to be dominated by teacher-led lectures, occasional cookbook labs, worksheets, and bookwork. When asked about the life science course, Seth explained that he had spent the least amount of time changing that course. Since the workshops, he found

himself thinking about his teaching mainly in the other two courses. He continued: “maybe it is because I am used to using the set activities from before that are shared with the other instructor teaching the same course.” Other possible reasons for the lack of change in this course will be described in a subsequent section.

Seth had, however, included some demonstrations to catch students’ attention and interest. For example, when discussing osmosis and diffusion, he did a demo that involved placing an egg in three different solutions: water, vinegar, and corn syrup. He also occasionally utilized video clips of Bill Nye the Science Guy and other educational videos to partially replace his lectures. However, there was little change in terms of the students’ role in the learning process. They continued to play a passive role in the learning process in that they were most often observed listening to Seth, watching videos, and taking notes. They did work in teams for their labs, but this teamwork did not involve much collaboration or communication, and the conversations that did occur were usually about procedural details. There were hardly any discussions of the steps being carried out or the data gathered. Collaboration was not extensive; in most teams there were some students who were participating less than others. Collaboration was limited to following prepared steps, reading out loud the instructions, copying down the data, and cleaning up. There were few or no questions for students to think about and discuss to guide their learning. Seth did try to facilitate team discussions, but these were limited to procedures and observations. A significant portion of the teams’ results were confirmatory

of his lectures and the textbook information. As a result, students often simply repeated his statements or regurgitated information from the textbook.

One such example occurred when students looked at some slides of cells under the microscope. This lab was prefaced with reading the textbook section on cells and a lengthy lecture with transparency slides of plant and animal cells and cell organelles. When students were looking at the slides under the microscope, they simply scribbled a drawing of the slides without much discussion. They were often having off-topic conversations about their personal lives, other classes, and so forth. There was hardly any discussion of their observations, the differences between the types of cells, or the organelles. The only recognizable features of the cells in their drawings were the cell wall, the cell membrane, and the nucleus. In addition, most students copied down a few other lines or shapes that they struggled to label. When Seth approached one of the teams and inquired about their drawings, students began checking their lecture notes in order to point to and name the organelles that they had observed. His conversations with the teams were very limited and brief.

Factors promoting change

Seth was cognizant of the changes that had occurred in his core conceptions and the ways in which that was beginning to take shape in his teaching. He also repeatedly mentioned that his understanding of the processes of teaching and learning, especially inquiry-based instruction, had been enhanced as a result of his participation in the PD.

I just feel very good about the PD. I learned a lot, more than I can describe. It will take me some time to be able to digest all of it and apply it in my classes. Like I said before, I am finding myself thinking about my teaching all the time. I am incorporating some changes here and there, and, even though it may not be much, I have learned so much!

Similar to the participants in the Lotter et al. (2007) study, Seth cited numerous aspects of the PD experience that he had found beneficial to enhancing his understanding. He felt several features of the two-week summer workshops were especially valuable. First, the workshops modeled effective instructional methods rather than just informing participants about them. Seth noted, “It was nice not to be told or trained on what to do but rather shown by the action of the facilitators themselves. It was more powerful that way.” Similarly, he found it immensely useful to be an active participant and experience inquiry-based learning first-hand.

I felt like my students. I was doing things in this workshop rather than being given lots of information. We went out and made observations, we did the inquiry activity with the bread facilitated by the science facilitator, and so forth. I found myself constantly thinking and active. We then put to use the information we had gained about inquiry-based teaching and looked for ways to change one of our current lessons. I could not imagine participating this much and applying my knowledge so quickly.

He also discussed the importance of being in a group of peers and having ample opportunity to discuss ideas with them. He found the large and small group discussions and conversations “very stimulating and encouraging.” Finally, he considered the readings, activities, and discussions regarding the inquiry process especially useful, because “gaining a better understanding of the process of science meant that I would also try to portray science more accurately in my classes and would also try to have my students’ learning mimic inquiry.” He added:

Learning about inquiry-based learning and all the other stuff we learned wouldn’t have made a difference if we had not addressed our misconceptions about the scientific inquiry process first. I used to drill the scientific method into my students’ head. My teaching of science was dry and linear and mimicked the unrealistic scientific method rather than the more accurate model of the inquiry wheel that we learned about.

Seth also discussed the importance of the second portion of the summer workshops, the research experience. He felt it was extremely interesting and valuable to join science research laboratories and to work alongside science faculty and graduate research assistants. He mentioned that he thought the afternoon sessions “complemented the morning activities and discussions” by allowing participants to “see and experience science inquiry first-hand.” He noted the experience equipped him with a better understanding of science content, investigative techniques and equipments, and the process of doing science.

Although I like to stay up to date with information in my field, I found

much of the stuff I experienced in lab very interesting and eye opening. I had no clue about some of the procedures or equipments. It was so different to see these scientists in action and to have some part in their work during that short period of time.

The experience also allowed him to be more cognizant of his students’ experiences in science.

This was a great way for us teachers to step out of the teacher mode and see things from our students’ perspective. At times when I couldn’t understand what was going on around, I could totally sympathize with my students. Do they understand when I am lecturing them or is the information just way beyond them? At other times, I found myself thinking ‘how can I do this in the class’ or ‘how can I apply this to my teaching so that my students get to enjoy their experience and learn from it as I am’.

Finally, he noted the importance of the experience in helping him to better understand the value of working collaboratively and communicating effectively. They were able to “bounce around ideas, share frustrations, and explain things to each other.” He added:

It was great to see the collaboration amongst ourselves and also the scientists that we were observing or working alongside. I used to have my students work in teams but not enough and not effectively. I am hoping I have gained a thing or two in the PD.

At the time of the post-PD interview and class observations, Seth had already participated in one follow-

up workshop. He felt the follow-up session had been necessary. He indicated that going back to the schools and trying to implement the lessons learned in the summer was not an easy process and expressed gratitude for the opportunity to discuss those experiences with his peers. The sharing of lessons and the stories of successes, failures, struggles, and means of coping with the difficulties was cited as extremely valuable. He referred to the significance of feeling a sense of community that allowed members to benefit from sharing experiences, ideas, and feedback.

It was just fabulous. We got a chance to come back and just talk for a while and discuss what we had done and what it had been like. It was amazing some of the similar situations we had experienced. It was also great to share how our lessons went and share other lessons we had come up with.

Seth also found the additional inquiry activities that were modeled in the workshop to be a good refresher of the summer workshop. One such activity Seth referred to was the modeling of the 5E learning cycle that involved investigating the process of burning a candle and factors that affect the rate at which that occurred. Seth added: “The candle activity allowed me to see 5E as a model of inquiry teaching that we had learned about. This process made sense, and I got to understand it even better because I was experiencing it like a student.”

Constraints to inquiry teaching

As noted above, Seth’s views and core conceptions had undergone major changes as a result of the PD, but the implementation of inquiry-based teaching in his classrooms

was not as obvious nor as consistent. During the course of the interview and informal conversations, Seth alluded to several constraints and offered a number of explanations for not incorporating more changes and doing so consistently in the three courses. Figure 1 provides a depiction of the four main factors and explanations: 1) lack of support, 2) lack of time, 3) lack of resources, and 4) lack of flexibility and the interconnections between these four factors.

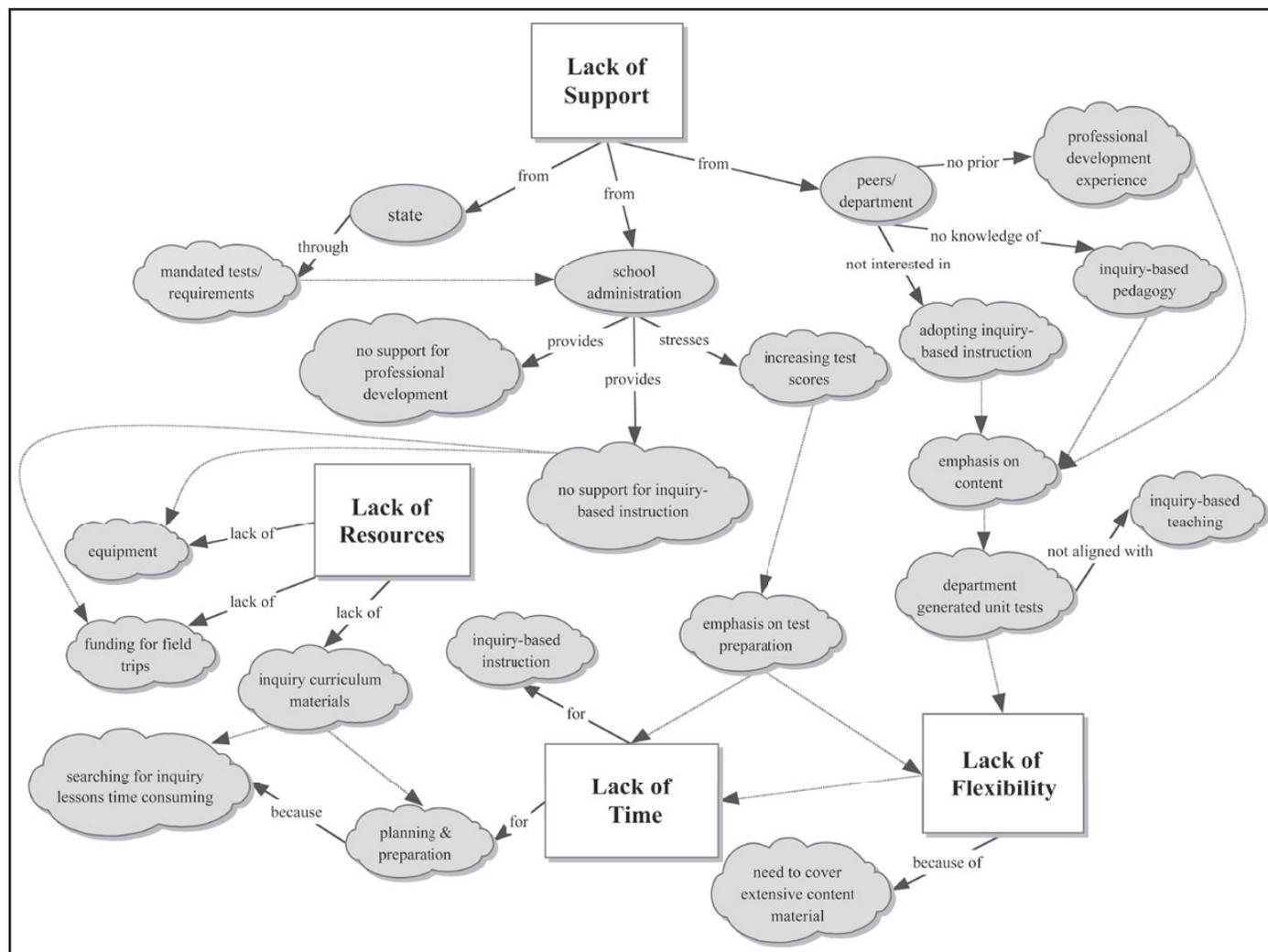
The overarching factor that directly or indirectly influenced many other areas was the lack of support that Seth

described having from his peers, the department, school administrators, and the state. Seth explained that state mandated tests and requirements had caused a series of practices and requirements at the district and school level that inevitably had made teachers, such as Seth, feel a lack of flexibility and autonomy in their classrooms, especially those such as CP biology, which has a state-mandated exit exam. Seth expressed feeling overwhelmed by the amount of content to be covered in the course as well as the need to prepare students for the state test and the end of unit tests that were created

and used jointly by all biology teachers at the school. The inflexibility paired with “a dearth of available inquiry-based curriculum material” caused him to feel as though he had an insufficient amount of time available for both the planning and execution of inquiry-based lessons.

I have tried looking for inquiry lessons to no avail. It is time-consuming and often unproductive. I just do not feel I have the creativity, energy, and the time to do more than a few inquiry-based lessons at a time or bring about more changes than

Figure 1: Four main constraints to implementing inquiry-based teaching



I have. It is just too much to try to do, and I have really tried.

I have to be honest that my lower level bio class is getting the least attention this year as I try to change my teaching. I have a hard time finding the time to change the other two courses, and so I find myself not paying as much attention to changing this class and resort to the old material I already have preplanned. Maybe next year I can spend more time on this course too.

In my bio class, I just try to tweak here and there and do some inquiry whenever I can, but I just feel that it is very hard to do in that class, because I don't have enough time to cover everything. All the biology teachers give the same test at the end of the unit, and, no matter what I do; I need to make sure my students are ready for those tests. There is hardly any time to do long-term projects and investigations.

Besides the lack of resources for planning inquiry-based teaching, there was also a lack of resources for carrying out inquiry-based instruction. For example, microscopes had to be shared by three different classes, other equipment and materials needed for various activities and projects were not available, and there was no funding to purchase such resources or pay for requested field trips.

Even in my environmental science, I feel I could do a whole lot more if I had the funding for purchase of equipment or to fund a field trip or two my students and I have been interested in taking. At least I can take them outside and use the areas around school to explore, but

I really feel the lack of resources in the other two classes.

Finally, Seth felt a sense of isolation and frustration, because he was the only one in his department who had undergone the PD experience, knew about inquiry-based learning, or cared much for it. He felt that he did not have the necessary support from his peers to be able to collaborate and bring about changes on a wider scale to science instruction in the school. This lack of support also led to other issues already mentioned above such as the overemphasis of content and pressure to prepare students for school and state exams.

Conclusions and Implications

This case study provided further support for the need for effective inquiry-based professional development opportunities for teachers in order to bring about the changes in their views and practices needed to enhance students' science learning experiences. As noted in earlier studies (e.g. Huberman, 1995; Lotter et al., 2007), changing teachers' views and instructional practices is a slow and intricate process that is dependent on a variety of factors, as has been illustrated to some degree in this study. Seth's case further demonstrated that professional development experiences should 1) occur over an extended period of time, 2) involve active participation of teachers by immersing them in authentic scientific inquiry, inquiry-based activities, and discussions, 3) model effective inquiry-based instruction, and 4) allow teachers opportunities for continuous reflection on their beliefs and practices during the PD and in their classrooms in

order to identify areas that could be improved upon and implement the necessary revisions. There is also an immense need to provide PD participants the means for continued communication and collaboration in an effort to 1) share ideas and inquiry-based lessons, 2) discuss frustrations, obstacles, and successes faced during the implementation of inquiry-based instruction, and 3) facilitate communal reflection on ways to further enhance students' science learning experiences.

Beyond the PD specific components, Seth's case illustrated numerous additional factors in the school environment that influence the implementation of inquiry-based instruction, and, therefore, require serious consideration. One such factor is the state-mandated tests and requirements that put extra pressure on schools, some of which, as illustrated in the case of Seth, place tremendous emphasis on testing and coverage of content material that allows little flexibility and time to plan and carry out inquiry-based lessons. Additionally, in an effort to increase test scores, little attention is given to professional development for teachers and, the promotion of inquiry-based instruction is virtually nonexistent. Furthermore, science teachers in their department are often instructed to keep their instruction the same, especially in the core courses that students get tested on, and administer the same end of unit exam for all sections of a course. These exams, along with the state mandated tests, often overemphasize content and vocabulary and are often unaligned with inquiry-based instruction that PD participants wish to incorporate in their classrooms.

It is imperative that school administrators realize the power of

inquiry-based learning in enhancing student learning and science experiences. The emphasis on testing and content-driven curricula must be replaced with an emphasis on the augmentation of student learning through experience in order to develop a science literate student population as defined by the NSES (NRC, 1996, p. 22). School administrators must play an active role in encouraging inquiry-based teaching and learning in all aspects of the school by providing teachers with the encouragement and support necessary for participation in professional development and implementation of inquiry-based instruction.

In addition to the lack of flexibility and time for inquiry-based instruction, the scarcity of time available to devote to creating and planning inquiry-based lessons makes achieving these goals extremely challenging. Truly, inquiry-based curriculum materials are scarce, and many teachers, such as Seth, find it difficult, time-consuming, and sometimes unproductive to undertake the process of converting to inquiry-based instruction. The science education community must strive to equip teachers with inquiry-based curriculum materials and aid teachers in finding resources and planning out their own lessons and units. Teachers who participate in PD experiences may find themselves struggling to concomitantly meet school requirements, adopt inquiry-based instruction, and create a community of change within their schools. In order for these teachers to be successful, they must be provided assistance along the way in the form of peer and expert coaching (Fullan & Stiegelbauer, 1991; Thiessen, 1992).

Another underlying issue is the lack of support and the sense of isolation PD teachers feel when they return to their schools and find themselves surrounded by colleagues who may not be familiar with inquiry-based learning or have no interest in non-traditional methods of teaching. Several steps, in addition to continued communication with the PD facilitators, must be taken to alleviate this sense of isolation and helplessness. First, PD facilitators should encourage and assist participants in finding a means of staying in communication with one another upon their return to their schools. This could be done by arranging group meetings or through social networks. Services such as Twitter and Facebook or online discussion forums provide a convenient, low-cost medium through which members can stay abreast of group activities and share lessons, ideas, problems, and so forth. These communities could even be extended to include other teachers, from across the country, who have gone through similar experiences through the formation of critical friends groups. Second, many of the previously mentioned obstacles may be eliminated if PD planners focus on teachers from the same schools or districts so that they are all equipped and better prepared to promote and instigate changes in science instruction once they return to their buildings. Moreover, this will enable these teachers to work collaboratively in planning lessons, creating assessments that are aligned with the curriculum, receiving feedback on their instruction from each other, and discussing issues and obstacles that they may continue to face. Focusing on “communities of

practice” and building a “professional culture” allow for supportive and nurturing environments that are key to the adoption of inquiry-based and effective instructional practices (Loucks-Horsley, et al., 2003, p. 91). If the ultimate goal is to better prepare a science literate citizenry, we must begin our work by not only enhancing the instructional capacity of teachers through effective professional development, but also by calling attention to the culture of the educational institutions to which they return and needs that may arise after the PD experiences.

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F ₂ Cross		
	Black	White
Black	0%	0%
White	14%	22%
Total	14	22

Concentration vs. time

Time (s)	Inside Conc. (%)	Outside Conc. (%)
0	20	5
5	15	7
10	10	10
15	10	10
20	10	10

Waxing gibbous

Time: 9 Days 21 Hours 45 Minutes