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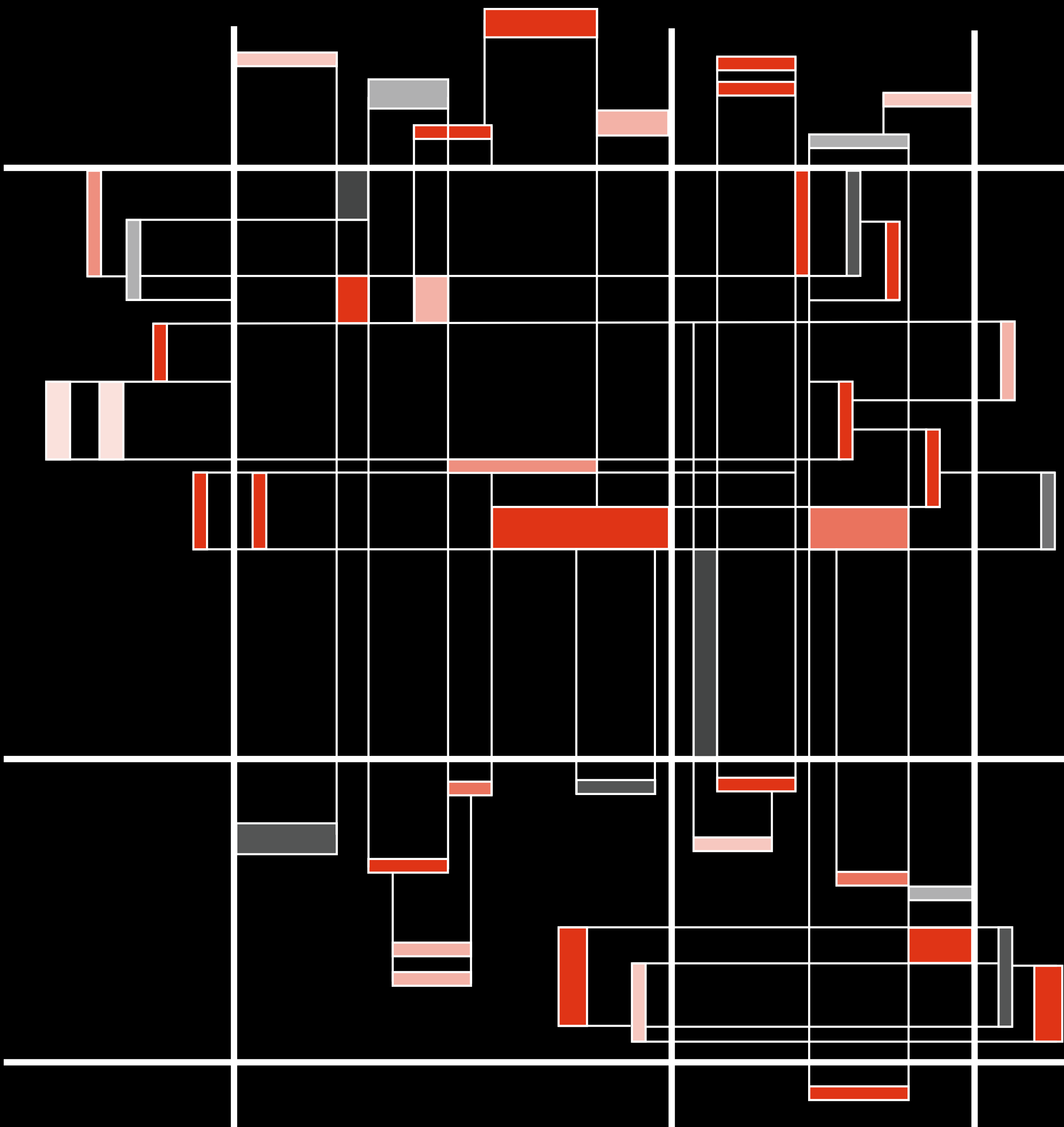

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Rebecca McNall Krall, John E. Christopher, Ronald K. Atwood

Comparison of Central Appalachian In-service Elementary and Middle School Teachers' Understanding of Selected Light and Force and Motion Concepts

This descriptive study investigated whether elementary and middle school teachers in the Central Appalachian region were prepared to teach selected standards-based light, force and motion concepts they could reasonably be expected to teach. The study also sought to compare their preparedness for teaching these concepts.

Basic light concepts and force and motion concepts are integral components of the K-8 national science education standards and frameworks. Specifically, the National Science Education Standards (NSES) (National Research Council [NRC], 1996) for grades K-4 indicate elementary students should understand and apply the concept that light travels in a straight line until it strikes an object. Students at this level should also understand that light can be reflected by a mirror, refracted by a lens, or absorbed by an object. Middle school students are expected to further this understanding of light phenomena by learning that the interaction between light and matter includes the ability to be transmitted, absorbed, reflected, and refracted. They should also understand that in order to see an object, light must be either emitted by an object or reflected by another object, and then, in both cases, the light must enter the eye (NRC, 1996).

The standards statements on position and motion of objects in the NSES (NRC, 1996) indicate that elementary students should be able to describe the position of an object by relating it to another object or background. They should also understand that the position and motion of an object can be changed by pushing or pulling the object, and that the greater the push or pull, the greater the change in the object's motion, and consequently, the greater the displacement of the object from its original position. In middle school, students should be able to demonstrate more advanced knowledge and skills about force and motion, including the abilities to represent an object's motion on a graph, interpret the motion of objects by reading a graph, and recognize the effect forces have on the motion of an object (NRC, 1996). That is, they should understand that forces acting on an object along a straight line can reinforce or cancel out another force, while unbalanced forces acting on a moving object can change the direction and/or speed of the object's motion. Recommendations in the *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science [AAAS], 1994) are similar to those described in the NSES. Looking

The odds are against in-service elementary or middle school science teachers having completed physical science courses that had incorporated contemporary conceptual change theory into their structure.

beyond standards from the United States, the targeted concepts appear to be viewed globally as fundamental to scientific literacy, which is evidenced by their inclusion in the Trends in International Mathematics and Science Study assessments (Beaton, Martine, Mullis, Gonzalez, Smith, & Kelly, 1997)

Previous studies have reported limitations in pre-service and in-service teachers' understanding of light concepts and force and motion concepts.

Much of the research on understanding light phenomena has focused on K-12 students (Crooks & Goldby, 1984; Feher & Rice, 1988; Fetherstonhaugh & Tregust, 1992; Guesne, 1985; Feher, 1990; Piaget, 1974a, 1974b; Ramadas & Driver, 1989; Shapiro, 1994) and college-level students (Goldberg & McDermott, 1986; Huang & Hwang, 1992). Other studies have addressed pre-service elementary teachers' conceptions of light phenomena (Atwood, Christopher, & McNall, 2005; Bendall, Goldberg & Galili, 1993; Feher & Rice, 1987), as well as the conceptions that in-service elementary teachers (Atwood & Christopher, 2004; Greenwood & Scribner-MacLean, 1997; Association for the Education of Teachers in Science [AENTS], 2004a) and middle school science teachers (Trundle, Atwood, & Christopher, 2002) have about the topic. Collectively, these studies document many of the same conceptual difficulties that are shared by individuals across a broad spectrum of age and experience. Research on conceptual understanding of force and motion phenomena reveals comparable findings. Previous studies have explored conceptual understanding of force and motion phenomena held by middle school (Morote & Pritchard, 2002), secondary (Champagne, Klopfer, & Anderson, 1980; Gunstone, 1984; Gunstone & Watts, 1985; Minstrell, 1982; McCloskey, 1983; McDermott, 1984; Oliva, 1999, 2003; Ridgeway, 1988; Peters, 1982; Thijs, 1992; Thijs & Dekkers, 1998; Tao & Gunstone, 1999) and college-level students (da Costa & Moreira, 2005; Halloun & Hestenes, 1985; Hestenes, Wells, & Swackhamer, 1992; Trowbridge & McDermott, 1981). Additional studies have documented difficulties that in-service elementary teachers (Kruger, Palacio, & Summers, 1992; Lawrenz, 1986) as well as pre-service and in-service secondary teachers (Preece, 1997) have with force and motion concepts.

Taken together, these studies indicate that individuals over a broad range of ages and with diverse educational experiences have many conceptual difficulties with light concepts and force and motion concepts. This research suggests non-scientific ideas develop early and persist into adulthood. That is, individuals tend to hold onto their non-scientific conceptions tenaciously, even after instruction. These research findings also suggest that teachers of K-8 students may hold similar, non-scientific conceptions. This is further evidenced by poor middle school student performance in physical science reported in the results for the 2005 National Assessment of Educational Progress (NAEP) (Grigg, Lauko, & Brockway, 2006). Our study investigated the conceptual understanding of samples of elementary and middle school teachers in the central Appalachian region to learn if, in fact, they hold similar alternative conceptions about standards-based light concepts and force and motion concepts, and if they hold these non-scientific notions in comparable frequencies.

Science Content Requirements in Elementary and Middle School Teacher Preparation

The first objective was to determine if, in practice, middle school science teachers do undergo stronger science content preparation than elementary teachers, who are more likely to be viewed as content generalists. The necessity for the distinction in science background can be evidenced in the NSES (NRC, 1996) and Benchmarks American Association for the Advancement of Science [AAAS], 1994), which clearly outline middle school science content that is significantly more advanced than science content recommended for the elementary grades. A comparison of science content requirements for elementary and middle school teacher preparation programs from eight higher education institutions in the Central Appalachian region did reveal a greater number of science course hours required in the middle school programs. Six of the eight institutions offered undergraduate elementary and middle school teacher certification programs. For these institutions, prospective middle school teachers were required to take, on average, an additional 16.42 credits in science than their elementary counterparts. More specifically, science requirements for the elementary certification programs ranged from 8 to 13 semester credits with a mean of 8.75 semester credits, compared to a range of 20 to 35 semester credits and a mean of 25.17 semester credits of science in the middle school certification programs. The wide range in subject matter requirements for middle school certification programs was due, in part, to the different requirements between single subject certification and dual subject certification. Additionally, the middle school programs also required a broader science background. Elementary program requirements only included coursework in life science and physical science, with the exception of two programs that also required coursework in earth science. In comparison, the middle school programs required coursework in life science, earth/space science, physics/physical science, and chemistry for certification in middle school general science.

These findings from the comparison of science course requirements in the Central Appalachian region were similar to findings reported in previous research studies on science requirements in elementary and middle school teacher certification programs. For example, results from the *2000 National Survey of Science and Mathematics Education* (Weiss, Banilower, McMahon, and Smith, 2001) revealed that elementary teachers most frequently reported completing coursework in life science (91%), earth/space science, (82%) and physical science (61%) (Fulp, 2002a). Note the emphasis on life and earth/space science requirements in the national sample compared to the emphasis on life and physical science in the Central Appalachian sample. Middle school teachers surveyed in the national sample indicated they had completed coursework in biology/life science (94%), earth/space science (85%), physical science/physics, (76%) and chemistry (72%) (Fulp, 2002b), and a similar trend was observed in the Central Appalachian middle school programs. It is disturbing that 39% of elementary teachers and 24% of the middle school teachers surveyed in the national study did not report completing coursework in physics or physical science.

Analysis of specific science courses completed, as reported by middle school teachers in the national sample, also revealed that these teachers tended to complete introductory level science courses, with few middle school teachers pursuing advanced courses in any one science content area (Weiss et al., 2001). For example, of the 85% of middle school teachers reporting completion of introductory biology courses, only 23% also reported completing a course in genetics (Fulp, 2002b). A similar trend was observed in middle school science teacher preparation program requirements for institutions in the Central Appalachian region. Specifically, none of the six undergraduate middle school programs reviewed required completion of advanced courses in any one science discipline. Similarly, elementary programs reviewed required only introductory science courses. Specific course data were not provided on elementary teachers surveyed in the 2000 science and mathematics education survey (Weiss et al., 2001).

In summary, it appears middle school science teacher preparation programs tend to require more science courses and sample broader content than is required in elementary programs. However, both elementary and middle school pre-service teachers typically receive science preparation through large, lecture-dominated survey courses that may have little impact on conceptual understanding (Christopher & Atwood, 2004; McDermott, 1991; McDermott, Heron, Shaffer, & Stetzer, 2006). Although both elementary and middle school science teachers are expected to provide effective instruction in the life, earth, and physical sciences, neither group is likely to have in-depth preparation that has focused on deep conceptual understanding.

A group of physicists and science educators reviewed the tests for content validity, and a group of elementary and middle school teachers reviewed the instruments for alignment with the science curricular of the three states.

Conceptual change research indicates that an important learning component in facilitating conceptual understanding is non-traditional instruction that requires students to make observations and complete lab work, followed by sense-making, interpretive discussions (Beeth, 1998; Osbourne & Freyberg, 1985; Vosniadou, 1991). In addition, research has shown that instructional activities that require students to support assertions with evidence and challenge them to become more metacognitive by comparing investigation results with previous suppositions are better associated with effective intentional learning (Vosniadou, 2003).

It is highly unlikely that the traditional instruction for light concepts and force and motion concepts commonly offered to pre-service teachers in institutions of higher education is aligned with contemporary conceptual change theory. Thus, the odds are against in-service elementary or middle school science teachers having completed physical science courses that had incorporated contemporary conceptual change theory into their structure. Therefore, a basis for expecting either group to develop effective strategies for helping students construct a deep scientific understanding is lacking, and furthermore, if a deeper conceptual understanding is absent, the additional coursework required for middle school certification may not prepare these teachers to perform adequately on assessment tasks that focus on conceptual understanding.

The Problem

Previous studies have reported limitations in pre-service and in-service teachers' understanding of light concepts and force and motion concepts. However, these studies are not well suited for the comparison of elementary and middle school teachers' conceptual understanding, because the assessment tasks employed in the studies varied considerably between the levels. The current study utilized three identical light tasks and four identical force and motion tasks to assess groups of elementary and middle school teachers' conceptual understanding. Science educators are interested in these two groups of teachers because they teach important foundational science concepts that are frequently the targets of standardized student achievement measurements. Consequently, efforts to improve student achievement in science are often geared towards elementary and middle school teachers. By using identical assessment tasks, the present study was able to compare groups of Central Appalachian in-service elementary and middle school teachers in terms of their conceptual understanding of light phenomena and force and motion phenomena. Results from the study should help inform instruction for both pre-service and in-service elementary and middle school science teachers in this region, as well as other regions with similar challenges.

This study's results provide further evidence that conceptual difficulties with light concepts and force and motion concepts are pervasive and not adequately impacted by traditional higher education science courses.

The research questions that guided this study are as follows:

1. In terms of science understanding, how prepared are Central Appalachian in-service elementary and middle school teachers to teach selected, standards-based light concepts and force and motion concepts?
2. How do Central Appalachian inservice elementary and middle school teachers' conceptual understanding compare on selected standards-based
   a. light concepts,
   b. force and motion concepts,
   c. light concepts and force and motion concepts combined?

Methods

Participants and Setting

The Appalachian Math and Science Partnership project in the Central Appalachian region, funded by the National Science Foundation, includes 51 school districts and nine institutions of higher education from three states: Kentucky, Virginia, and Tennessee. Enhancing the content comprehension of in-service K-12 mathematics and science teachers is one of four major goals of the project, and enhancing the content comprehension of pre-service teachers is another. Data for the study were collected at the beginning of four elementary and three middle school physical science summer institutes. These samples included 72 elementary and 51 middle school self-selected teachers.

Testing Procedure and Instrument

Content tests are routinely administered during science coursework for pre-service teachers. However, outside of a college course format, in-service teachers are seldom given conceptual understanding tests as part of professional development. Rather, professional development is often assessed by use of Likert-type questions that assess the degree to which participants judge the professional development to be interesting and useful. Such opinion instruments are designed to assess teachers' satisfaction, but are inadequate to assess teachers' conceptual understanding. This is a major concern of the math and science partnership, as well as of science educators in general. The limited time available for testing and the trepidation that many practicing teachers have towards content knowledge assessment further increase the challenge of obtaining reliable information. In an effort to overcome these challenges, prospective participants were informed that a short test on fundamental science concepts would be a requirement for participation, but that the system utilized would not allow the association of individuals with particular test scores. This strategy has proven acceptable to teacher-participants and has been effective in yielding data for evaluation and research purposes.

Multiple-choice questions with non-scientific conceptions embedded in distracter options were selected as the assessment vehicle (Hestenes, Wells & Swackhamer, 1992). Work reported by Goldberg and McDermott (1986), McDermott (1996), and Osborne and Freyberg (1985) was particularly helpful in providing ideas for light tasks, and previous work, including the Force Concept Inventory (FCI) by Hestenes et al. was helpful in providing ideas for the force and motion tasks. The test instruments administered to the groups of elementary and middle school teachers assessed all of the physical science topics addressed in the institutes. A committee of physicists, science educators and teachers developed the instruments using the literature cited above. A group of physicists and science educators reviewed the tests for content validity, and a group of elementary and middle school teachers reviewed the instruments for alignment with the science curricular of the three states. Among the several light tasks included on each test, three tasks on both tests were identical. Similarly, four of several force and motion tasks were identical on both tests. Results from administering these seven tasks during elementary and middle school institutes provided the descriptive data for this study.

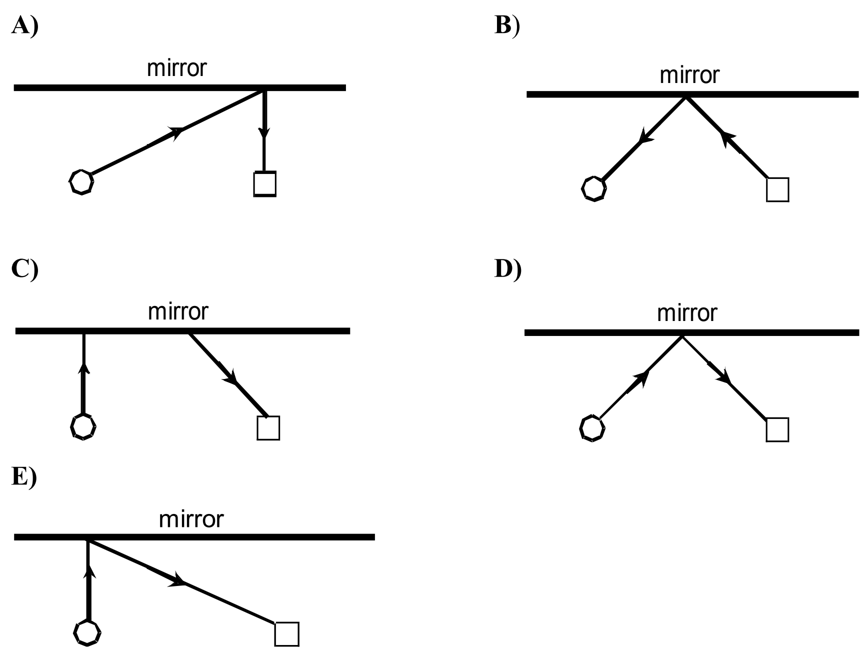
Data Analysis Procedures

Frequencies and percentages were determined for responses to each of the seven assessment tasks. This data serves to describe the conceptual understanding of the participants. Correct responses reflect a scientific conceptual understanding, and incorrect responses help identify non-scientific conceptions. The frequency data provided a basis for qualitative comparisons of performance within and across groups in the primary analysis. Chi-square comparisons of correct response frequencies for the two groups were completed to complement the qualitative judgments, and p values less than or equal to .05 were deemed statistically significant.

Responses to each option on the seven tasks for both the elementary and middle school groups were further divided into three subgroups according to teachers' performance on the entire test of over 30 tasks. Teachers that performed in the top third were placed in a high performance subgroup, and those that performed in the middle and lower third were placed in middle and low performance subgroups, respectively. The subgroup data facilitated important additional comparisons of teachers' understanding within and between the elementary and middle school groups that had previously not been reported.

Figure 1: ***Task 1*** assesses the understanding of light being reflected in a predictable manner by a plane mirror.

1. Light from a small light bulb, represented by a circle on the left in the diagrams below, encounters a mirror. Light from the mirror is observed to illuminate a small screen, represented by a small square on the right in the figures below. Which of the following diagrams best represents the path the light takes in reaching the screen via the mirror?



Results and Discussion

This section includes a discussion of results from the three light tasks and the four force and motion tasks. A figure showing each task as well as tables that summarize the results are included in order to facilitate analysis and discussion.

Light

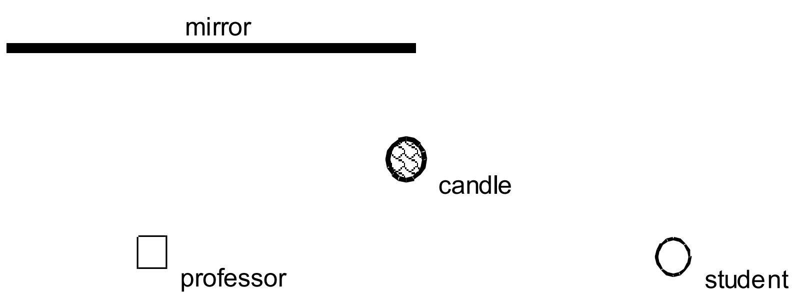
The first light task (Figure 1) assesses comprehension of the principle that light is reflected in a predictable manner by a plane mirror. Achievements of both the elementary and middle school groups can be seen in Table 1, which displays the results for Task 1, as well as the frequency with which each option, A-E, was selected. As previously indicated, teacher performance was categorized into high, medium, and low subgroups based on their performance on the entire test, including those concepts not discussed in this paper. The total frequency with which each option, A-E, was selected across the three performance subgroups is also expressed as a percent. The correct response is denoted with bold type.

Table 1: ***Task 1***, Light Reflected by a Plane Mirror, Results for Elementary and Middle School Teachers Showing Response Frequencies by Performance-level Subgroups and Totals as Frequencies and Percents

	Elementary							Middle School						
	A	B	C	**D**	E	Omit	Total	A	B	C	**D**	E	Omit	Total
High	0	1	0	**20**	3	0	24	1	0	1	**13**	2	0	17
Medium	2	0	1	**16**	5	0	24	2	1	0	**11**	3	0	17
Low	0	7	4	**7**	6	0	24	2	3	1	**3**	8	0	17
Totals as *f*	2	8	5	**43**	14	0	72	5	4	2	**27**	13	0	51
Totals as %	2.8	11.1	6.9	**59.7**	19.4	0	100	9.8	7.8	3.9	**52.9**	25.5	0	100

Figure 2: ***Task 2*** assesses the application of the law of reflection in determining whether the image of an object can be seen in a mirror from two different specified locations.

2. A student, a professor, an unlighted candle, and a plane mirror are arranged in a well-lit room as shown in a top view in [the figure below]. The size of the mirror is typical of a bathroom mirror. The professor and the student can tilt their heads. As they look into the mirror:



A. both the professor and the student will be able to see an image of the candle in the mirror.

B. the professor will be able to see an image of the candle, but the student will not.

C. the student will be able to see an image of the candle, but the professor will not.

D. neither the student nor the professor will be able to see an image of the candle in the mirror.

E. there will be no image of the candle in the mirror for anyone to see.

Note in Table 1 that 20 of 24 elementary teachers (83.3%) in the high performance subgroup selected the correct response, compared to only 7 of 24 (29.2%) in the low performance subgroup. The same pattern can be observed for the middle school group. Thirteen of 17 middle school teachers (76.5%) in the high performance subgroup selected the correct response, as opposed to only 3 of 17 teachers (17.6%) in the low performance subgroup. Although all subgroups included teachers who did not demonstrate the desired understanding on this task, the performance of the lower third of teachers in both groups is especially weak.

In order to select the correct response (D) for the first light task, the testee must understand the direction a light ray would travel from the light source to the plane mirror and then to the screen, utilizing the law of reflection. Looking at the data, 59.7% in the elementary group (Table 1) and 52.9% in the middle school group selected the correct choice. From a qualitative perspective, the performance of the two groups appears to be both comparable and inadequate. A chi-square value of .56 (1, N = 123), $p = .45$ supports this qualitative judgment.

performance subgroups for both the elementary and middle school groups is again strikingly similar.

In another study of pre-service elementary teachers' understanding of the principles involved in determining the path light travels from a non-luminous object to a mirror and then to an observer's eye, Bendall, Goldberg, and Galili (1993) found only 2 of 10 subjects demonstrated a solid scientific understanding. Although the teachers in the present study appear to have done somewhat better than those in the Bendall et al. (1993) study, it should be noted that the pre-service teachers in their sample had to generate their own responses, rather than select from a set of predetermined answers. Moreover, false positives represent a common limitation of multiple-choice testing

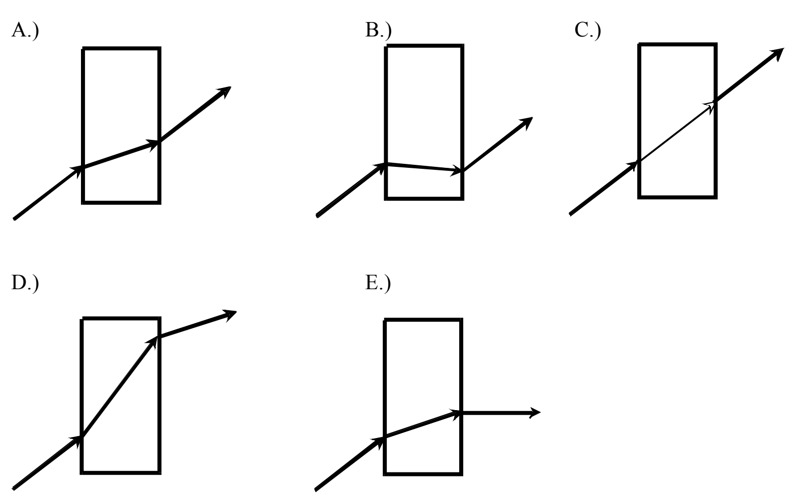
Table 2: Law of Reflection as Demonstrated by Candle Image in Mirror, Results for Elementary and Middle School Teachers Showing Response Frequencies by Performance-level Subgroups and Totals as Frequencies and Percents

	Elementary							Middle School						
	A	**B**	C	D	E	Omit	Total	A	**B**	C	D	E	Omit	Total
High	6	**18**	0	0	0	0	24	6	**9**	1	1	0	0	17
Medium	11	**9**	2	2	0	0	24	9	**7**	0	1	0	0	17
Low	17	**4**	1	1	1	0	24	10	**3**	2	1	1	0	17
Totals as *f*	34	**31**	3	3	1	0	72	25	**19**	3	3	1	0	51
Totals as %	47.2	**43.1**	4.2	4.2	1.4	0	100	49.0	**37.3**	5.9	5.9	2.0	0	100

Conceptually, the second task (Figure 2) is an extension of the first. It provides an opportunity to apply the law of reflection in order to determine if the image of an object can be seen in a mirror from two specified locations. On the face of it, Task 2 appears to be more difficult than Task 1, and the data (Table 2) appears to support that view. The popularity of option A suggests that each group included a comparable portion of the sample that held a poor understanding of the law of reflection. That is, the law was not appropriately applied in this option. The performance of the elementary and middle school groups on this task again appears to be comparable and weak. A chi-square comparison supports the comparable performance perspective with a value of .42 (1, N = 123), $p = .52$. The apparent difference in performance of the high and low

Figure 3: ***Task 3*** assesses the ability to apply an understanding of how transparent objects can refract light in predictable ways.

3. A light ray encounters the left side of a flat plate of glass as shown in the diagrams below. In each drawing, the ray initially hits the glass at the same spot and at the same angle. Which of the drawings best indicates the path that the light ray would follow as it travels through and exits the glass?



of conceptual understanding (Trundle, Atwood, & Christopher, 2002).

Task 3 (Figure 3) was intended to provide an opportunity for teachers to predict the ways in which transparent objects can refract light. The results are shown in Table 3. The drawings utilized in the task show a setup unlikely to be encountered outside of school-based instruction. Although the middle school group appears to have performed better than the elementary group, both groups included too many teachers who did not make the desired application. The chi-square comparison confirms the observed difference in performance of the two groups, favoring the middle school group with a resulting value of 7.09 (1, N = 123), p = .01. Again, note the very poor performance of the low subgroups: only 5 of 24 elementary (20.8%) and 3 of 17 middle school teachers (17.6%) in the low performance subgroups selected the correct response.

The selection of option C, a particularly popular distracter across all elementary subgroups, may have resulted from an inappropriate application of the concept that light travels in a straight line, a regrettable shortening of the more valid and useful idea that light travels in a straight line until it hits something. In any case, about two in five elementary teachers and one in five middle school teachers selected option C. It seems likely that teachers who selected B, D, or E were aware the path of the light would be altered, but that they did not know, and could not figure out, the manner in which it would be altered.

Reviewing the collective results for the two groups over the three light tasks, the elementary group selected 95 correct responses out of a possible 216 (44%) compared to 73 correct responses out of 153 (47.7%) selected by the middle school group. The apparent comparable performance of the two groups was confirmed by a chi-square value of .50 (1, N=369), p = .48. The distressing performance of the low subgroups over the three light tasks should be of particular concern to science educators. In the elementary low performance subgroup, only 16 of 72 (22.2%) choices were correct, and only 9 of 51 (17.6%) correct responses were selected by the middle school low performance subgroup. The apparent comparable performance of the two low subgroups is confirmed by a chi-square value of .39 (1, N = 103) p = .53.

Table 3: ***Task 3***, Refraction of Light through Glass, Results for Elementary and Middle School Teachers Response Frequencies by Performance-level Subgroups and Totals as Frequencies and Percents

	Elementary							Middle School						
	A	B	C	D	E	Omit	Total	**A**	B	C	D	E	Omit	Total
High	**11**	0	10	0	3	0	24	**14**	0	2	1	0	0	17
Medium	**5**	4	8	5	2	0	24	**10**	0	2	3	2	0	17
Low	**5**	3	12	2	1	1	24	**3**	3	7	3	1	0	17
Totals as *f*	**21**	7	30	7	6	1	72	**27**	3	11	7	3	0	51
Totals as %	**29.2**	9.7	41.7	9.7	8.3	1.4	100	**52.9**	5.9	21.6	13.7	5.9	0	100

There is a clear need to bridge the disconnect between research conducted on the status of teacher knowledge in the physical sciences and the desired instruction of physical sciences in K-12 schools, as well as in higher education institutions in the Central Appalachian region.

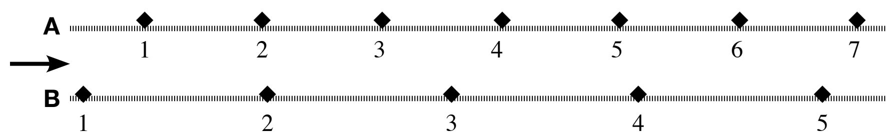
Force and Motion

The four force and motion tasks discussed in this section assess comprehension of position, velocity, and acceleration of objects, as well as the ability to apply aspects of Newton's laws of motion in a variety of contexts. Three of the four tasks involve motion in a straight line without reversal. As a result, the distinction between speed and velocity is not important for tasks 4, 5, and 6, and the two terms are used interchangeably. Task 7 focuses on direction of velocity, but not on magnitude.

In order to correctly select the best response from the motion diagram for the first force and motion task, Task 4 (Figure 4), differences between the speeds of two balls must be inferred based on the observed changes in position and time intervals. The most important result from this task, shown in Table 4, is that both groups performed far below expectations. Upon initial comparison, it appears, on a relative basis, that the elementary teachers outperformed the middle school teachers on this task. That is, 39 of 72 elementary teachers (54.2%) correctly indicated that the balls do not move at the same speed between clock times 1 and 5. In comparison, 22 of 51 middle school teachers (43.1%) made the correct selection. However, the chi-square comparison indicates that this difference is not statistically significant at the .05 level (1.45 [1, N = 123], p = .23). It is interesting to note that the performance across the subgroups appears to vary to a much lesser degree for this task than for the light tasks. The popularity of distracter option A in the two samples suggests many teachers in both groups had difficulty differentiating between position and speed from the motion diagram.

Figure 4: ***Task 4*** assesses the use of motion diagrams to differentiate between position and speed.

4. Two balls, A and B, are moving *steadily* as illustrated below. The numbers represent readings of a clock in seconds. At each clock reading, the position occupied by each ball is represented by a large black dot. At clock time 1, ball A occupies the position marked 1, and ball B occupies the position marked 1, etc. The arrow indicates the direction of motion.



Do the two balls have the same speed between clock readings 1 and 5?

A. Yes, at clock time 2.
B. Yes, at clock time 3.
C. Yes, at clock time 5.
D. Yes, at clock times 2 and 5.
E. No.

Teachers' conceptual difficulty identified in this task is consistent with previous research on university students enrolled in physics classes and with research on in-service elementary teachers (McDermott, 1984; Trowbridge & McDermott, 1980). Respondents in these studies tended not to differentiate between position and speed, or velocity. Trowbridge and McDermott (1980) reported that both university students and elementary teachers frequently incorrectly inferred that two objects occupying the same horizontal position at some point in time would be moving at the same speed, regardless of the speed with which the objects move before or after the shared position.

The second force and motion task, labeled Task 5 (Figure 5), is an extension of Task 4 in that two balls are moving at constant, but different, speeds. However, on this task each of the five options shows a position-time graph for the motion of the two balls. Responses (Table 5) indicate far too many teachers in both groups were unable to correctly identify two balls moving at constant speed portrayed as straight lines on a position-time graph, with D traveling faster than C, or option A. Specifically, only 23 of 72 (31.9%) elementary teachers and 24 of 51 (47.1%) middle school teachers selected option A.

Option C was the most favorable distracter for both groups, and B was a popular distracter for the elementary teachers. Although B is an incorrect response, selecting it may provide an

Table 4: ***Task 4***, Differentiating Position and Speed in Motion Diagram, Results for Elementary Teachers Showing Response Frequencies by Performance-level Subgroups and Totals as Frequencies and Percents

	Elementary							Middle School						
	A	B	C	D	**E**	Omit	Total	A	B	C	D	**E**	Omit	Total
High	6	0	0	0	**18**	0	24	7	1	0	0	**9**	0	17
Medium	12	1	0	0	**11**	0	24	9	1	0	0	**7**	0	17
Low	10	1	2	1	**10**	0	24	9	0	2	0	**6**	0	17
Totals as f	28	2	2	1	**39**	0	72	25	2	2	0	**22**	0	51
Totals as %	38.9	2.8	2.8	1.4	**54.2**	0	100	49.0	3.9	3.9	0	**43.1**	0	100

indication of partial understanding, since the motions of both objects are described by straight lines, with different slopes corresponding to different velocities. The selection of B could indicate an incomplete understanding of the relationship between the steepness of the line and the velocity for a position-time graph, and the selection of C could reflect a lack of comprehension that two accelerating objects are represented in this graph, with object C accelerating faster than object D.

The poor results for Task 5 are troubling. Upper elementary and middle school teachers may reasonably be expected to help their students create and interpret position-time graphs. In order to address the inadequate content preparation through professional development activities, additional research is needed to more clearly identify the nature and extent of the conceptual difficulties teachers experience on this task. It is important to note that Grayson and McDermott (1996) reported similar difficulties for university-level physics students studying kinematics as they attempted to represent the motion of a ball in position-time graphs.

Although it appears the middle school group outperformed the elementary group on this task, a chi-square comparison does not support the qualitative comparison at the .05 level (2.89 [1, N = 123], p = 0.09). Note the comparable results for the low subgroups. Specifically, only 5 of 24 elementary teachers (20.8%) and 4 of 17 middle school teachers (23.5%) in the low performing subgroups selected the correct response.

In Task 6 (Figure 6), it is intended that the average speed be determined

Figure 5: ***Task 5*** assesses the ability to interpret position-time graphs representing the motion of two objects.

5. Ball C is moving at constant speed. Ball D also is moving at constant speed but faster than C. Which of the following could be a graph describing the motion of balls C and D?

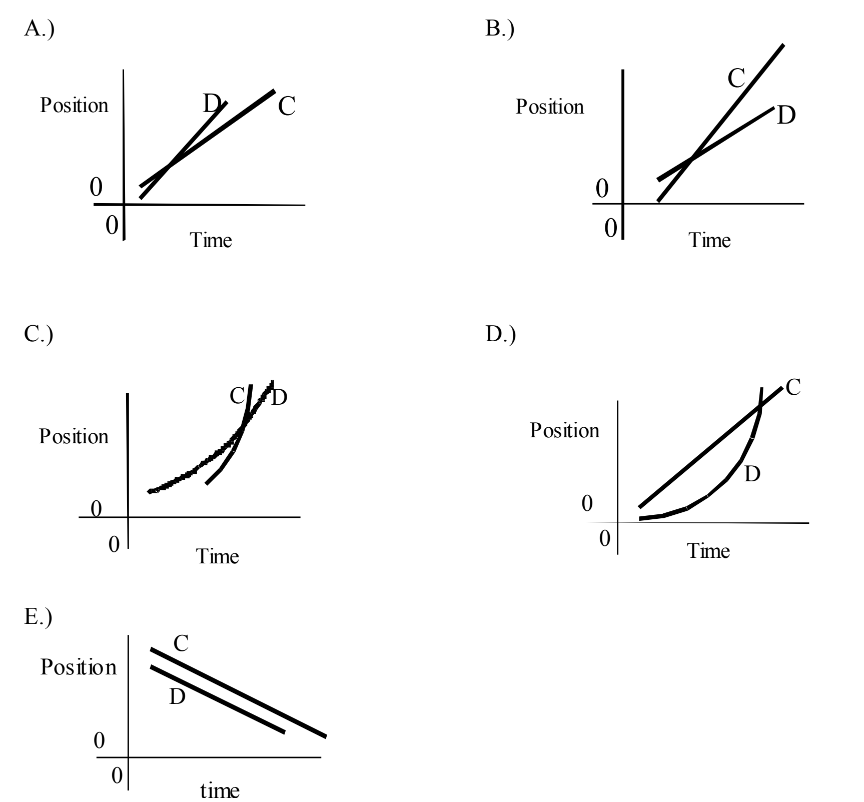


Table 5: ***Task 5***, Interpreting Motion in Motion-Time Graphs, Results for Elementary and Middle School Teachers Showing Response Frequencies by Performance-level Subgroups and Totals as Frequencies and Percent

	Elementary							Middle School						
	A	B	C	D	E	Omit	Total	**A**	B	C	D	E	Omit	Total
High	**11**	3	2	6	2	0	24	**13**	1	1	1	1	0	17
Medium	**7**	7	7	1	2	0	24	**7**	3	1	4	2	0	17
Low	**5**	4	9	4	2	0	24	**4**	0	7	2	4	0	17
Totals as *f*	**23**	14	18	11	6	0	72	**24**	4	9	7	7	0	51
Totals as %	**31.9**	19.4	25.0	15.3	8.3	0	100	**47.1**	7.8	17.6	13.7	13.7	0	100

Figure 6: ***Task 6*** assesses the ability to use values for position and time to determine an average speed.

6. Imagine that at 1:00 p.m. you drove onto an interstate highway at mile marker 60, which is 60 miles from the state border (where the mile marker is 0). You drove further away from the border, and, at 3:00 p.m. you got off the interstate highway at mile marker 200. If you were able to keep your speed essentially constant during the trip, what was that speed?

   A) 55 miles per hour
   B) 60 miles per hour
   C) 65 miles per hour
   D) 66.7 miles per hour
   E) 70 miles per hour

Table 6: ***Task 6***, Determining Average Speed, Results for Elementary and Middle School Teachers Showing Response Frequencies by Performance-level Subgroups and Totals as Frequencies and Percents

	Elementary							Middle School						
	A	B	C	D	**E**	Omit	Total	A	B	C	D	**E**	Omit	Total
High	0	1	0	0	**23**	0	24	0	1	0	0	**16**	0	17
Medium	0	2	2	3	**17**	0	24	0	1	0	0	**16**	0	17
Low	1	7	4	2	**10**	0	24	1	5	2	0	**9**	0	17
Totals as *f*	1	10	6	5	**50**	0	72	1	7	2	0	**41**	0	51
Totals as %	1.4	13.9	8.3	6.9	**69.4**	0	100	2.0	13.7	3.9	0	**80.4**	0	100

by dividing the displacement, which in this case is equal to the distance traveled, by the time elapsed during the displacement. Summary (Table 6).

Both groups performed relatively well on this task when compared to performance on other tasks in the study. The roughly comparable performance of the two groups included 50 of 72 (69.4%) elementary teachers and 41 of 51 (80.4%) middle school teachers selecting the correct option, E. A chi-square of 1.86 (1, N = 123), $p = .17$ supports the qualitative judgment that the difference is not significant. Option B was the most attractive distracter option for both groups, especially for teachers in the low performance subgroups. Additional study is needed to determine whether the problem was due to inability to determine the displacement, or if it was simply due to faulty calculation.

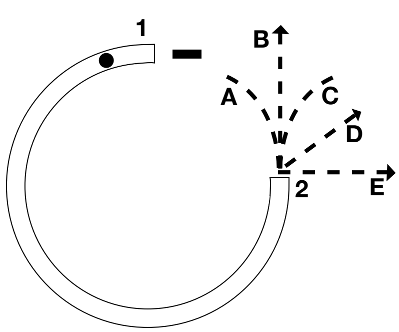
Again, note the relatively poor performance of the low subgroups in both samples. Only 10 of 24 elementary teachers (41.7%) and 9 of 17 middle school teachers (52.9%) selected the correct response. It appears that several teachers in both groups need further professional development in order to acquire the understanding required to complete this relatively simple task.

Task 7 (Figure 7) is intended to require the subject to apply Newton's first law of motion in order to identify the expected path of a ball emerging at high speed from a circular tube. The concept to be applied in this task is that an object will remain in its uniform state unless acted upon by a net, or unbalanced, force. As the ball exits the tube at Point 2 in this task, it will continue to move in a straight line relative to the horizontal plane, as indicated by letter B, since no force in the horizontal plane will be acting upon the ball.

Figure 7: ***Task 7*** assesses the ability to apply Newton's first law of motion in the context of an object emerging from a rigid circular tube.

7. The accompanying diagram depicts a fixed and rigid tube lying in a horizontal plane. Traveling at a high speed, a ball enters the tube at "1" and exits at "2". Which of the path representations—A, B, C, D, or E—would most nearly correspond to the path of the ball as it exits the tube at "2"?

   A. A
   B. B
   C. C
   D. D
   E. E



The correct response, option B, was the most frequently selected response by both groups, including 42 of 72 elementary teachers (58.3%) and 39 of 51 middle school teachers (76.5%). Examining the data in Table 7, the group of middle school teachers appears to have outperformed the group of elementary teachers on Task 7, and a chi square comparison supports this observation at the .05 level (4.37 [1, N = 123], p = .04).

It is discouraging that 29 of 72 elementary teachers (40.3%) and 11 of 51 middle school teachers (21.6%) selected responses that suggest they believed after exiting the tube, the ball would follow a path consistent with the missing tube piece, option A, or would follow a path represented by option C, which is a reflection of the missing tube piece. However, these responses are similar to previous research findings on high school and university students' conceptions of curvilinear motion. More specifically, in previous studies, respondents reportedly believed the ball acquired an implied force inside the tube, which they extrapolated on the ball after it exited the tube (Freyd & Finke, 1984; Gardner, 1984; Gunstone, 1984; Hubbard, 1996, 2005; McCloskey, 1983; McCloskey, Caramazza, & Green, 1980; McCloskey & Kohl, 1983; Ridgeway, 1988).

Comparing combined results for the two groups on the four force and motion tasks, 154 correct responses of a possible 288 (53.5%) were chosen by the elementary group and 126 correct responses of a possible 204 (61.8%) were selected by the middle school group. The apparent, modest difference favoring the middle school group was not statistically significant at the .05 level based on a chi-square of 3.35 (1, N = 492), p = .07. Focusing only on the low performance subgroups for the four force and motion tasks combined, 35 correct responses of a possible 96 (36.5%) were selected by the elementary, low performance subgroup, and 31 correct responses of a possible 68 (45.6%) were chosen by the middle school, low performance subgroup. These findings reflect a highly unsatisfactory performance for both low subgroups. The apparent, modest difference in performance of the two low subgroups was not significant, based on a chi-square of 1.38 (1, N = 41), p = .24.

Finally, combining results for the seven tasks discussed, the elementary group selected 249 correct responses out of a possible 504 (49.4%), and the middle school group selected 199 correct responses out of 357 (55.7%). The low performance of both groups is unsatisfactory, and it indicates a need for professional development in these areas in order to help these teachers develop the level of comprehension necessary to teach students. The small apparent difference in the performance of the two groups was not statistically significant with a chi-square of 3.36 (1, N=861), p = .07. On the seven tasks combined, the elementary, low subgroup selected 51 correct responses of 168 (30.4%), and the middle school, low subgroup selected 40 correct responses of 119 (33.6%). These results are particularly alarming. The performance of the two subgroups appears to be comparable, and a chi-square of .34 (1, N = 287), p = .56 supports this perspective.

Table 7: ***Task 7***, Newton's First Law of Motion in Circular Tube Context, Results for Elementary and Middle School Teachers Showing Response Frequencies by Performance-level Subgroups and Totals as Frequencies and Percents

	Elementary							Middle School						
	A	**B**	C	D	E	Omit	Total	A	**B**	C	D	E	Omit	Total
High	8	**15**	1	0	0	0	24	2	**15**	0	0	0	0	17
Medium	4	**17**	3	0	0	0	24	4	**12**	1	0	0	0	17
Low	8	**10**	5	0	1	0	24	2	**12**	2	1	0	0	17
Totals as *f*	20	**42**	9	0	1	0	72	8	**39**	3	1	0	0	51
Totals as %	27.8	**58.3**	12.5	0	1.4	0	100	15.7	**76.5**	5.9	2.0	0	0	100

Conclusions and Implications

Far too many elementary and middle school teachers demonstrated a lack of conceptual understanding on the light tasks and the force and motion tasks utilized in this study. In addition, the high degree of similarity in the frequencies with which particular distracter options were selected by the two groups suggests that the conceptual frameworks held by individuals within the two groups are very similar. This appears to be true for the elementary and middle school performance subgroups as well. Unfortunately, the problem of a lack of conceptual understanding is likely greater than the data reported here indicates, because participants were self-selected, and multiple choice testing frequently results in false positives (Trundle, Atwood, & Christopher, 2002).

The findings that result from analysis of responses to the light tasks and the force and motion tasks indicate a need to take action, as well as a course of action likely to prove beneficial. As these tasks utilize conceptual knowledge that elementary and middle school teachers may reasonably be expected to teach, these results have major implications that should be considered with respect to the education of both pre-service and in-service science teachers. When considered from a relative basis, the assumption that middle school teachers are generally better prepared to teach these topics than their elementary counterparts is not supported by these results. As stated earlier, middle school science teacher preparation programs in the Central Appalachian region, like the elementary programs, require candidates to complete a series of introductory, lecture-style, survey science courses that tend to emphasize breadth over depth of understanding. Despite the greater number of science content requirements in middle school teacher preparation programs as compared to elementary programs, contemporary conceptual change theory discussed earlier (Driver & Oldham, 1986; Hewson & Hewson, 1988; Vosniadou, 1991, 1999, 2003) provides a basis for predicting and, subsequently, explaining these results.

This study's results provide further evidence that conceptual difficulties with light concepts and force and motion concepts are pervasive and not adequately impacted by traditional higher education science courses (Christopher & Atwood, 2004; McDermott, 1991; McDermott, Heron, Shaffer, & Stetzer, 2006). Data from the most recent National Assessment for Educational Progress (NAEP) in science (Grigg, Lauko, & Brockway, 2006), discussed earlier in this paper, also reinforces this conclusion. Specifically, middle school student achievement in science showed no change on the NAEP between 1996 and 2005. However, in reviewing student achievement across the specific science disciplines, an alarming decline in student scores is evident during the same period in physical science. The similarity of this national data to data from this study indicates that conceptual understanding limitations identified in groups of teachers from the Central Appalachian region may be present in other groups of elementary and middle school teachers throughout the nation. We urge testing of this prediction, and we would be pleased to cooperate with colleagues who wish to do so.

Beyond the implication that both groups share a pressing need for professional development on light concepts and force and motion concepts, the results for each task should be studied by science and science education faculty. The purpose would be to more closely align physical science coursework completed by pre-service elementary and middle school science teachers with educational methods proven effective for helping students develop a deep level of conceptual understanding. The results for each task also should be considered by instructional supervisors and other district leaders, particularly those in this region, who have responsibility for professional development. It seems probable that the personnel responsible for professional development of in-service teachers is not fully aware of the nature and magnitude of the problem.

Awareness of the problem by instructional leaders in the K-12 schools and faculty in higher education institutions is viewed as a necessary condition for the corrective action needed at both the pre-service and in-service teacher preparation levels. There is a clear need to bridge the disconnect between research conducted on the status of teacher knowledge in the physical sciences and the desired instruction of physical sciences in K-12 schools, as well as in higher education institutions in the Central Appalachian region. Over the past three decades, many studies have been conducted on the status of teachers' and students' science conceptions. Unfortunately, it appears results have had little impact on the course content and presentation of the science course work completed by prospective elementary and middle school teachers in this region. Non-traditional instructional approaches selected in accordance with modern conceptual change theory and with respect to conceptual weaknesses revealed by research, such as the present study, have the potential to improve the status of teachers' physical science knowledge.

Finally, we recommend individual interviews in order to gain greater insight into the conceptual frameworks (Vosniadou, 2003) held by elementary and middle school teachers on light concepts and force and motion concepts before and after non-traditional, evidence-based instruction is pursued. These interviews could provide further explanation of non-scientific conceptions indicated by the data resulting from the multiple-choice test. As a practical matter for researchers, pre-service teachers are likely to be much more accessible for interviews than in-service teachers, and, in terms of understanding targeted science concepts, pre-service teachers near the completion of their programs may be a good proxy for in-service teachers.

This additional information would allow professional development sessions to be designed that more specifically address common non-scientific conceptions, as well as provide information that would be useful for improving the instruction of pre-service teachers.

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Pedagogical Content Knowledge As a Foundation for an Interdisciplinary Graduate Program

The authors offer a working model of a transferable teacher preparation program that is founded upon the concepts of reflective practitioner and teacher as researcher.

Despite the long history of the study of pedagogical content knowledge (PCK), two facts remain obvious. First, there are almost as many conceptions regarding the definition of PCK as there are researchers interested in it. Second, it is largely unclear which methods enable teacher educators to best prepare teacher candidates to use PCK. Recently, two themes have emerged strongly as mechanisms for helping teacher candidates become more accomplished practitioners. These two ideas, reflective practice and teacher as researcher, can be seen in a variety of teacher preparation programs. However, prevailing systems for preparing and accrediting teachers seem to have a strong enough hold over the process that completely different approaches to preparation, centered on these ideas, may have difficulty getting started.

Heibert, Morris, Berk, and Jansen (2007) have proposed one such new framework for teacher preparation. This framework focuses on helping candidates develop competencies in four areas: setting instructional goals, evaluating student performance relative to these goals, hypothesizing connections between the material taught and the material learned, and using this analysis to improve instruction. They acknowledge that their proposal is largely untested and that few studies exist to fully support the reorganization they suggest; however, their argument is compelling. As a further step in the development and analysis of ways in which these skills can be incorporated into teacher preparation programs, we offer a study of the Graduate Program in Mathematics, Science and Technology Education at our school as an example of one way in which these ideas can be used to reorganize teacher preparation programs with the explicit goal of preparing teachers to become reflective practitioners and creating teachers as researchers.

PCK and Domains of Teacher Knowledge

Since Schulman (1986) introduced the concept of PCK, there have been numerous attempts to define the components of PCK and its relationship to other domains of teaching knowledge. Broadly, Gess-Newsome (1999) categorized the literature on PCK as falling on a continuum between the *transformative* and *integrative* models of PCK. In the former, classroom teaching makes use of PCK only, and all other teaching knowledge, whether it is related to content, context, or learners, is transformed into PCK in order to be used in the classroom. In the integrative models, PCK exists as the intersection of the sets of content knowledge, the contexts of learning, and pedagogical knowledge. Specific models of PCK tend to fall somewhere in the middle of this continuum and make use of different components of teacher knowledge. However, these models all tend to agree that there are at least three distinct domains of teacher knowledge: content knowledge, context knowledge, and pedagogical knowledge (Gess-Newsome, 1999). These three components are clearly reflected in the definition of PCK given by the National Council for Accreditation of Teacher Education (2002).

> [PCK is the] interaction of the subject matter and effective teaching strategies to help students learn the subject matter. It requires a thorough understanding of the content to teach it in multiple ways, drawing

> on the cultural backgrounds and prior knowledge and experiences of students. (NCATE, 2002, p. 55)

In many models of PCK, these three knowledge categories are present, but in modified forms. For example, Mohr (2006) discussed the framework for Mathematical Knowledge for Teaching (MKT) originally developed by Hill, Rowan, and Ball (2005). In this framework, MKT is the combination of common content knowledge, specialized content knowledge, knowledge of content and students, as well as knowledge of content and teaching. This definition explicitly connects the learners and the teaching process to the content, with no separate category for pedagogical knowledge.

Content Knowledge (CK) includes both deep and broad knowledge of subject matter. This includes the facts and concepts of a subject discipline, as well as multiple ways of thinking about the subject matter (Manouchehri, 1997; Noddings, 1998). This is facilitated when teachers are able to formulate clear connections between the content area in question and other content areas and applications (Manouchehri, 1997). Regarding the content knowledge of mathematics teachers, Lappan (2000) included additional features, specifically that they be good problem solvers capable of uncovering abstractions and generalities. Davis and Simmt (2006) also argued for deep content knowledge in teaching mathematics, claiming that "knowledge of established mathematics is inseparable from knowledge of how mathematics is established" and that "insights into the historical emergence of core concepts, interconnections among ideas, and the analogies and images that have come to be associated with different principles" are essential aspects of mathematical knowledge for teachers (p. 297). The level of depth deemed appropriate is of critical importance to discussions of teacher content knowledge. Lederman and Flick (2003) addressed this directly by questioning the precise level considered to be *in depth* subject matter knowledge and encouraging teachers go *above and beyond* the level of learning expected of their students. They claim that these questions are largely unanswered in regards to mathematics, science, and technology. As evidence, they point out their belief that the subject matter knowledge needed by different grades is qualitatively distinct, rather than hierarchical. To put it simply, the math knowledge required of a K-6 teacher is not less than the math knowledge required of 7-12 math teacher. Instead, the mathematical concept knowledge required of teachers at those distinct levels varies qualitatively rather than quantitatively.

The domain of context knowledge includes learners, their interests and motivations, their needs, the local (state and national) standards, and expectations of the discipline. Teachers must also possess an intimate understanding of constraints that exist upon teaching, including time, materials, and administrative issues. Another component involves understanding the flow of content from one grade level to the next. This component is connected on a deep level with curricular design issues and the psychological development of learners. Because of the huge impact such a domain of knowledge can have on teaching, Barnett and Hodson (2001) argued that a new category of teacher knowledge, one that subsumes content knowledge, pedagogical knowledge, and PCK, is needed. Their pedagogical context knowledge is developed as a taxonomy covering four categories of knowledge: academic and research knowledge, PCK, professional knowledge, and classroom knowledge. Oppewal (1993) and Kumar (1999) argued that in order for conceptual change to occur, the role of context and prior knowledge must be part of a quality science teacher education.

Pedagogical Knowledge (PK) includes having a theoretical knowledge of an array of instructional and classroom management strategies. This typically includes examination of educational history, learner development, sociological contexts for teaching, and strategies for teaching diverse learners (Morine-Dershimer & Kent, 1999). Within this set of instructional strategies, teacher preparation programs tend to emphasize strategies and philosophies of a particular nature, such as constructivism and inquiry-based teaching strategies. Often, PK includes general strategies for the integration of technology and other devices, such as manipulatives. The goal of these strategies is to improve the teaching/learning environment and provide deeper contexts for teaching judgments and decisions.

Models Of PCK And Reflective Practice

The transformative approaches to PCK treat it as a separate knowledge domain that emerges when one combines content, context and pedagogical knowledge in the presence of a stimulus. Manouchehri (1997) emphasized this model during a discussion about the need for teachers to "[make] the transition from a personal orientation to a discipline to

We expect that PCK will be difficult to implement once teachers are in the field unless these teachers have a solid foundation for reflecting on the educational decisions and issues that arise in the course of daily teaching.

thinking about how to organize and represent the content of the discipline to facilitate student understanding" (p. 203). One implication of these models is that different subject matter may require different instructional strategies to facilitate learning in different contexts. Using this model, Loughran, Mulhall, and Berry (2004) found that PCK varied considerably from teacher to teacher and that it was extremely difficult to get teachers to explicitly express the assumptions and decisions underlying their personal PCK. These difficulties, and the current lack of adequate PCK models for different content, suggest that another approach to developing PCK could be more fruitful and productive.

One such option is the integrative approach, in which the domains of teacher knowledge overlap in PCK. Thus, PCK is not a new knowledge domain. Instead, teachers develop an understanding of the current context in which learning takes place. Based on this knowledge, the teacher can then select specific strategies and information from PK to decide how to approach teaching CK. This integration is often fostered through Reflective Practice (RP) (Jay & Johnson, 2002; Yost, Sentner & Forlenza-Bailey, 2000).

Since every teacher is a part of the context in which learning occurs, PCK remains a personal construct (Loughran, et al., 2004). Therefore, in order for teachers to develop a deeper understanding, they must reflect on their own practice. This process entails the recording of data and the reflective study of that data. Logically, in order for this to be accomplished, teachers must be prepared to undertake this type of reflective work. Halim and Meerah (2002) indicated that most problems with current teaching are caused by a failure to adequately account for student prior knowledge and misconceptions, by misconceptions held by the teacher, or by a lack of sensitivity concerning the content difficulty. The tendency of even experienced teachers to have difficulties with these points serves to emphasize the need to develop PCK in pre-service programs. Even for experienced teachers, the "daily working environment does not facilitate the teachers to identify such knowledge … such as the knowledge of students' conceptions and misconceptions of specific topics" (p. 224). Considering this limitation, we expect that PCK will be difficult to implement once teachers are in the field, unless these teachers have a solid foundation for reflecting on the educational decisions and issues that arise in the course of daily teaching.

Bullough (2001) concluded his historical overview of PCK with a description of suggestions for moving forward by providing teachers with an opportunity to develop professional judgment relating to selection, adaptation and modification of pedagogical strategies based both on the content and the learners involved. His solution clearly defines the notion of reflective practice: "Teachers need to think more complexly about their practice and the reasons behind their actions in the light of how particular pupils learn and in relationship to specific formal, academic knowledge" (p. 665).

A reflective practitioner considers several aspects of teaching and learning (Yost, Sentner, & Forlenza-Bailey, 2000). One must reflect on one's own content understanding, considering the material that is understood and the ways in which this knowledge was acquired. Teachers must also reflect on student work samples, student needs, and the local context. The best teaching also grows from reflection on the curriculum at all levels, including an understanding of state and local standards as well as the standards from national content area organizations. Teachers must also reflect on curricular materials at all grades in order to understand where students came from and where they need to go. Teachers must also reflect on their own ideas and beliefs about teaching and learning and the connections among these aspects of the teaching environment. Through this process of reflection, teachers transform their inert knowledge into active, classroom practice that continually evolves as they encounter new situations and reconsider past experiences in light of more recent experiences. Manouchehri (1997) emphasized the role of the teacher as a reflective practitioner, paying "careful attention to consequences of their experiments …" (p. 205) in attempting to solve the pedagogical problems they encounter.

Teacher Using PCK

Clearly, one cannot teach a subject well without knowing the content of the subject well. Thus, a strong PCK-teacher is well versed in the content.

This means constantly viewing the material from different perspectives, considering applications of the content, and maintaining an active link with current developments in the field. These teachers make use of constant assessment (formative) to stay informed about the context of learning in which they operate. This also requires them to monitor current standards movements, curricular goals, and the school climate. Constantly updating contextual knowledge means that teachers rarely teach the same material in the same way. Since teachers possess a wide array of flexible strategies for helping learners in many different situations, they can use informed decision-making to adapt previous approaches to teaching in new situations. Informed decision-making (judgment) is built on reflective practice that allows teachers to be aware of the ways that different strategies may impact different learners in different situations. Another noteworthy aspect of this type of teaching is that learners of many different abilities, interests, and levels of preparation are welcome in the classroom, because the informed judgment of the PCK-teacher allows for flexible differentiation (in the sense of differentiating the lessons, the assignments, etc.)

This cycle of instruction and formative assessment will differ greatly from teacher to teacher, content area to content area, and context to context. It is not based upon a fixed time scale; rather it is based upon the teacher's ability to observe and address needs. That is what it means to be a reflective practitioner. Reflective practitioners do not merely use predetermined intervals to reflect and make changes. Instead, they continually reflect on the material that they are teaching as well as their students' understanding, in order to make ongoing adjustments. One consequence of this cycle is that PCK-based teachers frequently "go outside the teacher's manual," developing their own lesson and unit plans, designing them to meet the needs of the learners that currently comprise their class. Such lessons are not present explicitly in any existing sources; instead, existing materials are developed and modified according to the professional judgment of the teacher.

Developing PCK

In an historical look at PCK, Bullough (2001) speculates that the ultimate success of PCK-driven teacher preparation programs hinges on the answers to questions concerning the definition of PCK and the best ways to split its teaching between pre- and in-service teacher preparation. After a lifetime of different educational experiences, we cannot hope to completely change a candidate's mindset about the nature of teaching and learning all at once. Manouchehri (1997, p. 205) argued "prospective teachers must have the opportunity in their university coursework to strengthen their content knowledge and pedagogical content knowledge while being exposed to the type of teaching consistent with the recommendations of the reform movement" in order to counteract the tendency of instructors to simply teach in the ways they encountered most frequently during their educational experiences as learners.

Tied to this discussion is the nature of subject-specific knowledge. Given that all subject areas lead to unique PCK, we must consider the supposition that candidates would be best served by focused learning within their content areas. This would necessitate separate teacher preparation programs for each subject, with no common coursework possible, even in pedagogical or professional background. We reject this compartmentalized model for teacher preparation as impractical and lacking of important opportunities for teachers. Instead, it seems that there are enough similarities among certain content areas, such as mathematics, science and technology, to allow for a productive integration. This can occur in several ways. First, we can focus more general pedagogical courses on a subset of disciplines. This allows candidates to compare and contrast their organizations of knowledge with each other. These opportunities for building connections across disciplines eventually lead to greater student learning (Frykholm & Glasson, 2005). Second, we can create courses that are hybrids of content and pedagogy, helping teachers simultaneously enhance their content understanding as well as their methods for teaching that content. These courses would be more content-area specific, but teachers from related disciplines would stand to gain a great deal. For example, after seeing their content from the perspective of an outsider, such as a teacher from a different content area, candidates in our program often remark, "I never thought of it that way. Now it makes sense." Integration of math, science, and technology helps illuminate the connections among the various content areas, allowing participants to reconceptualize the content from a distance. Additionally, participants can consider the effectiveness of the teaching process being demonstrated without being concerned about knowing the specific content. In order to bring about a deep appreciation for and understanding of PCK, it is not sufficient to simply hope that periodic professional development programs made available after teachers enter the field will provide deep enough experiences to have a lasting impression. Much of this must take place in pre-service teacher preparation or in subsequent advanced degree programs. But it must take place in the presence of specific classroom examples in order to foster the integration of different knowledge domains.

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An example serves to highlight this approach to teacher preparation. Van Driel, et al. (2002) discuss a series of professional development activities intended to help teachers improve their classroom practices. During the activities, teachers looked at recent research on teaching and learning. Consistently, the teachers reported deriving little benefit from the components of professional development that involved simply reading the articles and digesting them in order to improve their PK (knowledge of learning and teaching strategies). Instead, the teachers reported the most value from discussions and activities that encouraged them to apply the research to classroom practice and consider ways that they may be able to modify the technique for their content area. Teachers also reported high benefits from making use of these papers to evaluate examples of classroom observation in order to make sense of the situations observed. In effect, these instances of reflection pushed the teachers to higher levels of Bloom's taxonomy. Even though reading and understanding a research article (essentially developing PK) may be difficult due to an abundance of specialized jargon or methodologies, it still falls at the lower end of Bloom's hierarchy for thinking skills. However, by evaluating classroom experiences in light of a research article or by thinking about ways to apply an article to a different situation, higher order thinking is accessed, helping teachers transform the knowledge into effective practice.

Another concern is the nature of content specific coursework for teachers. Programs cannot simply offer additional or higher-level courses in the content area. This becomes apparent when looking at masters programs for teachers in New York State. These programs are required to include four content specialty courses. However, enrolling these candidates in standard mathematics courses for a traditional masters program will not serve the purpose of this requirement effectively, because the goals of such courses are differently aligned, typically seeking to prepare students to become researchers or practitioners of mathematics. When learning new content, Davis and Simmt (2006) argue that the "deliberate presentation of images and analogies should probably be at center stage when introducing new topics" (p. 302) because one of the key abilities of a good teacher is to negotiate among these different images and metaphors. The ability to constantly adjust metaphors requires teachers "to *translate* notions from one symbolic system to another" (p. 303). Fluency with different representations of ideas and connections within the content area is a very different focus, and it requires the development of different advanced content courses for teacher candidates.

In addition to helping candidates develop specialized content knowledge, teacher preparation programs must guard against the teaching of overly generalized notions of PCK. These dangers are pointed out by Garcia and Ariza (2004) following their study of a teacher development program. They state "we would question the utility in science teacher education of presenting psychological concepts (or concepts from any another discipline) in a directly academic form, disconnected from the processes of teaching and learning the subject … an academic presentation of the knowledge of a discipline … is neither meaningful nor useful for them to improve their professional knowledge" (p. 1238). Garcia and Ariza reinforce Van Driel's work by noting that in order for teacher education to be meaningful, teachers must have opportunities to explicitly connect theoretical and practical knowledge. This requires more than simply designing units that illustrate applications of particular theoretical constructs, since teachers recognized that teaching units developed in this manner do not accurately reflect classroom realities. These types of teaching units fail to provide solutions to common, practical concerns that arise in the average classroom, and consequently, they are difficult to implement outside the professional development experience (Garcia and Ariza, 2004, p.

1243). In addition, it is not reasonable to assume that we can send candidates into practice with examples of every possible lesson or unit they may be expected to teach; the context is constantly changing, which obviates any static curriculum materials. Teachers must, instead, develop judgment to adapt existing materials and to design new materials that respond to student needs in the moment.

The GMST Program

The master's curriculum of the Graduate Program in Mathematics, Science and Technology Education (GMST) is designed and organized around putting into practice educational theory and research relating to the ways that students learn mathematics, science, and technology. The mission of the program is to prepare teachers of grades 1-12 by endowing them with a strong background in the content of mathematics, science, and technology, as well as understanding of the particular needs of diverse learners with respect to teaching mathematics, science, and technology. Further, the program seeks to prepare leaders in the field of mathematics, science, and technology education so that constructivist, inquiry-based approaches to learning these subjects can occur for all students. Finally, the program is designed to help teachers see the commonalities among subjects in order to foster integrated, research-based instructional approaches that effectively utilize technology, assessment, and other resources.

The aim of the GMST program is to immerse teachers in a constructivist learning environment designed to provide direct experiences with knowledge and skill development in mathematics, science and technology through inquiry-based learning. The program stresses the "connectedness" that exists between the grade levels and among the disciplines, as well as the application of concepts to new situations. The teachers work together in courses that deepen their content knowledge and skills, which include the effective use of discourse and technology to strengthen their expertise in construction of appropriate and effective inquiry-based experiences, assessment of student learning, collaboration in interdisciplinary teams, and application of knowledge in new settings.

The GMST program is committed to providing an experience in which teachers interact with college faculty in an environment that encourages participants to ask, not just answer, questions and pose, not just solve, problems. The theme of the program is *Teacher as Researcher*, in the sense described by Heibert, Morris, Berk, and Jansen (2007, p. 50). If a teacher has experienced the curriculum as a researcher/explorer, then that teacher will, in turn, be able to assist students in the development of inquisitive attitudes and skills necessary to facilitate deeper student learning and skill development in mathematics, science, and technology. The faculty in this program model constructivist/inquiry pedagogical and authentic assessment strategies.

Today's real-world problems are complex, and their comprehension and solutions require knowledge and integration of several subject areas. In order for candidates to become responsible citizens capable of making informed decisions and helping their students to do the same, they must see the relevance of the material that they are learning and understand the possibilities for transferring that information to a variety of real-life situations. Learning experiences must offer the opportunity for candidates to investigate, explore, discuss ideas, develop conjectures, test hypotheses, and apply concepts to real-world problems; in other words, to be a researcher. How can we expect the students in the 21st century to be inquirers if their teachers have not had these same learning experiences in their education? Due to the nature of all real-world problems, teachers must have interdisciplinary experiences in mathematics, science, and technology from which they can develop knowledge and skills that enable them to better assist their students to live and work in a highly technological, interdisciplinary society. This does not diminish the importance of the individual discipline; rather, it acknowledges the symbiosis of these disciplines.

Candidates must complete 30 hours of traditional course work. Out of these, 9 of the units are core courses required of all students, and the other 21 are elective courses that consist of either supporting or content courses. In addition to these 30, there are six hours allocated to a culminating action research project. The required coursework models team-oriented, active learning environments and provides direct experiences with foundations in learning mathematics, science, and technology; methods and processes of inquiry and problem solving; further study of concepts in mathematics, science, and technology; the relationships among the disciplines; working in teams across grade levels and disciplines; research-based pedagogical strategies based on the knowledge of diverse learners; as well as the use of a variety of assessment methods to achieve authentic assessment.

Inquiry and problem solving skills are a key focus for the program, beginning with the first course in the program. This introduction to inquiry in the classroom uses a strong constructivist philosophy to help candidates explore the ways in which learning develops in the framework of their predispositions and history. Later coursework expands on these ideas, integrating across content areas of mathematics, science, and technology. Furthermore, the program helps candidates integrate educational technology into their teaching. Candidates also experience integration between pedagogy and content (PCK) in almost all of their coursework. In addition, technology and curriculum integration is woven throughout the program.

The culminating experience in the program requires a thesis based on action research. Candidates explore ways to improve learning in the classroom by using lesson study. Lesson study provides candidates with an additional data collection tool and reinforces the importance of being a reflective practitioner. This is an attempt to develop leadership qualities and allow candidates to demonstrate their research abilities, as well as an opportunity to step into the role of an activist striving to improve learning for all students. These opportunities result in confident researchers and practitioners. As a result of this program, candidates are able to alter the way they think about teaching and collaboration and share the change in their perspectives with others. Fernandez and Chokshi (2002) describe lesson study as “a Japanese professional development process that enables teachers to systematically examine their practice in order to become more effective instructors” (p. 128). They explain the ways that lesson study can be used to improve collaboration between teachers either at one site or across several. Teachers first select a goal and pick a lesson to study. They work together to prepare a lesson plan, then one teaches the lesson while the others observe. The group then reflects and revises the lesson, which is followed by the lesson being taught again with another reflection and revision session. The last iteration is then written up in a reflective report. This process helps teachers to become reflective practitioners. Rock and Wilson (2005) found that teachers valued lesson study as professional development not only because they believed that it encouraged them to grow as teachers, but also because it increased their confidence. They also discovered that lesson study enabled the teachers to provide differentiated instruction, improve their math vocabulary, and better incorporate math manipulatives.

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Candidates completing the GMST program receive a Masters of Science degree and initial professional certification in New York State. After completing initial certification, teachers are given five years to attain professional certification. In order to accomplish this, they must have three years of teaching experience and a related master’s degree which must have at least 12 units linking content to pedagogy. As a result of these demands, our candidates are a diverse group comprised of three populations: those who have just completed a bachelor’s degree and are now seeking to teach math or science in grades 7-12, career changers who have at least a bachelor’s degree but are not prepared to teach, and those who already have certification and are now seeking a master’s degree.

The full time faculty in the GMST program is comprised of mathematicians and scientists who also have a significant background in education. All hold a Ph.D. and have extensive backgrounds in mathematics and science education. Most have teaching experience in the K-12 setting. Besides teaching in the GMST program, they also teach undergraduate content courses. GMST also hires qualified adjunct faculty who are experts in their field. In addition to possessing a master’s degree, adjunct faculty must also have extensive experience in the K-12 classroom.

Courses In GMST and PCK

Davis and Simmt (2006) made the central argument that pedagogical and content knowledge must be integrated into the content courses for teachers. One of their key conclusions was that in order for teachers to experience processes that help them develop the rich conceptual change needed to continue growth, the programs that service them should proceed by “organizing courses in mathematics-for-teaching around doing mathematics that is new to the doers … [focusing] on, for example, the roles of metaphors and other language in the development of mathematics" (p. 316). This supports the basic foundation of the GMST courses, especially the content enrichment courses, in which students are expected to struggle with new ideas in order to experience the process of learning mathematics (or science, or technology) as a learner similar to the way their students will experience learning. Since this is a primary focus of the program, all of the courses in the GMST program integrate pedagogical content knowledge. The amount to which PCK becomes a significant part of the course depends upon whether it is a core, supporting, or content course. In the following discussion, several courses are highlighted to provide specific examples for how the program blends the three areas of teacher knowledge.

In the introductory core course of the program, Inquiry, students are exposed to the concept of inquiry as well as some of the ways one can implement it in the classroom. The students explore many types of inquiry-based activities ranging from structured to open inquiry. For instance, they start with a guided inquiry activity, and then they expand that guided activity into an open-ended investigation. This allows them to see the pedagogy of inquiry while also uncovering misconceptions they have with respect to the content. While at the beginning many students struggle with this type of learning, mostly because they have never experienced it before, most see the value and embrace it by the end of the course. Since our candidates typically have never experienced learning in this way, these experiences take them out of their comfort zone. During their exposure to inquiry, they are also delving slightly deeper into the content while reflecting on how they could use this in the classroom. Toward the end of the semester, they are required to compare the different types of inquiry and reflect on how and when they can be effectively used in the classroom. They also observe the use of guiding questions, as opposed to providing direct answers, employed as a method for helping students overcome misconceptions. A culminating experience in this course requires the students to read a book related to the nature of mathematics and science, and then they must create and implement an inquiry-based lesson based on their chosen book. This enables students to demonstrate their PCK. The pre-service teachers present their lesson to the class, and the in-service teachers must incorporate their lesson into their curriculum. After teaching the lesson, they summarize the experience and provide reflections. They present this to their classmates and provide samples of student work. The entire class then reflects on the process and the lessons. For both groups, this reflection is a significant part of the lesson, because discussion of results may have a greater impact than mere observation of technique.

Teacher educators work in one of the most complex professions in history.

Another one of the core courses, Assessment, focuses on helping candidates to understand how they can effectively assess learning. Candidates struggle to ensure that students understand the content rather than simply being familiar with it. To achieve these ends, they employ formative and summative assessments that include discussions, observations, use of technology, and traditional paper and pencil assessments. They explore the various types of questions that are used for assessments and develop an understanding of the types of questions that best correlate with assessment of knowledge, understanding or recall in conjunction with Bloom's taxonomy. Students spend time investigating their content and creating ways to engage students while simultaneously effectively assessing learning. Candidates learn quickly that without a strong content base of their own, the task of effectively assessing their students becomes insurmountable.

In the supporting course, Integrating Technology into a Learning Environment, candidates learn about the use of technology, and they become familiar with both practical issues and theoretical implications of its use. The course is project-based and focuses on theoretical research of educational technology, developing usage skills, understanding the technology, and application of the theoretical research base to the development of classroom applications. Each student presents a research paper centered on a question related to technology use, such as "what new literacy skills are required in the digital age". The culminating applications project requires that students research strategies for developing computer-based activities, including program design, and then implement their recommendations. For example, students may develop a Web Quest and explain the ways in which the design of their Web Quest fosters student learning. Students complete projects of their choice at their own pace, allowing them to focus on areas that are most valuable to their current or anticipated situations and needs. Throughout the course, candidates are developing a new set of instructional tools and conceptual understandings while constantly considering the content in which these tools will be used, thus transforming these ideas into PCK.

In the content course Geometry: Theory, Application and Technology, candidates explore the worlds of non-Euclidean geometries. The course begins by taking the students out of their comfort zone and into spherical geometry. This allows them to experience mathematics the way many of their students do. They then take a step back and explore the axiomatic systems, which lead into Euclidian geometry and other non-Euclidean geometries. The way in which this course evolves allows the candidates to uncover the other geometries by exploring *what if* questions. What if an axiom is not accepted? What does that do to the geometry? What if the metric is changed? How does that affect the geometry? During each of these explorations, there is also time to reflect on the ways that these concepts relate to the 7-12 mathematics classroom. Students create geometric portfolios using technology, manipulatives, and reflection upon classroom use.

Historical Development of GMST

The content areas have always been envisioned as the main driving force of the program. Thus, it was housed within the mathematics department at the college. In order to keep the program relevant and connected to current trends in K-12 teaching, an advisory board was formed from college faculty, K-12 teachers, and administrators. The board meets to review program issues, discuss course development, consider current trends in local education, and evaluate the program. As it is not a cohort-program, candidates can enter the program at different times and they are allowed some choices in their preparation.

The original program was designed around five strands: interdisciplinary learning, teacher as researcher, inquiry, constructivism, and curriculum standards. Courses were divided into the core, supporting, and content enrichment categories, but two significant changes have taken place as we have gained a better understanding about effective teacher preparation. First, the core courses have undergone a major revision. Originally, the core courses consisted of a foundation in the program strands, a course in problem-based learning (PBL), and a course in inquiry. Since many students in the program are just beginning their teaching experience, the PBL course was difficult for them to comprehend. The foundations course also seemed to be an inefficient use of time. We discovered a need to provide more connection to content and technology. We also recognized the importance of assessment in the learning process. This led us to change the core courses to their current structure: inquiry, assessment, and three areas of technology.

A second major change in the program involved the capstone research experience. As the program grew, from six graduates in the initial class to between 20 and 30 candidates per class, the original design of the research courses broke down. Candidates from the first classes worked closely with a faculty member to develop an action research project. This process was supported with coursework in methodology for conducting action research, and candidates benefited greatly from the experience. The two semesters of closely guided action research led many of our candidates to grow deeply in their understanding of the program strands as related to their own teaching. Unfortunately, the process was faculty time-intensive, due to the individual nature of the projects. Our solution was to focus the projects. Using a lesson study design, all students now develop a capstone project involving collaboration and reflection. With more focused methodologies, the research courses can now involve more candidates in an efficient way, while still capturing much of the value of the old experience.

At the same time these changes were being implemented, all programs leading to either initial or advanced teaching certificates at our school were undergoing accreditation with both the state of New York and NCATE. The demands of overseeing the program thus increased, which necessitated a slight change in the administrative structure. Formerly, the program was housed in the mathematics department, and the department chair served as the program director. Now there is a separate faculty member serving as program director. This also allowed the director of the program to spend more time on the candidate applications, interviewing each individual prior to admission into the program. Enrollment in the program steadily increased over the next several years, as word of it spread and as the quality of our graduates became apparent. Two local school districts (one a high-needs urban district and the other suburban) now pay for their teachers to complete our program in order to receive professional certification (now required from all K-12 teachers in New York State.), and this buy-in has contributed significantly to the increase in program popularity.

The NCATE accreditation process also highlighted a major issue in program governance. Since the final decision about candidate certification was controlled by the school of education, and our program was housed in the school of arts and sciences, a formal agreement had to be reached in order to allow our program autonomy while still being connected to the process. The college thus formed a separate unit, the Professional Education Unit (PEU), which is composed of members from all certification-related programs. The multidisciplinary nature of the program also led to significant issues in accreditation, both at the state and NCATE levels, since these required separate program submissions for each certification area, and our program can lead to certification for mathematics, biology, chemistry, or physics. Our dual status in both content and teacher preparation led to considerable tension from both education and arts and sciences faculty. The formation of the PEU and the organization of the college into schools significantly reduced this tension.

One major concern throughout the history of the program has been identifying quality faculty. The interdisciplinary nature of the program and the PCK-focus require the faculty to be content specialists with a significant background in education. Since many of the full-time faculty teach in both the undergraduate content majors and the graduate program, adjunct faculty are vital aspects of the program. However, as the program has developed, many of our earlier graduates are now distinguished teachers themselves, and we have been able to bring several of them in as faculty.

The program has continued to grow and develop. It maintains a strong reputation in the area, which is vital, since within 50 miles there are roughly 10 major colleges and universities that offer Education programs. Although the need for highly qualified teachers of mathematics and science is significant, many certified teachers have difficulty finding positions in their content areas locally, but our candidates have not, typically, had difficulty securing positions. In fact, all of the candidates who graduated from GMST in spring 2007 have positions in their content area. Even more significant, we think, is that even though there are many teacher-preparation programs nearby, our graduate program is the only one that certain school districts will pay for their teachers to complete.

Conclusion

Teacher educators work in one of the most complex professions in history. We are preparing teachers to teach in a constantly changing world, and for this reason, preparing them with a fixed, bounded set of skills and concepts seems a disservice. The "Did you know? 2.0" video by Fisch, McLeod, and XPLANE (2007) makes this point quite clearly, drawing on a wide array of data and trend analysis to support its conclusion: teachers are teaching students in a world where the pace of change forces much of the content they learn to be out of date before graduation. In this world, problems that do not now exist will need to be identified and solved. The implications for teachers are staggering, which makes our job as teacher educators even more challenging. Not only do teachers learn from their own practice and continue exploring their teaching so that they can grow and adapt to the changing world, but we must also continually update our practice in preparing these teachers so that candidates are prepared to teach in this way. This means preparing teachers with base concepts in content and pedagogy, developing skills in implementing various teaching strategies, and understanding the ways in which student learning develops. Most important of all, we have argued, is that teachers need to develop a metacognitive knowledge about the reasons that they are teaching the way they do and ways in which to study their teaching in order to learn more from the process.

It is far too early to know whether any of us are really accomplishing these goals of fully preparing teachers for the 21st century. The GMST program we have discussed began in 1997 and has already experienced a significant reorganization. The fact that the program is growing, has a good reputation, and has received accreditation from NCATE and the state of New York seems to indicate that it is possible to design successful programs around alternative models of teacher preparation. Providing a space where many different models can thrive is of vital importance if we are to ever learn more about effective ways for teachers to learn to teach. Throughout these models, though, we must stress the importance of having programs for teachers that expand on their content while explicitly linking content and pedagogical practices. One efficient mechanism for this is through reflective practice, which is necessary, but not sufficient, for preparing prospective teachers to quickly and effectively adjust to shift in math, science, and technology. We believe strongly that our program is accomplishing this goal by developing strong, reflective teachers.

We have now reached the point in the program where it is possible, and indeed necessary, to perform longitudinal studies. These studies need to follow up not only on recent and past graduates and their students, but they must also focus on exploring the "ripple effect" we suspect our graduates are having on their departments, grade levels, and schools. The reason that we suspect our graduates are positively affecting their communities is that many of our candidates find themselves in positions of leadership (not necessarily authority) shortly after completing the program. One recent student exemplified the leadership capabilities of our graduates when his comments at meetings directly resulted in his spearheading a mission to bring lesson study into the district as their central focus for future professional development. Many of our candidates experience the first glimpse of their new roles as leaders during their student teaching when they are asked to share some of the methods they utilize with which the current teachers are unfamiliar, and some districts have even requested that our faculty meet with them in order to discuss and elaborate on the skills demonstrated by our student teachers.

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Peer-Led Team Learning: A Prospective Method for Increasing Critical Thinking in Undergraduate Science Courses

This study examined the impact of Peer-Led Team Learning (PLTL) on critical thinking gains in science and math courses at a research university in the Pacific Northwest.

In their search for more effective ways to teach college-level science, technology, engineering, and mathematics (STEM) courses, many instructors employ small groups to improve student learning outcomes. Small group learning is considered a best practice in undergraduate education (Angelo & Cross, 1993; Chickering, Gamson, & American Association for Higher Education, 1989; Cooper, MacGregor, Smith, & Robinson, 2000; Springer, Donovan, & Stanne, 1999). National associations recommend small group instruction to promote thinking skill in STEM courses (American Association for Higher Education, 1989; National Research Council, 1995; National Science Foundation, 1996; Tobin, 1993; Tobin, Tippins, & Gallard, 1994; United States Department of Education, 1990).

Peer-Led Team Learning (PLTL) is a specific form of small group learning recognized by Project Kaleidoscope as best practice pedagogy (Varma-Nelson, 2004). PLTL was first developed by Woodward, Gosser, and Weiner (1993) as an integrated method that promoted discourse and creative problem solving in chemistry at the City College of New York. The PLTL method is thoroughly described in other works (Cracolice & Deming, 2001; D. Gosser et al., 1996; Gosser et al., 2001; Gosser et al., 2003; Gosser & Roth, 1998; Woodward et al., 1993). Briefly, PLTL is characterized by a cohort-based social learning structure whereby trained undergraduates, or "peer leaders", guide 4-8 less experienced peers toward conceptual understanding through group-focused science and math problem solving (Cracolice & Deming, 2001; Gosser et al., 2003; Gosser & Roth, 1998; Lyle & Robinson, 2003). Peer leaders are not expected to be content experts or surrogate instructors; rather they are students who have successfully completed the course and have been trained in small group dynamics and learning theory. PLTL usually serves as a supplement to traditional lecture, although some replace a portion of weekly lecture with a PLTL session (Alger & Bahi, 2004; Lewis & Lewis, 2005). Student attendance may be voluntary, pass/fail, or graded. Weekly PLTL sessions are typically 1.5 – 2 hours long, during which time students explore and develop creative solutions to problems. PLTL is thought to work because students who are at similar developmental levels socially negotiate and construct individual meaning (Bruffee, 1993; Collier, 1980; Jones & Carter, 1998; McKeachie, 1990; Springer et al., 1999; Tobin et al., 1994; Vygotsky, 1978). By providing a framework that encourages questioning, analysis,

Peer leaders are not expected to be content experts or surrogate instructors; rather they are students who have successfully completed the course and have been trained in small group dynamics and learning theory.

discussion, and debate among group members, PLTL is thought to help students collaboratively build their knowledge and master course material (Gosser & Roth, 1998; Jones & Carter, 1998; Springer et al., 1999; Tobin et al., 1994; Woodward et al., 1993).

Influence of PLTL on Student Learning

The positive effects of PLTL on grade performance and student retention are well established. Previous research indicates that PLTL increases the percentage of students receiving an A, B, or C grade and decreases the percentage of students that fail, withdraw, or drop relative to traditional, non-PLTL courses (Alger & Bahi, 2004; Gafney, 2001a; Lyle & Robinson, 2003; Tien, Roth, & Kampmeier, 2002; Tien, Roth, & Kampmeier, 2004; Wamser, 2006). PLTL has been employed in organic chemistry, general chemistry, human anatomy and physiology, and other STEM courses, with grade improvements ranging from 1-29% (Gafney, 2005). PLTL has also improved student retention by as much as 12% at some institutions (Gafney, 2001a).

The positive, but variable, effects of PLTL on grade performance and retention in STEM courses are based primarily on course grade distributions using either control groups or historic grade performance before and after PLTL implementation (Cracolice & Deming, 2001; Gafney, 2001a; Gosser et al., 2003; Lyle & Robinson, 2003; Tien et al., 2002). This provides fodder for skeptics who question PLTL effectiveness and argue that studies based on student grades (Gafney, 2001a; Gunawardena, 2001; Tien *et al.*, 2002; Wamser, 2006; Zurer, 2001) do not provide sufficient evidence because of their subjectivity. For students who experience PLTL in addition to lecture (the most common method), skeptics contend that PLTL students receive higher grades and are more frequently retained because they spend more time on content and problem-solving. Conversely, skeptics argue that students who experience PLTL in lieu of some lectures (a less common method) have higher performance because they are held to mastering less content (Gunawardena, 2001).

Several different types and levels of science and math courses were chosen to determine the range over which PLTL might affect critical thinking, as well as grade performance and retention.

Some studies have tried to minimize subjectivity by using common test bank questions (Alger & Bahi, 2004), analyzing total points prior to assignment of final grades, and maintaining a consistent point threshold for a passing grade (Tien *et al.*, 2002; Wamser, 2006). Others have employed standardized instruments like the American Chemical Society (ACS) test, with mixed results. One study showed no significant differences in pre- and post-test ACS scores between PLTL and non-PLTL groups in general chemistry but did show increased lecture exam scores in the PLTL group (Alger & Bahi, 2004). Another study showed PLTL students in organic chemistry increased their standings in terms of national percentile on the ACS exam relative to a non-PLTL group (Wamser, 2006).

Perhaps of greater concern than grade or standardized test performance is the lack of evidence that shows PLTL students become better critical thinkers than non-PLTL students. PLTL will continue to be criticized until research clarifies this point. Critical thinking is a better measure of student learning than course grades or discipline-specific exams, because it is a common requirement in all STEM disciplines, and because the component skills of critical thinking (Ennis, 1985; Facione & American Philosophical Association, 1990; Walsh & Paul, 1986) can be compared across different STEM content areas, such as science or math.

Purpose of the Study

The purpose of this study was to discover if PLTL influences critical thinking in STEM courses. Several different types and levels of science and math courses were chosen to determine the range over which PLTL might affect critical thinking, as well as grade performance and retention. This multi-layered approach was selected in order to assemble a more complete picture of PLTL effectiveness in STEM courses and to compare potential critical thinking gains across these disciplines. The research questions for this study were:

1. Does PLTL affect critical thinking performance?
2. Do critical thinking gains vary by STEM discipline?
3. Which variables have the largest impact on critical thinking gains?

Methods

Study Context

PLTL was implemented in six undergraduate science and math courses at a research university in the Pacific Northwest according to established PLTL criteria (Gafney, 2001a, 2001b; Varma-Nelson, 2004). Critical thinking was assessed at the beginning and end of several organic chemistry and mathematics courses (see Table 1) using the valid and reliable CCTST (Facione, 1990). Science and math courses were included in the sample, because it was assumed both course types required critical thinking for success. PLTL was employed in some manner in all courses except Discrete Mathematics, which served as a non-PLTL comparison group for critical thinking. Participant demographics are provided in Table 1.

Implementation of the PLTL Model

The choice to use PLTL initially came from a small group of organic chemistry faculty at a research university in the Pacific Northwest that wanted to improve undergraduate critical thinking. Given the reality of teaching large lectures (over 150 students), faculty wanted to give students a more engaging experience than traditional teaching methods had provided, as well as reduce the student fail, withdraw, and drop rate, which had periodically exceeded forty percent. Chemistry faculty first identified student goals for courses based on ACS-recommended learning outcomes (American Chemical Society Committee on Professional Training, 2003a, 2003b). PLTL was chosen after several group learning models were evaluated. Conversations between chemistry and math faculty and shared learning goals eventually led to an invitation to use PLTL in four mathematics courses.

Successful implementation of PLTL required changes to faculty teaching styles. A PLTL learning community comprised of chemistry and math faculty, graduate coordinators, learning specialists, and undergraduate peer leaders was formed. In general, less emphasis was placed on individuals than on group efficacy. This required faculty to reevaluate their role in student learning, a task that proved difficult for some. Faculty provided content and problem solving expertise, organization, and scheduling for PLTL sessions and presented lectures on basic science or math concepts that were subsequently discussed during weekly peer leader training sessions. Graduate coordinators were chosen based on interest in STEM education, and, between PLTL sessions, they served as rovers in order to provide continuity and assistance. Graduate coordinators also helped train peer leaders, and observed peer leader (and faculty) implementation of PLTL during the term.

Successful implementation of PLTL required changes to faculty teaching styles.

Scheduling PLTL sessions for a large number of students was a logistical challenge. One lecture per week was replaced with a two-hour PLTL session that took place on Wednesday, Thursday or Friday. Software was used to assign four to eight students to specific peer groups based on schedule availability. PLTL attendance was mandatory for all courses, except for one section of Organic Chemistry II (optional) and Discrete Mathematics (non-PLTL comparison group). Students worked with their assigned groups for the entire term unless significant problems required transfer to another group.

Peer Leader Recruitment and Training

Peer leaders were recruited from a pool of students that had successfully completed the class and earned at least a B grade. Prospective peer leaders completed a written application and interview, which were discussed by course instructors and graduate coordinators. Interview questions were chosen from a PLTL handbook (Roth, Cracolice, Goldstein, & Snyder, 2001). Selected peer leaders received a stipend of $500 per semester. A one credit special topics course was also available for chemistry peer leaders. Math peer leaders were incorporated into an existing tutoring program.

PLTL training based on the national PLTL model (Roth *et al*., 2001) was conducted prior to the start of the term in conjunction with the university's Center for Teaching and Learning. Discussed topics included multiple intelligences (Gardner, 1987), the key role of the peer leader, methods for building group dynamics, and methods for modeling problem solving and critical thinking. Particular emphasis was placed on ability to: (a) ask leading questions, (b) stimulate peer interaction and group problem solving, (c) balance boisterous and reserved student personalities, (d) allow sufficient wait time, and (e) treat all students with respect.

Instructors and peer leaders met weekly throughout the academic term to draft problem sets and discuss problem solving strategies. Problem sets expanded on lecture concepts and were sufficiently rigorous as to require group work. Conceptual understanding of course material was emphasized over rote memorization. Peer leaders were not informed of the "correct" solution to the problems, nor were they expected to provide one for the students. Rather, instructors discussed a range of possible ways to approach the problem set, provided hints for reasonable problem solving pathways, and suggested appropriate leading questions that peer leaders could use with their group during the week. Ongoing challenges, role-playing scenarios, testimonials from experienced peer leaders, and techniques for overcoming common conflicts (e.g., dominant students) were also addressed.

Scheduling PLTL sessions for a large number of students was a logistical challenge.

A Typical PLTL Session

Four to eight students met weekly with their peer leader to address the problem set, which was provided at the beginning of each session. Students assembled into groups in their assigned rooms and, once they received the set, began by clarifying the intent of each problem. Then, students began to free think creative approaches to the problem by verbally describing, drawing, or representing their thought process on a whiteboard or butcher paper. Students analyzed the elements of each problem, discussed potential solution pathways, and argued over the relative merits of each approach until they reached a consensus. A peer leader roamed the room, asking leading questions to stimulate thinking, promoting group efficacy, and addressing student frustrations. Students were allowed to use any available resource, including textbooks. Each group's consensus solution was then shared out to other groups using course management software; this allowed each group to compare their work with others and to reflect on their problem solving effectiveness. Each group received process and solutions feedback from the course instructor. Course instructors further reinforced the PLTL model by including similar types of problem solving questions on exams.

Organizational and Institutional Support

The pedagogical vision, instruction, and organization provided by the learning community were necessary, but insufficient, to fully implement PLTL. Administrative support at the college and departmental levels was also necessary. Initial support was provided through internal professional development funding; however, PLTL continuation required institutional support. Previous reports by Kampmeier (2003) suggest a PLTL maximum cost per student of approximately $100; in the current study, a target cost of $62 per student was used. To fund PLTL after grant funds were depleted, $25 was collected as a course fee, $25 was matched by the College of Science, and the remaining $12 per student was funded by the Department of Chemistry. The rationale used to justify institutional expenses included increased student retention, stronger student preparation, and increased student satisfaction.

Research Design and Data Analysis

A quasi-experimental pretest/posttest control group design was used to determine critical thinking gains in PLTL/non-PLTL and science/math groups. This design minimizes threats to internal and external validity (Campbell & Stanley, 1963) and was appropriate because intact groups were used. Remaining threats of history, maturation, pretest sensitization, selection, and statistical regression toward the mean were minimized by administering CCTST pretests and posttests 14 weeks apart, using a valid and reliable instrument to assess critical thinking (Facione, 1990) and including multiple co-variables (e.g. gender, class standing) in the statistical analysis. A frequency distribution of critical thinking gains was constructed to evaluate sample randomness.

An embedded experiment for Pre-Calculus was conducted within the context of the quasi-experimental design. Four concurrent sections of Pre-Calculus Math provided an opportunity to more specifically investigate PLTL impacts in math while controlling for instructor and course. Two instructors each taught two sections of Pre-Calculus, one of which utilized PLTL and the other of which did not. Critical thinking gains were then compared between PLTL and non-PLTL sections by instructor and course.

Influence of PLTL on Critical Thinking Gains, Grade Performance and Student Retention

Students were divided into PLTL and non-PLTL groups, or science and math groups, and the impact of PLTL on critical thinking gains was assessed. Critical thinking was determined using a paper version of the CCTST (Facione, 1990; Facione, Facione, & Giancarlo, 1992; Facione, Facione, & Insight Assessment, 2004). Raw scores were used for all analyses, but in some cases scores are reported as national percentile rank based on an equivalency conversion scale provided by the test manufacturer in order to increase clarity and relevance. Critical thinking gains were compared between PLTL/non-PLTL and science/math groups using mean, standard deviation, and effect size, as well as two-way repeated measures analysis of variance (RM ANOVA). The two-way RM ANOVA was employed due to the use of matched pre- and post-test scores and a comparison group. Gender, ethnicity, academic term, and class standing co-variables were concurrently analyzed in order to increase statistical accuracy and precision and minimize validity threats. RM ANOVA assumptions of homogeneity of variance, co-variance, and normality were evaluated using Levene's and Box's tests and by constructing a frequency distribution of critical thinking gains, respectively.

Grade performance and student retention was analyzed using percent of students receiving an A, B, or C grade in the course (%ABC), and percent of students that failed (D or F grade), withdrew, or dropped the course (%FWD). Percent ABC and % FWD were each subsequently divided into female and male categories and compared across PLTL and non-PLTL groups.

Table 1: Demographics for PLTL and Non-PLTL Groups by Course

Method	Course	N	Class Standing (%)					Gender (%)	
			Fr	So	Jr	Sr	2nd Sr	M	F
PLTL	CHEM 340	212	5	55	29	10	1	40	60
	CHEM 342	62	2	50	29	18	2	44	56
	MATH 251	25	44	28	28	0	0	8	92
	MATH 252	27	0	30	59	11	0	11	89
Non-PLTL	MATH 107	142	79	13	6	2	0	63	37
	MATH 216	84	11	37	43	7	1	86	14
Total		552	26	39	26	8	1	50	50

Table 1a: Demographics profile for the study sample

Method	Course	N	Ethnicity (%) Caucasian	Asian American	Latino	African American	Native American	Other*
PLTL	CHEM 340	212	86	5	0	1	2	5
	CHEM 342	62	87	6	0	5	2	0
	MATH 251	25	84	12	0	0	0	4
	MATH 252	27	96	0	0	0	0	4
Non-PLTL	MATH 107	142	78	6	4	2	1	8
	MATH 216	84	65	17	0	1	0	17
Total		552	82	7	1	2	1	7

Course names refer to first and second term organic chemistry for majors (CHEM 340, 342); pre-calculus (MATH 107); first and second term mathematics for elementary teachers (MATH 251, 252), and discrete mathematics (MATH 216).
*Includes 'choose not to answer' response.

Results

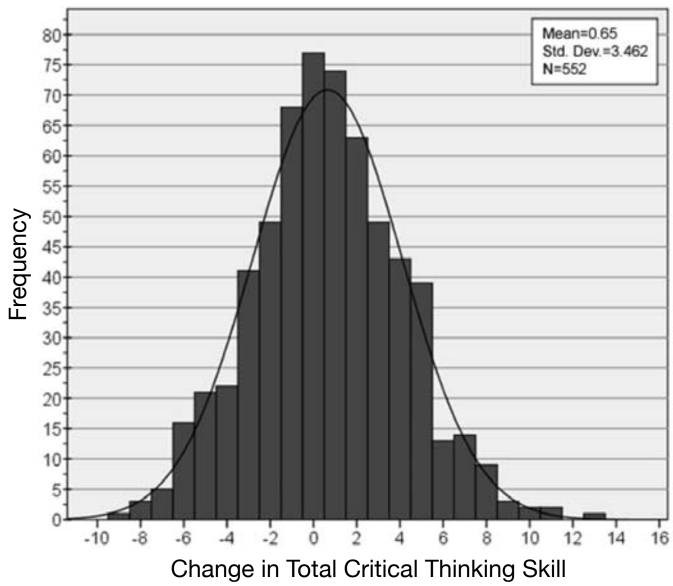
Participant Demographics

A distribution of class standing, gender, and ethnicity (see Table 1) indicated that the majority of students were sophomores and juniors except for in the Pre-Calculus course, which was comprised mainly of freshmen. Although gender distribution was an even split for the total sample, it varied considerably by course, with predominantly female class composition in the Math for Elementary Teachers course and predominantly male class composition in the Discrete Mathematics course. Over 80% of participants were Caucasian, with Asian American, Other, African American, Latino/Hispanic, and Native American students comprising the remainder in decreasing frequency (Table 1a).

Statistical Assumptions

The Levene's and Box's tests used to evaluate critical thinking gains showed that the homogeneity of variance and co-variance assumptions were met for the PLTL/non-PLTL group, $F(1, 549) = 0.100$, $p = 0.752$, and $F(3, 542) = 1.361$, $p = 0.253$, but not for the science/math group, $F(5, 545) = 5.264$, $p = 0.000$, and $F(15, 530) = 3.068$, $p = 0.000$. Figure 1 shows that the distribution of critical thinking gains approximated a standard normal curve.

Figure 1: Frequency Distribution of Critical Thinking Gains



Distribution of critical thinking for the experimental sample. Gains are indicated by difference in CCTST pretest and posttest raw scores.

Influence of PLTL on Critical Thinking Gains

A significant interaction was observed for critical thinking gains and PLTL, Wilk's $\lambda = 0.984$, $F(1, 545) = 9.068$, $p = 0.003$, power = 0.852, partial $\eta^2 = 0.016$. Table 2 shows raw score gains in PLTL and non-PLTL groups. PLTL accounted for 1.6% of the variance in critical thinking gains, with PLTL students demonstrating approximately 9 times greater gains than non-PLTL students in science but not math courses. PLTL students had an average national rank increase of 5.38 (61^{st} to 66^{th} national rank). Figure 2a shows critical thinking national percentile gains in PLTL and non-PLTL groups.

Gender, ethnicity, class standing, and academic term did not significantly affect critical thinking gains. In contrast, a post hoc comparison of gains relative to prior critical thinking showed that students with the highest prior skill had the largest gains in critical thinking, whereas students with low prior skill exhibited the largest decreases. Specifically, students scoring 2 standard deviations above the sample mean gained nearly 39 percentile (44^{th} to 83^{rd} national rank). As prior thinking skill decreased, performance dropped steadily, with gains of 18 percentile (53^{rd} to 71^{st} national rank) for +1 standard deviation, decreases of 2 percentile (65^{th} to 63^{rd} national rank) for -1 standard deviation and decreases of 23 percentile (72^{nd} to 49^{th} national rank) for -2 standard deviation of prior thinking skill.

Influence of Course Type on Critical Thinking Gains

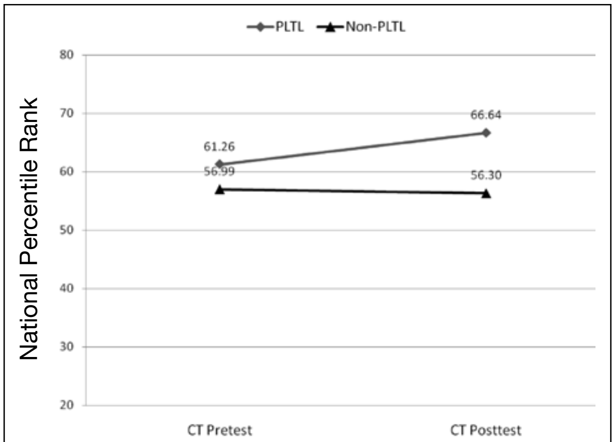
A significant interaction was also observed between critical thinking gains and course type, Wilk's $\lambda = 0.973$, $F(5, 541) = 3.049$, $p = 0.010$, power = 0.869, partial $\eta^2 = 0.027$. Science students showed average critical thinking gains of 6.27 percentile (67^{th} to 74^{th} national rank), whereas math students showed average gains of 0.95 percentile (53^{rd} to 54^{th} national rank). Course type accounted for 2.7% of critical thinking gains, which was nearly 6 times greater for science students than math students. Figure 2b shows critical thinking national percentile gains by course type.

Table 2: Influence of Method on Critical Thinking Raw Score Gains

Method	Course	N	Mean (pre)	S.D. (pre)	Mean (post)	S.D. (post)	CT Change
PLTL	Chem 340	212	19.69	5.01	21.03	4.65	1.34*
	Chem 342	62	20.52	4.73	21.42	4.92	0.9*
	Math 251	25	15.48	3.33	15.60	3.99	0.12
	Math 252	27	16.11	3.33	16.56	3.71	0.45
Non-PLTL	Math 107	142	16.73	3.91	16.94	4.00	0.21
	Math 216	84	19.31	6.20	19.14	6.40	-0.17
Total		552	18.60	5.04	19.23	5.16	0.67

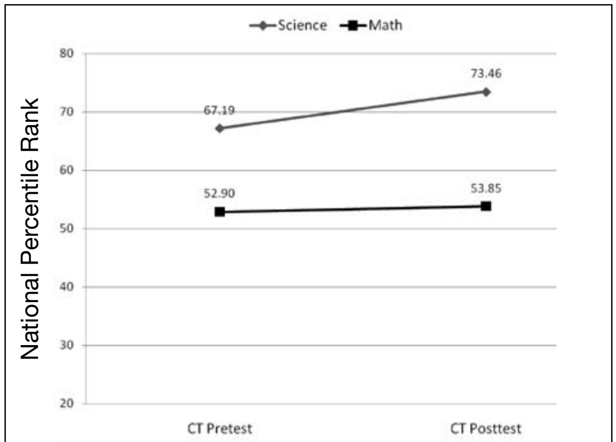
Critical thinking gains indicated by CCTST raw scores. Course names refer to organic chemistry for majors (CHEM 340, 342); pre-calculus (MATH 107); mathematics for elementary teachers (MATH 251, 252) and discrete mathematics (MATH 216). S.D. indicates standard deviation.
*Significant at 0.05 level.

Figure 2a: Influence of Method on Critical Thinking National Percentile Gains



Comparison of critical thinking gains between PLTL and non-PLTL groups. National percentile ranking was computed from CCTST raw scores using an equivalency scale from Insight Assessment and a linear conversion script in SPSS. Values above data points represent mean national percentile rank.

Figure 2b: Critical Thinking Gains by Course Type



Comparison of critical thinking gains between science and math groups. National percentile ranking was computed from CCTST raw scores using an equivalency scale from Insight Assessment and a linear conversion script in SPSS. Values above data points represent mean national percentile rank.

Influence of PLTL on Grade Performance and Student Attrition

Historical and PLTL grade performance was compared using %ABC to indicate achievement (see Table 3). Comparisons were based on total percent of students receiving A, B, or C grades; male and female %ABC was also determined for both science and math courses. In general, science students showed a 3% increase in total %ABC when historical (65%) and PLTL (68%) grade performance were compared. The science course grade improvement corresponded with critical thinking gains of approximately 7 national percentile. When analyzed by gender, female science students showed a 12% increase (60% historical to 72% PLTL), whereas male science students showed a 5% decrease in %ABC (70% historical to 65% PLTL). These results indicated that female science students, who on average performed less well than males prior to PLTL, erased those deficits and outperformed males when PLTL was used.

Although no significant critical thinking gains were observed for math students, they did show an 11% increase in total %ABC when historical (66%) and PLTL (77%) grade averages were compared. Female math students showed a 10% increase (67% historical to 77% PLTL), whereas male math students showed a 1% increase (64% to 65%) in %ABC. These results indicated that female math students, who on average performed at about the same level as males historically, outperformed males when PLTL was used.

Historical and PLTL attrition was also compared. For both science and math courses, total %FWD was calculated, as well as female and male %FWD. In science courses, PLTL students had 3% lower attrition than they had historically. When analyzed by gender, 12% percent fewer females

Instructors and peer leaders met weekly throughout the academic term to draft problem sets and discuss problem solving strategies.

failed, withdrew, or dropped science courses when PLTL was employed. In contrast, 5% more males dropped when in PLTL science courses. Lower attrition was seen in all math courses using PLTL; total %FWD went down 9% (33% to 26%), female %FWD decreased by 10% (33% to 23%), and male %FWD decreased by 1% (36% to 35%). Collectively, grade performance and student attrition data indicated that male-biased historical advantages were reduced or eliminated when PLTL was used. In all cases, use of PLTL served to equalize grade performance and reduce attrition gaps between males and females.

Table 3: Grade Performance and Retention by Method and Discipline

Course	Historical Baseline (1997-2000)						PLTL (2000-2001)					
	%ABC			%FWD			%ABC			%FWD		
	Total	F	M	Total	F	M	Total	F	M	Total	F	M
CHEM 340	67	63	71	33	37	29	67	67	66	33	33	34
CHEM 342	63	57	69	37	43	31	70	77	63	30	23	37
MATH 107	50	55	47	50	45	53	60	66	56	40	34	44
MATH 251	67	67	62	33	33	38	75	77	65	25	23	35
MATH 252	75	75	71	22	25	29	86	88	76	13	12	24
MATH 216*	59	66	58	41	34	42	80	71	81	20	29	19
Total Science	65	60	70	35	40	30	68	72	65	32	28	35
Total Math	66	67	64	33	33	36	73	77	65	26	23	35

Historical and PLTL grade performance and course attrition indicated by percent students passing the course (%ABC) or failing, withdrawing, or dropping (%FWD) the course, respectively. Course names refer to organic chemistry for majors (CHEM 340, 342); pre-calculus (MATH 107); mathematics for elementary teachers (MATH 251, 252); and discrete mathematics (MATH 216). *Course used as a non-PLTL comparison group.

Discussion

The purpose of this study was to discover whether PLTL could promote critical thinking in undergraduate STEM courses. Results indicated that PLTL students showed small but significantly greater critical thinking gains than non-PLTL students in science but not math courses. National percentile gains indicated PLTL had a practical influence on critical thinking, an outcome not observed in non-PLTL courses. Critical thinking gains were unaffected by gender, ethnicity, class standing or time of year; however, students with high prior thinking skill gained disproportionately more than students with low prior skill. PLTL appeared to reduce gender-based grade bias, with females receiving passing grades more frequently and dropping or failing the course less frequently than in non-PLTL courses.

PLTL appeared to help underperforming students make positive gains in critical thinking. For example, the largest gains in critical thinking in this study occurred during a second-term Organic Chemistry I course containing a high percentage of students who previously had failed the course (PLTL was not used). In these PLTL courses, average gains of 17 national percentile were seen, which is surprising since these students were 18 national percentile lower than their peers at the onset of the class. These results indicate PLTL may provide a venue for underperforming science students to develop necessary critical thinking skills.

In order to ensure fairness and consistency for all students, institutions of higher education should consider explicitly teaching critical thinking skills rather than assuming all students possess them *a priori.*

Although gender did not influence critical thinking gains, females, who had historically lower grade performance and retention in both science and math courses, were retained and received passing grades more frequently than males when PLTL was employed. Male biased grade performance and retention issues were essentially erased, and in some cases they were reversed to favor females in both science and math courses using PLTL. While it is not completely clear which particular aspects of PLTL helped, it is reasonable to suggest that the collaborative nature of PLTL supported increased female performance and retention. Conversely, males may have done less well in PLTL courses than historically due to an emphasis on collaboration instead of competition. Collectively, this data seems to indicate that PLTL helps ensure a more level playing field for student learning, regardless of gender.

Instructor commitment to PLTL also played an important role in critical thinking gains. A comparison of gains in Organic Chemistry I between successive fall terms showed highly consistent results (6.24 and 6.19 national rank increases, respectively) when both courses were taught by a strong PLTL advocate. Furthermore, when Organic Chemistry I and II were taught in successive terms by the same instructor, students showed a 6 percentile and additional 4 percentile gain for the first and second terms, respectively. It may be that students reach a saturation point for gains in critical thinking with particular instructors; however, this interpretation is speculative and will require additional research.

Frequent observations indicated that chemistry instructors integrated PLTL into courses more deeply than most of the math instructors. This may have occurred because the PLTL model is well established for chemistry courses (Baez-Galib, Colon-Cruz, Resto, & Rubin, 2005; Gosser & Roth, 1998; Gosser, Strozak, & Cracolice, 2006; Kampmeier, Wamser, Wedegaertner, & Varma-Nelson, 2006; Lewis & Lewis, 2005; Lyle & Robinson, 2003; Tien et al., 2002; Wamser, 2006; Woodward et al., 1993; Zurer, 2001), but it is less developed in mathematics. Although verbally supportive of PLTL, Pre-Calculus instructors and peer leaders seemed to have difficulty adjusting to the PLTL model, which required them to make a philosophical and pedagogical shift. PLTL had been implemented in Organic Chemistry I and II for one year prior to the rollout in math, so many chemistry peer leaders had opportunity to refine techniques that most math peer leaders were using for the first time. Many of the Pre-Calculus peer leaders also taught as tutors in other math courses, and they may have been unable to separate these differing roles. Thus, the lack of PLTL-based critical thinking gains in Pre-Calculus may have had less to do with the model than with improper implementation, insufficient support, or lack of developed materials.

It was not possible to compare PLTL effectiveness to historical performance, because no baseline measures of critical thinking were collected prior to this study. However, the notion that students with low initial skill may be at a comparative disadvantage is troubling. Considering that many STEM courses require critical thinking for success, students without the necessary prerequisite skills could face an uphill battle that becomes increasingly more difficult as they progress through an undergraduate program. In order to ensure fairness and consistency for all students, institutions of higher education should consider explicitly teaching critical thinking skills rather than assuming all students possess them *a priori*.

The relative lack of within-course controls constitutes a limitation of this study. No pre-PLTL assessment of critical thinking was performed, so it was not possible to determine whether critical thinking gains in Organic Chemistry I courses were a function of the PLTL treatment. PLTL was used in Organic Chemistry I for one year prior to this study; as such, it was not possible to wash out previous PLTL experiences in order to establish a pre-treatment critical thinking baseline. Discrete Mathematics was used in an attempt to provide some context for critical thinking in the absence of PLTL, and course type was included as an RM ANOVA co-variable to more specifically investigate critical thinking across science and math disciplines. However, there is no way to know which student critical thinking gains would have been prior to PLTL implementation.

Developing a PLTL program is not a trivial undertaking. Successful PLTL implementation requires well-trained peer leaders and committed faculty who believe in the method. Like others (Cracolice & Deming, 2001; Tien et al., 2002), this study found that administrative support (i.e., funding, section enrollment, and room scheduling, copying, etc.) is essential to successful PLTL.

Conclusions

Results of this study show that PLTL has a small but positive impact on critical thinking gains in some science courses, and that it improves grade performance and retention in science and math courses, particularly for females. While math students did not show significant critical thinking gains, it is premature to conclude that PLTL does not promote critical thinking in math. Many factors affect the development of critical thinking skills, and more study is necessary to discover their influence. These results indicate PLTL has potential to improve undergraduate critical thinking. Continued development of PLTL and related methods may serve to further enhance critical thinking gains for undergraduate learners.

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Claire Bove

What Happens When Even the Teacher Doesn't Know What the Next Experiment Will Be?

The author describes the educational and professional experiences that helped shape her approach to teaching middle school science through open-ended inquiry in an urban middle school setting.

For many years, I taught science in an urban middle school. One thing I learned during those joyful, stressful years was that teaching science through inquiry is almost impossible. This is the story of my attempt to teach science through open-ended inquiry and the moments when it becomes, briefly, possible. I offer this account, not as a blueprint, but as a report from the field, in the hope that it may spark in other teachers, principals, science resource specialists, and others, new ideas to apply to their own, unique situations. This is the story of one year during which my seventh grade students and I investigated the concepts of density and buoyancy. I also describe the particular factors in my education, reading, and experiences that influenced me to try to teach in this way.

Background: A University Lab Group

A long time ago, when I was an undergrad at a research university, I worked in a cell biology lab. My lab was investigating cell division in a beautiful, little diatom (algae) called *Cylindrotheca fusiformis,* and I was in charge of the electron microscope part of the investigation. It was excruciatingly laborious and deeply fascinating. There was a lab meeting every week, and each week, one of the group members would present so that we all would be informed of everyone's activities and processes. We would ask questions and help each other interpret our interim results. Sometimes, one of the group members would be preparing to present at a conference. The others would play the role of the conference audience, and people would ask, "Do you want us to be an easy audience or a tough audience?". I was one of the most junior members of the group, but I also presented and took part in the discussion.

In these meetings, I learned a lot about the process of scientific inquiry. The head of the group was a professor. There were three post docs, three doctoral students, a lab technician, and two undergrads in the group. With the exception of the other undergraduate, everyone knew much more than I did, but none of these people knew the answers to the questions we were investigating. The professor, although he didn't know the answers, knew a lot about finding answers, and he was good at guiding us to the most promising course. As a result, I learned a lot. But learning, in an academic sense, wasn't the main point. The point was to use the questions and projects that we were working on to discover new knowledge.

After I started teaching middle school, I thought a lot about ways to bring the experience of actively participating in science to my sixth and seventh grade classrooms. There are, of course, one or two differences between a university lab group and a middle school classroom. For example, a bored post-doc can retreat into an inner world to contemplate a research problem or to go over plans for the weekend. By contrast, sitting quietly while others are talking is not a skill most middle school students have mastered. If you have 30 twelve-year-olds in the room, they are completely present at all times, and they need to be engaged.

Another difference between lab meetings and middle school lessons is that in our lab meetings, no one knew the answers to the questions we were asking. In the science classroom, the teacher usually does know the answer. "Good students" are adept at figuring out the answer that the teacher has in mind. Yet, in creative thinking in science, as in creative thinking of any kind, the important skill is the ability to figure out the answer on your own. My goal is to help students get past the school-savvy habit of reading the teacher's mind.

Another difference is that, in a classroom, there are a lot more people than there are in a lab group, and very few of them are as independent as doctoral students. If you were to have students conducting their own experiments, you would have 30 experiments going on simultaneously. If you have the students work in pairs, you could get it down to 15 experiments, or if you have groups of four, you could reduce it to seven or eight. But … many secondary science teachers have five classes. If you multiply all those numbers by five, the task approaches impossibility.

Through trial and error over many years, I came up with the ideas that led to the classroom experiments described below. The account that follows occurred many years after my work in the cell biology lab, after I had completed a Master's and credential program, and after I had taught middle school science for eight years.

A Middle School Lab Group

Over the period of a year, two of my seventh grade classes conducted a series of open-ended, student-designed inquiry experiments on the density and buoyancy of various liquids and solids. One of my goals during this year was to document the development over time of student understanding of concepts of buoyancy and density, and, simultaneously, to document the development of the strategies I used to support this understanding. Specifically, I was trying to create a classroom environment in which students could learn to pursue their own ideas about buoyancy and density by collaboratively designing experiments to test their ideas.

The experiments

We first experimented with ice in clear liquids. Then, to figure out what we saw, we found that we needed to explore what happened to ice in many different liquids.

Ice in clear liquids. One day, early in the fall semester, I rolled out the demo cart. On it were two plastic cups, each filled with clear liquid. I held up some cubes of ice. I told the students that I was going to drop the ice into the cups, and before I did, I wanted them to draw and label the cups and the ice. Then, I asked them to guess what they thought would happen when I dropped in the ice, and I had them write down a prediction. Finally, I asked them to think about the reasoning behind their prediction. (To view copies of journal pages, copies of other student work and video of these experiments, go to <http://feelingathome.org/inquiry.htm>.)

I dropped an ice cube into each cup. The ice cube floated in one cup but sank in the other. The classroom was silent, and many faces showed puzzled looks. (I didn't tell them that one of the cups had rubbing alcohol in it, while the other was water. The cups of liquid looked identical.) I asked them to make an observation in their journals. Then we had a conversation. Some people thought there was something "wrong" with the ice; others thought there was something "wrong" with the water. I dropped more ice into each cup. Eventually, we compiled a list of liquids that might make the ice sink. We went back to their predictions, and I asked different people to share their predictions and to explain their reasoning. Most of those who spoke talked about their past experience with ice and water. After the discussion, I asked "What question do you have now?", and I had them respond in their journals. I told my students that, next time, I would bring all the liquids that had been suggested, and we would test them.

Students followed their own understandings and consulted their own experiences when there was not a particular pathway charted out ahead of time.

One of the problems I was trying to resolve in my teaching was the execution of experiments that were genuinely student-generated. This was difficult, because I might not anticipate the supplies and materials necessary for their experiments. My solution was for the whole class to work together to design an experiment, and then to give myself a week or two to collect the materials and figure out the best way to do the experiment in class. Should it be conducted as a teacher demo, as a student demo, or as a hands-on experiment?

Ice in many different liquids. Two weeks later, I came to class with these liquids (or the means to prepare them): vinegar, Sprite, salt water, hot water, rubbing alcohol, and tap water. Part of my goal in developing this teaching strategy was to make it possible for a teacher to use this technique with multiple classes. For this reason, when I brought the liquids, I brought some that were suggested by each class, and I did the same demo for both classes. As it happened, no one in either class guessed rubbing alcohol, which was the substance in the second glass. I brought it and said that someone in another class had suggested it. It actually WAS someone in another class, but that class was from a different year. The point was to make the experiment a student-generated one, but one that would, at the same time, work, without causing too much frustration too early in the careers of these young experiment designers. (I had some qualms about bringing a liquid that had not been specifically suggested by that very class, but I felt it was important for my students to experience success in order to help them develop a taste for continuing with this kind of endeavor.)

On the overhead, I showed my students how to make a chart showing their predictions and observations, and I asked them to predict, for each liquid, whether the ice would float or sink. I also asked them to think about the reason behind each prediction. Then I dropped the ice into each one. It floated in every cup, except for the one that contained the rubbing alcohol. As a group, we talked about ideas to explain possible reasons that this happened. In the conversation, students said that some of the liquids might be "heavier" than others. Then students thought of ways to test that idea.

All the experiments we did, like these first ones, were simple ones: experiments involving common materials that a student could find at home. The difficult part lay in eliciting student ideas without revealing my own, as well as in using student-generated experiments to lead us to new material.

As we tried to make sense of our experiments, I kept asking for predictions, explanations of the predictions (hypotheses), observations, explanations of the observations (inferences), and ideas for new experiments. I asked clarifying questions, but I did not try to direct the ideas to include certain experiments. Students followed their own understandings and consulted their own experiences when there was not a particular pathway charted out ahead of time.

I needed the time between experiments to figure out the best way to nudge our investigation in a direction that would bring us to a deeper understanding of the concepts, while, at the same time, taking care that each experiment we did was, fundamentally, the result of student ideas and student thinking.

How students made sense of the problems

Because I did not have a particular direction in mind, the students came up with ideas I had not anticipated. For example, after watching an experiment in which I layered water underneath alcohol in a graduated cylinder, Luis, a male Latino student, said he thought that the viscosities of the two liquids might be different, and that might be the reason alcohol sits on top of water. He proposed an experiment in which a marble is dropped into the two liquids and the rate at which it falls is recorded. Luis was remembering an experiment the students had done as sixth graders in which they tested the viscosity of different liquids by dropping a marble into bottles containing the liquids and timing the number of seconds it takes for the marble to fall to the bottom. (A video of this experiment about viscosity, along with student work, can be viewed at <http://feelingathome.org/viscosity.htm>.) In my mind, viscosity and density are not related, so I would not have thought to send students in this direction, or to remind them about the results of the viscosity experiments.

A second example in which students found their own way to understand the evidence is a method I have come to think of as the "experimental common denominator." As we tried to explain the reasons that ice floated in water and sank in alcohol, students hypothesized that one was "heavier" than the other, so we decided to weigh them. There was consensus that in order to compare, we had to weigh the same amount of each liquid. Then the question came up: how do you compare the ice to the water and the alcohol? The strategy the class developed was to freeze water in a graduated cylinder. We put in 40 milliliters of water, and after we froze it, we had 44 milliliters of ice. Then, students proposed that we weigh 44 milliliters of water, and 44 milliliters of alcohol. Instead of using a mathematical operation to compare different substances (dividing mass by volume), these seventh graders equalized the volume and then compared the mass. We made a chart of the results, and, as we investigated other substances, we added them to the chart. This method of comparing the density of the substances made intuitive sense to these students.

I did not supply the steps for any of the proposed experiments. When an idea was proposed, I asked questions to help students build up the steps themselves. In this way, many students were able to follow the rationale for a particular experimental protocol that they might not have understood if a teacher-designed protocol had been presented without their participation.

The students expanded on their ideas about ways to make measurements. For example, when they were trying to figure out a method to find the volume of a carrot in order to compare its density to the liquids they had tested, one student, an African American female named Jasmine, proposed putting the carrot into a one-liter graduated cylinder, and then reading the numbers off the side of the cylinder to get the volume. When she said this, I put the carrot into the cylinder and asked a student to read the number off the side. Then I asked her to look at how much air there was in the graduated cylinder. I asked if air was taking up some of the space. Jasmine then proposed putting the carrot into a smaller cylinder, the kind we use in the lab. I put the carrot into a 50 milliliter cylinder. She then said that we could read the volume of the carrot from the numbers on the side. I pointed out that there was still air taking up some of the volume, even though there was less than with the other cylinder. Finally Jasmine came up with the idea of pouring water into the cylinder to take up the space around the carrot, and then subtracting the amount of water from the total amount of water plus carrot. Other students in the room followed this exchange closely, and they contributed ideas and encouragement. This conversation was followed by an experiment conducted by students working in pairs. Each pair calculated the density of a carrot using this “add water and subtract” method to find the volume.

These are three of many examples during this series of experiments in which students took a different pathway to understanding the data from the one a science-literate adult would have taken. In my past experience, many students got lost trying to follow teacher-designed steps. Conversely, the path opened up by students thinking out loud, was one that the other students in the class could follow.

Inquiry experiments in multiple large classes

Here is the solution I found to the problems involved in making student-designed inquiry experiments possible for teachers who teach multiple large classes. We conducted the experiments at intervals of one to two weeks, and sometimes longer. After each experiment, I took student ideas for experiments to answer further questions. I shared the ideas from one class with the other class. Lastly, I chose one experiment to do next from among all the proposed experiments. My criteria were (1) that the experiment should be possible to do (in terms of materials and practicality), either as a demo, or preferably as a hands-on experiment; and (2) that it should lead towards understanding the concepts. In this way, students designed the experiments and were able to see their own ideas put into practice, but I was able to minimize the frustration students can experience without guidance.

Students of color and female students were the most active participants in these discussions. I did not privilege “scientific” interpretations and connections over everyday ones. As students contributed examples from their everyday life, other students responded and agreed that they had seen the same examples. We actually put the ideas offered into our demonstrations and experiments, and as a result, students who initially were not willing to contribute began to offer ideas.

We did about twenty experiments over the course of the year, at intervals of one or two weeks. Many of the experiments involved combining different materials, and then weighing and measuring, or else weighing and measuring first, and then predicting what would happen when we combined them. Plans for the experiments, and the reasoning behind them, came from the students as they tried to make sense of their observations. (To view a list of experiments, and brief descriptions, go to <http://feelingathome.org/inquiry.htm>.)

Collaboration helped me achieve a practical understanding of methods for implementing inquiry in the classroom.

A problem arising from the inquiry

As the teacher, I was often unable to predict the results of these student-generated experiments and I was often puzzled about how to proceed when something unexpected occurred. The first time we weighed water, ice, and alcohol, for example, students weighed the liquids as a demo in front of the class, but someone made a mistake and their numbers came out wrong. Their results indicated that ice was less dense than alcohol. I wasn’t sure how to respond, because I didn’t want to say, “that’s not what you are supposed to get”. That may have destroyed all the hard work I invested to help them stop trying to make predictions based on results already known by the teacher. After puzzling over this for a while, I decided to have the whole class repeat the experiment working in pairs. We would have fifteen sets of numbers instead of just one. Scientifically this solution is sound, because when results do not come out as expected, you repeat the experiment until you understand the reasons for those results. In the classroom, the solution to this problem didn't occur to me until I had thought about it for a while. I needed the time between experiments to figure out the best way to nudge our investigation in a direction that would bring us to a deeper understanding of the concepts, while, at the same time, taking care that each experiment we did was, fundamentally, the result of student ideas and student thinking.

Theoretical Basis for Teaching Through Inquiry

At this point in the story, I would like to give you more background about my development as a teacher, the source of my teaching perspective and the influences that inspired me to teach in this way.

A number of experiences and readings formed the basis for my understanding of teaching and learning. These experiences stem from undergraduate science experience, teacher preparation, and collaboration with other teachers. In the following, I will explain the story of the origin and development of my commitment to teach through inquiry, including the sources of my beliefs about learning, about science, and about students. This can be considered a teacher's response to the call for research in *Studying Teacher Education* (2005), a report by the AERA panel on Research and Teacher Education: "There is a clear need to look more at how teachers' knowledge and practices are shaped by their preparation, including after they have completed their programs." (Cochran-Smith & Zeichner, 2005, p.742).

Undergraduate Science Experience and Teacher Preparation Program

My undergraduate education consisted mainly of courses in which researchers lectured to hundreds of students gathered in large auditoriums. These classes served as painful examples of how difficult learning can be. Then I joined the cell biology lab group, described above, and, although I was in the same university, I felt as if I had traveled to a different world. Like other teachers who value inquiry (Windschitl, 2003), my experiences here were essential to my eventual commitment to engaging my students in inquiry-based learning. After I completed my undergraduate work, I earned a credential to teach secondary life science and a Master's degree at a research university that taught prospective teachers by placing them in classes with doctoral students. The focus of the program is to convey to teachers the theoretical underpinnings of educational practice and provide them with experience in educational research. Its goal is to bridge the chasm between educational research and educational practice (See: <http://www-gse.berkeley.edu/program/macsme/report.html>). My classes were made up of a roughly equal ratio of doctoral candidates and future teachers. Many of the papers we read were on theories of knowledge, particularly its nature and acquisition. The emphasis, with respect to teaching practice, was on helping students learn to ask their own questions and pursue the answers to those questions: that is, teaching through inquiry.

Foundations of knowledge acquisition

Early in the program we read and discussed writings by Piaget and Vygotsky, and we continued to refer back to their theories regarding the construction of knowledge. Both the readings and the class discussions helped me to construct my own understanding of the role of individual experimentation in the construction of knowledge (Piaget, 1974) and the role that teacher and peer interactions have on the social construction of knowledge (Vygotsky, 1978).

Knowledge acquisition in the classroom.

The papers reporting research in classrooms were concerned with putting theories of knowledge acquisition into practice. In a course called Cognition in Science, we read a paper by Roth and Bowen (1995) in which they described inquiries carried out in the field by eighth grade students. Students learned to actively engage in science by pursuing their own idiosyncratic pathways in order to answer their own questions. The paper described a small class, and there were many resources available to these students and their teacher.

Constructing knowledge with the help of a teacher and peers

Another paper we read was by diSessa, Hammer, Sherin and Kolpakowski (1991). A group of students generated a way to make a representation of data they were studying. These students, with the sensitive guidance of their teacher, actually invented the idea of graphing. It was a teacher-led discussion facilitating a collaborative development of ideas.

A third paper that influenced my approach to promoting thought-provoking classroom discourse was written by van Zee and Minstrell (1997). It described a teacher response called the "Reflective Toss" in which the teacher takes a student utterance and sends it back to the student in such a way that the student retains ownership of it. The teacher's handling of the idea allows the student to develop it further.

Understanding the scientific concepts: Density and buoyancy

As a part of my teacher preparation program, there was a methods course in which we developed lessons. In this class, I talked with my science methods teacher about some of my experiences in the cell biology lab studying mitosis in diatoms and separating the parts according to their density by spinning them in a layered series of sugar solutions. In response, my methods instructor described a demo he had seen performed by another teacher. Water was layered under alcohol, and then the teacher dropped in an ice cube, which became suspended between the layers. He encouraged me to design a lesson based on my lab experience and this ice cube demo. I taught this demonstration lesson to my fellow students in the methods class, and this experience started me down the road leading to the series of experiments described above.

Equity and social justice

I came into teaching with a strong commitment to equity, social justice, and teaching science in diverse, urban school settings. One of the many sources of this commitment was that, in my undergraduate years, there were few African American or Latino students in my science classes, whereas there were many in my social science classes. When I asked my African American and Latino colleagues about their majors, a surprising number told me they were majoring in sociology or psychology, but they would have preferred medicine or science. Many said that when they got to college, they had found that their secondary education had been inadequate, and they didn't have the preparation necessary to take science courses at the university. I realized that becoming a teacher was one way I might be able to work towards social justice and make a contribution using the skills I had. I could try to give students of color better access to jobs in medicine and science by giving them a better secondary science experience.

Teaching is dynamic in nature, and it must be responsive to the individual needs of the learner.

In my teacher preparation program, I found that my commitment to equity and social justice was shared by the faculty and by the other pre-service teachers. In one of the courses in the program, "Urban Education," I read Gloria Ladson-Billings' book *The Dreamkeepers* (1994). Particularly important to me was the idea that, before trying to teach to another person, it is essential to identify with that person – to look for and to find parts of myself in that other person, in spite of the fact that we come from different backgrounds. When it came time to teach, I went to work in a diverse, urban middle school. I hoped to finally integrate my studies of equity and social justice with my studies of scientific inquiry.

Collaboration with other teachers

Inquiry occupies a prominent place in the *National Science Education Standards* (National Research Council [NRC], 1996), where it is described in this way: "Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results" (p. 23). When I started teaching, I was fortunate to join a department with an unusually collaborative group of science teachers. To inform our discussion as we planned our curriculum, this group used the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993), the *National Science Education Standards* (NRC, 1996) and, later *Inquiry and the National Science Education Standards* (NRC, 2000) as resources.

After I joined the department, we started a journal club where we would bring papers to share and discuss. The Roth and Bowen paper was one I brought to the group. We spent the better part of two years debating, on and off, whether this kind of teaching would be possible in our situation. We teach in a conventional middle school with a high numbers of students, a low amount of resources and limited access to field experiences. One of the veteran science teachers (David) argued that we must teach through inquiry, while another veteran science teacher

(Janet) argued that it was impossible. Janet is an excellent teacher who provides her students with extensive hands-on experience and uses a sensitive scaffolding of concepts. As we discussed this problem over the many sessions, she continued to argue that you simply couldn't follow the thread of questions posed by students and still manage the classes. Her colleague argued that we were not teaching science unless we attempted to teach through genuine inquiry. The discussions and the open atmosphere for people to argue, disagree, and test out our views, provided an excellent laboratory for me to explore my own ideas about inquiry and teaching.

Teaching, viewed from the outside, sometimes looks like magic, and it sometimes looks like chaos.

Collaboration and equity

Collaboration helped me achieve a practical understanding of methods for implementing inquiry in the classroom. Similarly, collaboration helped me convert my commitment to equity for the students from a goal into a set of actions. I had worked very hard on this goal for many years, but I felt that I was not very effective in achieving it. It was not until I had been teaching for several years and benefitted from the opportunity to work with student teachers that I felt this begin to change. Through my conversations with one of these gifted young teachers, I became acquainted with the writings of Claude Steele (1992). My student teacher and I discussed at length the ideas in Steele's papers. The most compelling of these for us were the ideas that students of color need to feel that the teacher first genuinely values him or her as a person, and second, challenges him or her in ways that convey that sense of value. Together, we were able to come up with strategies to do this. One particularly powerful strategy was to write individual letters to students in which we responded to ideas they had expressed in their written work (Bove & Reider, 2007).

Collaboration with math and science teachers: Teacher inquiry

If collaborative inquiry is the best way for students to learn, then it is logical to think that collaborative inquiry is also the best way for teachers to learn. With the goal of learning more about my teaching, I applied to the Carnegie Foundation's CASTL K12 program (Carnegie Academy for the Scholarship of Teaching and Learning). This program reflects Lee Shulman's ideas that through their practice, teachers develop a unique wisdom that should be made public so that others may learn from them (Shulman, 2004). A group of 11 math and science teachers from Bay Area schools met over the period of a year. Each of us conducted an inquiry into our teaching practice, and, collaboratively, we worked to understand our findings. The web site I have referred to above is a result of the study I conducted during that experience. The participants' web sites are available for use in programs for teachers (see <http://gallery.carnegiefoundation.org/gallery_of_tl/castl_k12.html>; also van Zee & Roberts, 2006).

Conclusion

My experience has shown me that teaching is always a work in progress. It always involves uncertainty, and it can only be successful when considered in the context of student learning. Each student is a unique individual, and each class has its own distinct personality, character, and needs. It is for these reasons that I believe that teaching cannot be prescribed or scripted. Teaching is dynamic in nature, and it must be responsive to the individual needs of the learner. This does not mean that a teacher must devise a separate curriculum for each learner. In the experiments described above, I have tried to see students as individuals while teaching them as a community of learners helping each other to develop understanding. I think this shows that teachers need to be learners themselves. They must construct their own understanding of teaching and learning, of the theoretical literature, of the content they are teaching, and of their learners as individual people. If teachers are learners, it follows that we need the same kinds of learning conditions that our students need. We need to be able to ask our own questions, experiment, collaborate with peers, and receive the support that we try to give our students.

Teaching, viewed from the outside, sometimes looks like magic, and it sometimes looks like chaos. As a teacher, my understanding of teaching is that it is a set of practices and understandings, built up through years of trial and years of error, combined with years of reflection, both individual and collaborative. This paper is a view of one teacher's attempt to teach students of a diverse, urban middle school the concepts of density and buoyancy by using open-ended inquiry. It is, furthermore, an attempt to reveal the ideas and experiences underlying the teaching methods I have used. I offer it in the spirit of collaborative inquiry. I hope others will be able to use the ideas presented here to add to their own understanding of learning and teaching, to borrow, to critique, and to go further.

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Louis S. Nadelson

How Can True Inquiry Happen in K-16 Science Education?

In his analysis of current research on teaching through the use of inquiry in the science curriculum, the author explores student learning, students' misconceptions of the nature of science, and ideas for curricular support, as components of the challenge teachers must face when implementing an inquiry curriculum.

In my nearly 20 years of high school and undergraduate college instruction, I have implemented many inquiry assignments. Inquiry instruction has been an effective method for creating a context that allows my students to better understand concepts through the processes of engaging in scientific research. In my prior attempts to integrate inquiry-based learning opportunities into the curriculum, my students consistently responded with numerous questions, confusion, frustration, and/or lack of motivation to learn. Yet, I persisted in use of inquiry-based instruction, because I perceived that there was something to be learned from engaging in the scientific process.

Initially, I attributed negative student reaction to inquiry assignments as a lack of initiative. Nevertheless, I wondered if anything else could possibly explain my lack of success. The wisdom and philosophy of Dewey (1938) suggests that providing my students a supportive environment and the freedom to construct their own knowledge would motivate them to become engaged learners. In practice, I have found this response to be rather atypical. I asked my students to explain their lack of excitement for inquiry-based assignments and their reluctance to engage in the creative and authentic research opportunities that I had arranged for them. The students responded that they did not know what to do.

It took some time experimenting with this approach, but I have determined that the kind of inquiry that I want for my students is a complex process. Although inquiry appears to be a promising method for effectively conveying scientific principles, it unavoidably requires more prior knowledge and experience than typical high school or college undergraduate students have at their disposal (Settlage, 2007). Despite this limitation, there is an expectation that science teachers will engage students in inquiry-based instruction. This is further confounded by the wide range of perceptions of the definition of inquiry and the processes associated with it (Buck, Bretz, & Towns, 2008; Chinn & Malhotra, 2002). This has resulted in a diverse range of educational activities and lessons that are promoted as scientific inquiry. With this in mind, I considered the possibility that the form and structure of my inquiry-based assignments contributed to a lack of student enthusiasm.

The integration of scientific inquiry into the curriculum is closely aligned with the philosophy of constructivist learning, which asserts that students construct knowledge and develop deeper understanding through experience.

The expanding emphasis on inquiry in science education has motivated me to examine other views and experiences with this instructional approach. In addition, I have reviewed research investigating the effect of inquiry-based instruction on student engagement in learning, on their acquisition of content knowledge, and on development of research skills. In this article, I begin with a discussion of the definition of inquiry and the reasons that it is being promoted in the science curriculum. I have integrated into this discussion an exploration of student reactions to inquiry in order to support the argument that authentic inquiry requires expertise that is absent in most high school and undergraduate students. I then explain the ways in which a scaffolded approach allows inquiry-based assignments to be presented in a manner that increases student productivity and success. I conclude with suggestions for future research concerning the use and effectiveness of inquiry as a method for learning and teaching science.

What is Inquiry?

Inquiry is the processes and activities that expert researchers engage in during authentic scientific investigations, or, simply stated, it is the process of doing science (Chinn & Malhotra, 2002; Duschl & Grandy, 2008). Scientists and other professionals actively engage in inquiries as they explore various aspects in their domains of interest (National Research Council [NRC], 1996). Although it is argued that scientific research does not involve one specific scientific method (McComas, Almazroa, & Clough, 1998), there are similar steps and procedures found within most scientific investigations.

The National Research Council developed a definition of inquiry as a component of the *National Science Education Standards* (NSES) (NRC, 1996). The NRC defines inquiry as:

> *The diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p. 23)*

This definition reveals the approach to scientific investigations that professional researchers consider the most effective. This definition also makes clear that student engagement in inquiry is considered to be an instructional method for learning scientific principles. However, examinations of published science curricula that claim to provide inquiry instruction to help students meet the NRC goal to "*develop knowledge and understanding of scientific ideas*", reveal diverse perspectives concerning activities that involve inquiry (Buck, Bretz, & Towns, 2008; Chinn & Malhotra, 2002). I embrace a pragmatic perspective which maintains that inquiry should have the detectable presence and implementation of three essential elements: research question(s), methodology and data collection, and the interpretation and explanation of results (Schwab, 1962; Herron, 1971). Additionally, I argue there is justification for a fourth element involving the evaluation of the validity, plausibility, and credibility of research results. However, for the sake of discussion, I will use the three element perspective contained within Schwab's model of inquiry.

Using the model proposed by Schwab (1962), student and teacher engagement in an inquiry can generally be classified into one of four levels. This four-tiered classification scheme is based on the extent to which the student, as opposed to the teacher, is responsible for each of the three essential elements. The level of inquiry increases from 0 to 3 as the responsibility for the various aspects of the research shifts from teacher (or curricular sources) to learner (see Figure 1). At Level 0, the student is provided with the research questions, methodology for gathering data, and the approach for interpreting the data. By Level 3, the student is working almost independently and is responsible for all three inquiry elements.

It is apparent that students engaging in Level 0 or 1 inquiry activities are most likely following prescriptive procedures with little resemblance to authentic scientific research. However, in order to engage in authentic Level 3 research, students must assume a high level of responsibility for research activities, and they must possess an understanding of the complexities and variations associated with conducting original investigations. These conditions illustrate a paradox that arises during inquiry instruction.

Here is the nature of the paradox: students engaging in the prescriptive inquiry activities of Level 0 and 1 are likely able to complete these activities without difficulty, but they are also apt to develop the perception that scientific research is the process

Figure 1: Schwab's Levels of Inquiry (Schwab, 1962)

Inquiry Level	Source of the Question	Data Collection Methods	Interpretation of Results
Level 0	Provided	Provided	Provided
Level 1	Provided	Provided	Open to Learner
Level 2	Provided	Open to Learner	Open to Learner
Level 3	Open to Learner	Open to Learner	Open to Learner

of following established, precise steps to achieve a predetermined solution (Chinn & Malholtra, 2002). However, if students engage in the scientific activities of the authentic inquiry represented by Schawb's (1962) Level 3 inquiry, their lack of experience is likely to be overwhelming, leaving them unable to successfully complete these assignments. This may cause students to develop the perception that scientific research is inaccessible (Edelson, 1998). Simply stated, if the inquiry is attainable for students, it will most likely be superficial, but if the inquiry is substantial, then it will most likely be unattainable. If inquiry methodology is to be considered useful for science instruction, then we need to find an effective solution that resolves this paradox.

Inquiry in the Curriculum

The integration of inquiry into the science curriculum is founded on the conjecture that student participation in these assignments will lead to an increase in their knowledge of the concepts and processes of scientific investigations, as well as the nature of science (Abd-El-Khalick et al., 2004; Driver, Leach, Milar, & Scott, 1996; Llewellyn, 2002; NRC, 1996). Simplified, there is the expectation that by actively engaging in scientific activities students will learn scientific principles. The integration of scientific inquiry into the curriculum is closely aligned with the philosophy of constructivist learning, which asserts that students construct knowledge and develop deeper understanding through experience (Kirschner, Sweller, & Clark, 2006; Lewis, 2006, NRC 2000). Some perspectives of constructivist instruction maintain that learning is most effective when learners are prompted to ask questions

Perhaps the greatest obstacle impeding the effectiveness of inquiry instruction is the limited experience and prior knowledge of students.

and are provided with the opportunity or context necessary to answer those questions (Dewey, 1938). Since the 1960s, efforts to create constructivist ecologies have produced several curricular variations, which include problem-based learning, discovery learning, and inquiry (Kirschner, Sweller & Clark, 2006).

It is possible for methodologies that incorporate the principles of problem-based learning, discovery learning, and inquiry, to use similar instructional approaches in order to engage students in active, participatory learning (Kirchner et al., 2006; Savery, 2006). Depending on the learning goals and abilities of the student, the process and procedures of these approaches may take on marginally different appearances (Lewis, 2006; Savery, 2006). All three of these approaches encourage learners to pose questions, develop hypotheses, design experiments, gather data, interpret results, draw conclusions, and form theories (Audet & Jordan, 2005; Kirschner et al., 2006; Lewis, 2006; Llewellyn, 2002; Mayer, 2004). The anticipated learning outcome is greater understanding of concepts, acquired through the process of answering self-generated questions and solving associated problems.

Inquiry-based methodology has become an emphasis in science education standards, because it is predicted that engaging in authentic research will enable students to learn about the nature of science, the scientific process and research procedures, as well as to gain science concept knowledge (Abd-El-Khalick et al., 2004; Driver et al., 1996; Llewellyn, 2002; NRC, 2000). However, as Anderson (2002) points out, "inquiry means different things to different people" (p. 3). Thus, Anderson recognizes the variability in the way that teachers, researchers and curriculum developers interpret and use the concept of inquiry. Diverse approaches to inquiry instruction and the corresponding variations in expected learning outcomes is further evidence of the diverseness promoted by inquiry-based instruction (Buck, Bretz, & Towns, 2008; Chinn & Malhotra, 2002). Thus, definitions of inquiry may be perceived to be relative, influenced by the source of the inquiry, the levels of experience and perceptions of those involved in the instructional process, as well as the desired learning outcomes. In my early attempts at inquiry instruction, I was fully committed to approaches that utilized the definition of inquiry as: *the processes engaged in by professional researchers*, which could be considered to be Schwab's (1962) Level 3 inquiry. I anticipated that this approach would increase opportunities for my students to learn about authentic research, and would resolve the perceptions that research was similar to the prescriptive structure of canned laboratory exercises that they had previously encountered in their science education. However, my students' learning outcomes were not consistent with my expectations. They were overwhelmed and were not learning from the process. By balancing my expectations with a desire to engage my students in authentic research opportunities, over time I was able to modify my expectations to fit the readiness of my students to actively engage in inquiry activities.

Influences on Inquiry Engagement

Variations in student learning through inquiry-based activities reveals many challenges (Anderson 2002; Chinn & Malhotra, 2002; Echevarria 2003; Kaartinen & Kumpulainen, 2002; Keys & Bryan, 2001; Kirschner et al., 2006; Lewis, 2006; Marx et al., 2004; Roehrig & Luft, 2004a, 2004b; Roehrig, Luft, Kurdziel, & Turner, 2003; Sandoval, 2005). Some of this research reveals outcomes similar to those I have experienced. That is, they report that authentic inquiry instruction led to increased levels of student frustration due to lack of direction combined with incomplete or inaccurate conceptual development. Due to the correlation between attitude and retention, student attitudes concerning inquiry-based activities must be considered when evaluating the challenges and complexities associated with this instructional technique. The reported results from investigations of authentic inquiry instruction are relatively the same for high school students and undergraduate college students.

Perhaps the greatest obstacle impeding the effectiveness of inquiry instruction is the limited experience and prior knowledge of students (Anderson 2002; Kaartinen & Kumpulainen, 2002; Keys & Bryan, 2001; Roehrig et al., 2003; Sandoval 2005). Results from investigations that examine learning through inquiry expose the critical influence of prior knowledge and experience on the instructional success of inquiry-based instruction (Mayer, 2004). Wolpert (1997) contends that the ability to apply problem-solving techniques to commonplace situations and the ability to scientifically problem solve do not necessarily overlap. Wolpert maintains that the knowledge necessary for effective participation in scientific investigations is highly specific and relates to awareness and familiarity of work accomplished by other scientists. It is unreasonable to expect students to have this knowledge, experience, and awareness. Therefore, we should anticipate that novice learners will exhibit a limited ability to successfully carry out authentic scientific inquiry.

Authentic inquiry, pure discovery, and problem-based learning require a tremendous amount of mental effort even for an expert researcher.

Authentic inquiry, pure discovery, and problem-based learning require a tremendous amount of mental effort even for an expert researcher (Schoenfeld, 1987). Kirschner et al., (2006) argue that considerable background knowledge and experience are essential to the complex problem-solving required for accomplishing authentic inquiry. Thus, authentic inquiry lessons and activities (Schwab's Level 3) require novice learners to perform expert functions, which they typically are not equipped to perform (Kirschner et al.; Schoenfeld, 1987).

In my attempts to engage my students in authentic inquiry activities, I frequently neglected the extensive skill set that is required for successful completion of research. I expected that my content instruction and the examples I had provided through structured labs (Schwab's Levels 0 and 1) would prepare my students with the knowledge and experience necessary to engage in independent inquiry. This expectation was not met, because in addition to content knowledge and knowledge of the scientific process, authentic inquiry also requires the participant to utilize advanced metacognitive skills. The necessary skills are those associated with complex problem-solving, posing researchable questions, and determining fruitful approaches for gathering pertinent evidence (Schoenfeld, 1987; Wolpert, 1997). My students had not yet mastered all of these skills. In order to compensate, I try to keep in mind the idea that learners rely on prior knowledge to productively solve problems while simultaneously acquiring new knowledge through experience (Bransford, Brown, & Cocking, 1999). Thus, when determining the level of sophistication and structure of inquiry activities appropriate for a particular class, the instructor should begin by assessing the cognitive and metacognitive abilities of the learners, as well as their prior knowledge. The instructor should then choose activities that build on these capabilities and perspectives.

Inquiry and Misconceptions of the Nature of Science

Widely differing views pertaining to the nature of science (NOS) and the structure of scientific knowledge accentuate the differences between the perspectives of professional scientists and novices (McComas, 1998). According to the scientific perspective of knowledge, hypotheses are predictions and explanations based on evidence, theories are explanations based on evidence, and scientific laws are measurable constants. The naïve conception that scientific knowledge evolves from hypothesis, to theory, and progresses through the accumulation of evidence into scientific law is well documented among novice learners (Driver et al., 1994; McComas, 1998; Miller, 2008). This common misconception regarding the nature of science constrains the ability of the learner to understand the process of scientific advancement through inquiry, because it gives the impression that knowledge is goal-oriented. These misconceptions can lead learners to develop additional NOS misconceptions, such as the notion that scientific endeavors are guided by a distinct set of prescriptive procedures used to determine ultimate truths (Chinn & Malhotra, 2002; McComas, Almazroa & Clough, 1998; Trumbull, Bonney & Grudens-Schuck, 2005).

Previous research indicates that professional scientists, educators, and students hold vastly different views of knowledge (Chinn & Malhotra, 2002; Schoenfeld, 1987). Therefore, individuals from these different groups are likely to use different approaches when participating in inquiry-based activities (Anderson, 2002; Chinn & Malhotra, 2002; Hakkarainen, 2003; Keys & Bryan, 2001). Common student misconceptions, such as the belief that scientific methods are a rigid set of research steps and the belief that knowledge is absolute and consistent, create significant barriers to effective engagement in inquiry activities (Chinn & Malhotra, 2002; Hakkarainen, 2003; Marx et al., 2004; Sandoval 2005). The misguided belief that knowledge is absolute and that therefore the goal of science is to discover ultimate truth often causes students to expect to find the one right answer to questions or problems rather than to exclude possibilities in an attempt to arrive at one of many possible solutions (McComas, 1998). Further, student participation in structured lab activities typically associated with Schwab's (1962) Level 0 or 1 inquiry may actually reinforce these misconceptions. When students engaging in traditional lab exercises encounter results that fall outside of the expected outcomes, they tend to apply their misconceptions (Schneps & Sadler, 1988, 1997) or simply conclude that they made a mistake, rather than seek deeper explanation. Because common student misconceptions typically impede their motivation to seek explanations for variations in inquiry outcomes, (Bruning, Schraw, & Roming, 1999) they are unlikely to uncover and understand more complex aspects of their research practices that may be contributing to the observed anomalies.

In summary, common student misconceptions limit the ability of novice learners to effectively engage in scientific inquiry through the application of problem-solving strategies. Placing novice learners in authentic inquiry environments without structured and targeted support can increase frustration and decrease learning. This ineffective strategy could have the long-term result of causing the learner to develop a general dislike for science. Therefore, I have found that for inquiry to be an effective instructional approach, it must be implemented in a manner that guides students through the obstacles they face while engaging in the scientific process.

Adapting to Learners – Guided Inquiry

The barriers limiting student learning with inquiry instruction suggest that teachers should use a technique that scaffolds (Vygotsky & Cole, 1978) the process by providing guidance at critical points during investigations and partitioning the overall process into attainable elements (Mayer, 2004; Palincsar, Collins, Marano, & Magnusson, 2000; Polman & Pea, 2001). Scaffolding instruction can account for factors that limit student success by guiding students through inquiry processes using a step by step approach (Vygotsky & Cole). Even though guided inquiry is effective in teaching students about scientific research, Buck, Bretz and Towns (2008) report that this instructional approach is rare in most science curricula, including undergraduate science programs. Buck and colleagues report that the vast majority of lab activities utilized in undergraduate science curricula are structured to provide Level 0 or 1 experience. The lack of sufficient guided inquiry experience available in post secondary education is critical, because most K-8 teachers may never receive additional exposure to authentic inquiry processes. Therefore, they are unlikely to pass them on to their students (Deemer, 2004; Llinares & Krainer, 2006).

Direct instruction and structured learning, advocated by Kirschner et al. (2006), assist novice learners in acquiring the knowledge necessary to productively engage in increasingly independent problem solving activities. Kirschner et al. argue that direct instruction is the most efficient way for students to acquire knowledge and develop expert skills. Although this approach may be effective at conveying knowledge of content material and addressing student misconceptions regarding the nature of science (Bransford, Brown, & Cocking, 1999), I have determined that direct instruction does not effectively lead to the development of student problem solving abilities, nor does it increase student understanding of inquiry and the scientific method. I have found that in order for inquiry instruction to be most effective, it is necessary to first identify learning barriers that hinder active engagement. Then it is possible to use guided inquiry activities teachers to expose students to models of research, laboratory practice and motivational learning opportunities that enable students learn through exposure to the complexities of authentic scientific investigation, thereby developing critical thinking and problem solving skills (Bransford et al., 1999; Bruning, et al., 1999).

Scaffolding Inquiry

A more effective instructional technique for developing inquiry skills involves scaffolding inquiry activities for students (Sandoval & Reiser, 2004; Vygotsky & Cole, 1978). Implementing inquiry curricula and instruction in which students learn and engage in guided research assignments that are detailed, scaffolded, and supported, will increase the chance of successfully acquiring the targeted knowledge while preparing them to be increasingly independent learners. Bransford and colleagues (1999) argue that careful planning, exposure to prior examples, continuous assessment, and constructive feedback are essential for preparing students to independently engage in complex learning activities. In addition, a scaffolded inquiry

Many advocates for inquiry methodologies expect that students will be able to successfully engage in the complex processes of inquiry that often take experts years to develop.

approach provides opportunities for teachers to directly address misconceptions regarding the nature of science and the scientific process as they pertain to the particular subject matter under discussion.

I have developed, used, and continue to use scaffolded inquiry assignments with high school, undergraduate and graduate students. Even though I have not formally investigated its effectiveness, my experience indicates that the scaffolding process allows my students to achieve much higher levels of success than cases in which students are expected to complete inquiry assignments individually without support. I begin my scaffolding process by providing students with an outline of the various processes and components required of their inquiry assignment. This outline is a decomposition of all the elements typically associated with a scientific inquiry, and it is accompanied by a timeline and instructions for completing different aspects of the overall assignment. My intention is to guide my students through the inquiry process by leading them slowly toward the development of a final outcome, while allowing for independent investigations. The process of scaffolding aids the students by reducing the perceived extent of complexity associated with conducting an inquiry, thereby reducing anxiety and allowing them to focus on specific achievable outcomes. I have observed that scaffolding one inquiry assignment does not necessarily transfer well to additional inquiry assignments. Even so, students do benefit from exposure to models of authentic research, and this has been very effective for each particular inquiry assignment. Through repeated use of scaffolded inquiry assignments, students may begin to develop the metacognitive skills necessary to begin transferring knowledge gained to additional concepts. The following is an example of how I utilize a timeline, an outline of the expected student products at each stage, and a list of final expectations to develop a scaffolded inquiry-related classroom activity.

An Example of Scaffolded Inquiry

The primary goal of my inquiry assignments is to increase student understanding of authentic research and the different steps involved in conducting and reporting investigations. My example is from an assignment that I designed to provide students the opportunity to apply data analysis techniques that were discussed throughout a semester course. The crux of the assignment involves student selection of an area of personal interest, development of associated research questions, conducting the investigation and reporting the results.

My students have proposed and conducted a diverse range of creative research projects. These investigations have examined: the physical parameters of different varieties of apples, pine cone dimensions in relationship to the number of scales, the effect of different amounts of baking soda on the height of cooked muffins, the time required for seed germination at various temperatures, the height of a golf ball bounce at different temperatures, the relationship between tree branch circumference and its length from the trunk, and many other unique ideas. These investigation topics were generated from discussions, brainstorming, and examination of prior research. Many of these ideas were suggested by students, and others projects came about as a result of suggestions and guidance on my part. The encouraging of students to select topics of individual interest helps to promote active participation in the inquiry assignment.

Once the inquiry project has been assigned, I provide a timeline that corresponds to the task to be completed (see Table 1). I have found that using a timeline to walk students through the major components of the project is an effective way of scaffolding the inquiry assignment. Through scaffolding, I have been able to guide students through the inquiry process by breaking inquiry assignments into achievable chunks that allow students to effectively work on independent inquiry projects. My inquiry assignments typically take place over two week periods, and much of the student work occurs outside of scheduled class time.

Along with the timeline and task table (Table 1), I also provide students with the details of the assignment criteria (see Figure 1). The assignment criteria will include descriptions of the purpose, procedure, and guidelines for the inquiry project. Note that the assignment also includes additional details of the contents expected in the final report and that these correlate directly with the tasks in the timeline table. Through the combination of these materials, I am able to address the need for structure and guidance as my students engage in independent inquiry activities.

Table 1: Time Line and Task for Completing the Inquiry Assignment

Day	Inquiry Task to be Completed
1	Select a topic for study, justify the choice
2	Provide at least 2 references and develop a proposal for further research
4	Gather data (at least a sub set of your final data set)
6	Hypothesis statements and analysis methods
8	Analysis and interpretation of results
10	Poster completed, Presentation of Research

All of the aspects of authentic inquiry are present in my assignments, starting with posing questions and concluding with publication and sharing results. I know that it is important for my students to learn about research by engaging in activities that are as close to authentic research as possible to bring further meaning and context to my assignments. I also integrate direct instruction to address common misconceptions of the nature of science and of other content that may hinder or limit student ability to successfully complete the inquiry process. By utilizing scaffolding to promote participatory learning and direct instruction to address possible conceptual barriers, I am able to produce a situation that has a high level of success in increasing student understanding through the use of inquiry assignments.

Future Research

During my more than 20 years in education, I have seen some excellent ideas and programs discarded or disregarded because they were not well supported or understood. Likewise, I have seen some very questionable attempts at educational reform embraced enthusiastically without any evidence to indicate that they increase student knowledge or aid in learning. Therefore, I think it is critical that we investigate instructional approaches prior to promoting their implementation, inquiry notwithstanding. It is apparent from my personal experience and the research of others that inquiry is a complex process that is limited by student experience, knowledge, and misconceptions. Despite this, the promotion of inquiry as an instructional method for learning science is clear and consistent. Therefore, if inquiry-based methodologies are going to be promoted as an approach for teaching science, we need empirical support to make evident which of the corresponding instructional strategies are the most effective techniques for successfully imparting knowledge of science, problem-solving, and research.

I have outlined a method for increasing student engagement in inquiry activities; yet, I do not have the empirical evidence to support my proposition that this increases student learning or understanding of scientific investigations. If inquiry is to be used as a method, we should have the evidence to support how and why it increases student knowledge of the content and processes of science. If inquiry approaches do not increase student knowledge, then we need to consider alternatives or modifications, such as integrating instructional techniques that have been determined to be effective, for example, scaffolding and continuous assessment. Although I advocate engaging students in independent science research, I am also practical in my philosophy that educational activities should increase student learning and that evidence is required to explain and support anticipated learning outcomes.

Figure 1: The criteria for an inquiry assignment which required students to gather unique data and apply appropriate statistical methods.

Using Statistics

Purpose: The purpose of this project is to provide you with an opportunity to apply the knowledge that you have gained throughout the semester to an authentic research project. It is an opportunity to gather your own data and conduct meaningful scientific investigations and communicate the process and results in a poster presentation.

Research: You may gather data for any situation that you would like, provided it meets the guidelines below. This project is a ***significant*** part of your grade; therefore, it is expected that your final product will be of high quality.

Guidelines: To begin this project, you are to submit a proposal for your research project, outlining what you plan to study and how you plan to study it. Once submitted and confirmed, you are to collect data that is original and does not belong to someone else. Once data collection is complete, you will develop your report as a poster to include the following:

- Title
- Name/Date
- Background – with at least 2 references
- Hypothesis
- The data and how it was collected
- Results
  - Descriptive Statistics
  - Plots with appropriate labels
  - Test Statistic
- Analysis
- Implications

This is to be assembled into a poster which will be evaluated according to a project rubric. This is a major component of your coursework and therefore, a strong emphasis will be placed on both the quality and depth of your work.

Abstract: In addition to the poster – which you will keep, I would like an abstract of your project – which I will keep. This is a ½ page summary of the entire project (no more than one page, approximately 250-500 words). I will collect the abstracts and keep them along with the scoring rubrics for verification of your work on this project.

Data: A reasonably sized sample of original data you collect - usually at least 30 events.

Analysis: You may use any of the hypothesis testing analysis techniques that we cover in the course, but you must use at least one.

Presentation: You will present your poster in a brief presentation (no more than 10 minutes) to the class during finals week.

Conclusion

Inquiry is viewed as a method of engaging learners in scientific investigations by exposing them to the processes used by professional researchers, in order to increase student comprehension of science content and methodology (Carlson, Humphrey, & Reinhardt, 2003; Echevarria, 2003; Llewellyn, 2002). However, the limited prior experience of students and common misconceptions as to the nature of science may greatly limit the likelihood that students will benefit from inquiry activities without substantial support and instruction (Kirschner et al., 2006; Kuhn, 1997; Mayer, 2004). These barriers necessitate teacher implementation of modifications and additions to inquiry instruction in order to assure success in student learning.

Direct instruction resolves some of the issues of limited experience and knowledge. An instructor may improve student understanding of science by directly addressing misconceptions. Yet, direct instruction does not provide experience by actively engaging students in research activities. Therefore, other techniques such as scaffolding (Vygotsky & Cole, 1978) should be used in conjunction with direct instruction. This would provide experience with inquiry and enable students to develop the skills and knowledge required to engage in independent activities.

Many advocates for inquiry methodologies expect that students will be able to successfully engage in the complex processes of inquiry that often take experts years to develop. This expectation is frequently not met, and it must be addressed as a significant issue associated with the promotion of this pedagogy. At the time it is necessary to bear in mind that lower levels of inquiry are unlikely to teach students how authentic research is actually conducted (Chinn & Malhotra, 2002). Both teachers and students need support in comprehending the inquiry processes, and they should be guided through numerous examples before they can effectively and productively engage in exercises that will lead to the processes found in authentic scientific research. There is a need to investigate the effectiveness of different approaches of inquiry-based methodologies in order to determine if there are more successful ways of increasing student comprehension of science content and understanding of scientific research. Students learn more about science through active participation in scientific practice, but, effective use of science practice activities requires that appropriate concessions be made to the needs, experience, and capabilities of the students involved.

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The Evolution of Creationism In America

This article examines the creationist movement and discusses the implications for science educators.

Recently, I was in a large chain bookstore when I noticed something odd about the way the books were organized. On the same shelf, I found creationist books like Michael Behe's *Darwin's Black Box* and Phillip E. Johnson's *Darwin On Trial* alongside pro-evolution books such as Eugenie Scott's *Evolution Versus Creationism* and Michael Shermer's *Why Darwin Matters: The Case Against Intelligent Design*. Tucked in between these attention-grabbing texts were desultory science books with relatively tame titles. I found this arrangement strange, because the sign on top of the shelf read "Science." I thought to myself, "Wouldn't the Religion section be more appropriate, because the theme of both the pro-creation and the anti-creation books is God's role in creating life on earth? Isn't that clearly a theological issue?"

My next thought was, "Why do these books have such assertive and defensive titles?" As I read the front and back covers of the books, I felt like I was in the middle of a verbal sparring match between the creationist and evolutionist authors. On the creationist side, there was a call for putting *Darwin On Trial* and there was a response from evolutionists for *Defending Evolution*. However, once I was able to put the authors' words into the context of the larger social, political and legal debates within American Society the titles made sense.

Research in the fields of political science, sociology, and moral psychology reveals that an individual's positions on issues like the death penalty, abortion, or the teaching of evolution are not formed in a vacuum; instead, they are the product of underlying moral and ethical frameworks (Haidt, Kohler, Dias, 1993; Hunter, 1991, 2006; Sowell, 1987). Differences between moral perspectives are responsible for seemingly irreconcilable conflicts over issues such as abortion, the death penalty, and gun control. Sociologist James Davidson Hunter (1991, 2006) devised the concept of a culture war in order to describe the conflict over the values and beliefs that will become dominant in society. One side is comprised of individuals with a conservative "orthodox faith" who believe that there are eternal, transcendent laws and guidelines for moral behavior. Alternatively, individuals with a liberal "progressive faith" believe that it is necessary to change values and laws in order to reflect contemporary society (Hunter, 1991, 2006).

Evolution is an example of an issue that can create rifts between individuals with orthodox and progressive faiths. Individuals with an orthodox view believe that evolutionary theory threatens traditional religious and moral values because it is viewed as one of the foundational principles for secular humanism (Coulter, 2007; Dawkins, 2006; Jacoby, 2004). In contrast, individuals with a progressive perspective see evolutionary theory as adding to the collective knowledge of mankind (Coulter, 2007; Dawkins, 2006; Jacoby, 2004).

In the culture war, science educators have become the front line defenders of evolution. Therefore, it is critical that we understand creationist agenda and tactics. This article addresses these issues by (1) identifying the different varieties of creationism, (2) summarizing the evolution of creationism in the United States, and (3) addressing the issues that are pertinent to the defense of evolution.

I. Creationism, The Diversity of Ideas

One of the misconceptions people have about creationism is that it is a unified movement. In reality, creationism exists along a continuum of beliefs (Numbers, 2006; Scott, 2004). At one end of the continuum is the idea that God personally created all life and actively intervenes to ensure its progress. At the opposite end of the continuum is the view that life is planned and initiated by God, and it progresses without any intercession.

The most God-centered creationist group is the Young Earth Creationists. This group insists the Bible is the inerrant word of God (Gish, 1995; Ham, 1998, 2007; Morris, 1985). Because they interpret the Bible literally, Young Earth Creationists believe that the earth was created in six days, that it is 4,000-6,000 years old, and that the biblical flood was a real event that was responsible for the extinction of creatures like the dinosaurs (Gish, 1995; Ham, 1998, 2007; Morris, 1985). The most established and active group of Young Earth Creationists is the Institute for Creation Research located in San Diego, California. It was founded in 1971 by Henry Morris, a professor of mechanical engineering, and the Evangelical Preacher Tim Lehaye, who is best known for his popular *Left Behind* series about the Christian rapture. The Institute for Creation Research is a major publisher and retailer of creationist and religious-based materials which are distributed through its web site at <www.icr.org>.

Old Earth Creationists, like Young Earth Creationists, believe that the emergence of different life forms is due to the actions of an intelligent creator. The issue that distinguishes Old Earth Creationists and Young Earth Creationists is that Old Earth Creationists do not believe the creation story in the Bible is literally true (Numbers, 2006; Pennock, 2000). Instead, Old Earth Creationists choose to interpret the Genesis creation stories so that they fit currently available scientific knowledge. The Old Earth Creationist position is exemplified by the organization Answers in Creation, which informs visitors to its web site, <www.answersincreation.org>, that they can both be a Christian and believe in an old earth as long as they accept the central doctrine of salvation through a profession of a faith.

A major problem that Old Earth Creationists have with a literal interpretation of the Bible is that it does not fit the current scientific evidence. In order to resolve the discrepancies between the Bible and science, Old Earth Creationists utilize two divergent explanations: the Day-Age idea and the Gap Creation idea. The Day-Age idea describes the creation of life as taking place during God-length days that may have lasted thousands or millions of years (Pennock, 2000; Scott, 2004). The alternative Gap Creation idea is based on the concept that life emerges in cycles of creation followed by long periods of stasis that are then repeated until humans were created (Pennock, 2000; Scott, 2004).

Further along the spectrum of the creationist ideals are the Progressive Evolutionist and Theistic Evolutionist groups. These two forms of explicit creationism most closely resemble Materialistic Evolution. The major difference between these creationist theories and Materialistic Evolution is the belief that God is involved in the evolution of life. Progressive Evolutionists envision God as both a creator and a hands-on guide for the progression of life on earth. One of the leading Progressive Evolution groups is the Reasons to Believe Ministries under the direction of the astronomer Dr. Hugh Ross. According to the ministry's web site, <www.reasons.org>, Progressive Evolutionists believe that the universe was formed during the Big Bang, the Earth is billions of years old, the Noachian Flood was a real event restricted to Biblical lands, and all life-forms on earth (with the exception of humans) evolved from simpler ancestral forms. It is on the issue of human origins that Progressive Evolutionists may have different views. Some Progressive Evolutionists agree with the Reasons to Believe Ministries' position that humans are the product of special creation. However, other groups contend that the physical appearance of humans may be the result of evolution but God is responsible for specially creating the human mind and soul (Zweerink, 2007).

Theistic Evolutionists differ from Progressive Evolutionists in that they believe God is responsible for creating the laws for the evolution of life, but God is not directly involved afterwards (Pennock, 2000, Scott 2004). Craig Rusbult, a Theistic Evolution curriculum developer, summarizes the Theistic Evolution position when he writes that it "proposes that God's method of creation was to cleverly design a universe in which everything would naturally evolve" (Rusbult, 2002). Because it preserves religious doctrines and accounts for the results of modern science, Theistic Evolution is the view that is most frequently taught at mainstream Protestant seminaries, and it is also the official view of the Catholic Church (Scott, 2004).

The latest form of creationism is Intelligent Design, which is not a novel idea but a reincarnation of a notion developed by the 18th Century Theologian William Paley (Pennock, 2000; Ruse, 2000). Paley's central idea is the belief that the complexity of the natural world is the product of an intelligent designer, God. In his book *Natural Theology* (1802), Paley uses the classic creationist analogy of finding a watch in a grassy heath. He reasoned that anyone who found the watch and observed its internal gears, dials, and levers would inevitably conclude that it was the product of an intelligent designer. Paley extends this analogy to include biological structures such as the eye, digestive system, and other bodily systems until he builds his case to include complete organisms.

The current version of the Intelligent Design movement began in the 1980s with the publication of two seminal texts (Numbers, 2006). In 1984, three Ph.D. scientists Charles Thaxton, Walter Bradley and Roger Olsen published *The Mystery of Life's Origins* in response to the growing materialism within evolutionary biology. Two years later, physician/geneticist Michael Denton published *Evolution: A Theory in Crisis* (1986). Of the two texts, Denton's has been more influential. Both Phillip E. Johnson and Michael Behe, two leaders in the Intelligent Design movement, claim Denton's book inspired them to abandon their belief in Materialistic Evolution (Forrest & Gross, 2004; Humes, 2007).

The term "Intelligent Design" was coined in 1988 in response to the United States Supreme Court's ruling in *Epperson v. Arkansas* (1968). In this decision, the court stated that public schools could not ban evolutionism or teach creationism because both actions were religious in nature and violated the constitutional separation of church and state (Thorndike, 1999). In order to avoid future court sanctions, the creationist author Charles Thaxton devised the agnostic term of Intelligent Design as the new code for creationism (Forrest, 2007).

Despite the claim made by Intelligent Design theorists to have developed a new scientific theory, practically all of the core concepts of Intelligent Design are adapted from older creationist beliefs (Forrest, 2007; Forrest & Gross, 2004). A prime example of this recycling process is the concept of irreducible complexity, which is simply a reincarnation of Paley's argument from design. Irreducible complexity is the idea that certain biological entities are too complex to have been formed by a series of random mutations, and therefore they must be designed (Behe, 1996).

Possibly, the one innovation attributable to the Intelligent Design theorists is their shifting of the case for irreducible complexity away from the observable macroscopic world to the molecular level. This is advantageous for the Intelligent Design theorists because the general public has a limited understanding of phenomena at the molecular level. For example, the proposed example of irreducible complexity is the bacterial flagella. Intelligent Design theorists like Michael Behe argue that the flagella could not evolve through a gradual building process because it can not function if a single protein is missing. Since an incomplete proto-flagellum can not function, it can not be adaptive; therefore, it can not be formed by natural selection (Behe, 1996). Empirical research has demonstrated that Behe is wrong about the flagella and all of his other examples of irreducible complexity (Dawkins, 2006; Miller, 1999). Unfortunately, a large percentage of the general public has minimal scientific training and must rely on intuition to decide if evolution or Intelligent Design is correct. In this situation, Intelligent Design has the advantage because it offers the comforting answer of design and purpose via God. On the other side, evolutionism remains agnostic on the issue of the creator, and it is restricted to a materialistic explanation of life.

II. The Development of Creationism in the U.S.

Superficially, the creationists appear to be unified by their belief in God and their disdain for evolution. In reality, however, the creationists are divided by irreconcilable theological positions on the Bible and the role God plays in the creation and progression of life. A brief web search can reveal the acrimony that exists between the different creationist groups. The most frequent criticism launched between creationists is a charge of infidelity to the underlying Christian values of creationism. The criticisms occur in a pattern analogous to a moral pecking order (Nelkin, 1982). Young Earth Creationists view all other creationists as sell-outs, because they selectively interpret God's word as it is recorded in the Bible. Old Earth Creationists criticize Progressive and Theistic Evolutionists for downplaying God's role in creation. Finally, more literal creationists express reservations about Intelligent Design theorists because they do not publicly identify the designer as the Christian God. Instead, Intelligent Design theorists envisage that life is the product of an unknown designer. In meetings with creationist groups, the proponents of Intelligent Design frequently refer to the designer as God, and they emphasize the connections of Intelligent Design and the Biblical account of creation (Forrest & Gross 2004). However, creationist groups tend to view the public strategy of Intelligent Design theorists as dubious because it appears that they are denying the Christian ideas behind creationism (Morris, 2006; Purdohm, 2006; Ross, 2007).

The schisms within the creationist movement are the result of theological changes that were prompted by judicial decisions and changes in public opinion. In order to fully understand how these divisions emerged, it is necessary to review creationism's historical development. In writing this brief history, I relied primarily on Edward J. Larson's book *Evolution On Trial* (2003) and Ronald Number's text *The Creationists* (2006). If readers want a more detailed understanding of creationism, they should consult these comprehensive and accessible books.

Creationism as Moral Reform

Before 1900, evolution was a relatively non-controversial subject among the general public, and it was prominently featured in science textbooks (Larson, 2003; Skoog, 2005). However, conditions changed in the early 20th Century with the advent of the Progressive Movement. Progressive activists aimed to improve the human condition through better education, improved working conditions, adequate health care, and moral reforms (Hofstadter, 1992; Hunter, 1991). One product of the Progressive Movement's moral reforms was Tennessee's 1925 Butler Act, which banned the teaching of evolution in any public elementary school, high school, or university in the State of Tennessee. In their effort to preserve students' moral values, Tennessee's legislators set into motion one of the most famous court cases in American history, the Scopes Monkey Trial (Larson, 1997).

John T. Scopes was a substitute biology teacher in Dayton, Tennessee, who was recruited by town leaders to be the defendant in the trial (Larson, 1997). Scopes was not sure that he violated the law, but he did admit to using George Hunter's *A Civic Biology* which included a section on evolution (Larson, 1997; Ruse, 2000). Based on this physical evidence and the testimonies of a few students, the prosecutors initiated the case (Larson, 1997). Despite the salient demonstration of the flaws within creationism made by Scopes' lawyer, Clarence Darrow, the jury was not swayed. They found Scopes guilty of teaching evolution and fined him $100 (Larson, 1997, 2003).

The Scopes Trial did not prove to be a definitive victory for either side. Creationists hoped the guilty verdict would inspire more states to pass anti-evolution laws and help the movement grow. After the trial, at least 20 new anti-evolution bills were introduced into state legislatures, but only two states (Arkansas and Louisiana) passed anti-evolution laws. A major reason the anti-evolution legislation failed was due to the negative public criticism of the Butler Act by the media. Throughout the trial, the State of Tennessee was denigrated with comments referring to it as an intellectual backwater (Larson, 1997). The governors and legislatures of other states noted the negative publicity. In order to avoid the same harsh treatment by the media, the anti-evolution bills were either killed in legislative committees or were soundly voted down by legislators (Larson, 1997, 2003).

Alternatively, the pro-evolution side could only claim a minor philosophical victory from Darrow's interrogation of William Jennings Bryan during the trial. Their ultimate goal was to challenge the Butler Act in front of the United States Supreme Court and create a legal precedent in support of evolution. Unfortunately for the pro-evolution lobby, the path to the nation's highest court was blocked by a decision made by Tennessee's Supreme Court. After reviewing the case, the court upheld the Butler Act because it believed that it only applied to individuals in their professional capacity at work and did not infringe on their personal beliefs (Larson, 1997, 2003). In addition, the court overturned Scope's conviction on a technicality and ended the possibility of future appeals (Larson, 1997, 2003). The anticlimactic end of the Scope's case marked the beginning of an unofficial truce between the supporters of evolution and creationism.

Evolution on the Offensive

On October 4, 1957, the Soviet Union's launch of Sputnik became the inspiration for major education reforms in the United States. In order to be competitive in the space race and other scientific endeavors, America's political leaders called for educational improvements in the areas of math and science (Deboer, 1991; Larson, 2003). One major curriculum change was the introduction of the more academically challenging Biological Science Curriculum Series (BSCS) which consisted of 3 different thematic texts that heavily emphasized evolution. As school districts across America adopted the BSCS books, other textbook publishers followed the BSCS's lead and added more content on evolution (Larson, 2003; Skoog, 2005). The new pro-evolution texts infuriated creationists and provided the supporters of evolution a means for challenging the anti-evolution laws in Arkansas and Louisiana. After nearly two decades of publishing textbooks that downplayed evolution in order to appease state legislatures and local school districts (Larson, 2003; Skoog, 2005), the new evolution-laden texts were clear violations of the states' anti-evolution laws.

The groundwork for challenging the anti-evolution laws was established by earlier Supreme Court decisions on the role of religion in public schools. In the cases of *Everson v. Board of Education* (1947) and *McCollum v. Board of Education* (1948), the court ruled that school districts could not use public funds to support religious activities. In both decisions, the court stated that the inclusion of religion in public schools violated the 1st Amendment Establishment Clause, which requires a separation of church and state (Larson, 2003).

After being on the books for over 40 years, Arkansas' anti-evolution law would be challenged in the U.S. Supreme Court in the case of *Epperson v. Arkansas* (1968). The case was initiated by high school biology teacher Susan Epperson, the Arkansas Education Association, and the American Civil Liberties Union (Thorndike, 1999). Epperson's legal challenge was based on the fact that the Little Rock School District had adopted a biology textbook that violated the law by including a chapter on evolution. As a result, teachers who used the textbook were technically breaking the law, and they could be prosecuted and/or dismissed from their jobs.

Epperson and her legal team initially brought their case before the State of Arkansas Chancery Court. The Chancery Court ruled that the anti-evolution law violated the guarantees of freedom of speech as outlined in the 1st and 14th Amendments of the United States Constitution. However, the Arkansas Supreme Court overturned the ruling and found the state was exercising its power to set the curriculum within public schools. Eventually, the case reached the United States Supreme Court, and the anti-evolution law was struck down. In its ruling, the court found the anti-evolution law violated the 1st Amendment Establishment Clause (Larson, 2003; Thorndike, 1999).

Equal Time- Fairness in Representation

After *Epperson* v. *Arkansas*, the creationists took the new tact of appealing to Americans' sense of fairness and democracy (Eve & Harrold, 1991; Larson, 2003). The new campaign focused on the need for students to critically reflect and debate issues in order to make informed decisions. Creationists argued that a debate-driven process was a central component of American democracy, as evidenced by the adversarial structure of America's electoral process and the judicial system. In effect, the creationists were re-conceptualizing the public debate by pitting science and evolution against America's democratic values.

In 1978, Yale Law Student Wendell Bird wrote a seminal paper on the concept of Equal Time for Creationism (Larson, 2003; Numbers, 2006). Bird's paper got him notoriety, and it was also published in the prestigious *Yale Law Review* (Larson, 2003; Numbers, 2006). His plan for attacking evolution served as the template for the development of Equal Time legislation in Arkansas and Louisiana. In 1981 and 1982, lawmakers in both states passed laws that required equal time be spent on the instruction of evolution and creation. In Louisiana, the law required equal time for creation only if evolution was taught (Larson, 2003).

Arkansas' *Balanced Treatment for Creation-Science and Evolution-Science Act* was challenged almost immediately in federal district court. In the case of *McLean v. Arkansas Board of Education (1982),* Judge William Overton ruled against the law on the grounds that it was based on religious motives and because creationism was not a scientific theory (Larson, 2003; Numbers, 2006). Five years later, Louisiana's *Equal Treatment for Creation-Science and Evolution-Science in Public School Instruction Act* would reach the United States Supreme Court. In the case of *Edwards v. Aguillard* (1987), the United States Supreme Court overturned Louisiana's law. Once again, it identified creationism as a religious doctrine that violated the 1st Amendment Establishment Clause (Larson, 2003; Numbers, 2006).

Teaching the Controversy

In 1983, the *National Commission on Excellence in Education* released its findings in a report titled *A Nation At Risk*. The commission found that American students were woefully under-prepared to meet the challenges of the modern economy, and it recommended that high school students take four years of coursework in the core content areas of English, Mathematics, Science, and Social Studies (Ravitch, 2000). The committee also proposed that the American educational system be standardized in order to ensure that all students were provided the same opportunities to achieve in school (Ravitch, 2000). Ten years later in 1993, President Bill Clinton finally provided financial support for the changes called for in *A Nation At Risk* by signing into law the *Goals 2000: Educate America Act*. Under this act, states were required to use standards based on the national standards or lose federal funding for education (Larson, 2003).

However, after the 2004 mid-term elections, the Republican-dominated senate rescinded the authority of the federal government to set or review states' educational standards (Larson, 2003; Ravitch, 2000). Creationists realized that without national standards, the states would be solely responsible for determining science standards. This was to their advantage because state politicians and state governments have been historically more willing to support the teaching of creationism in public schools. The conditions were right for a new anti-evolution campaign, and all that was needed was a form of creationism that would not be struck down by the courts. In the 1990s, the federal courts consistently refused to allow any form of creationism in the public schools or to permit the reading of disclaimers identifying evolution as a controversial theory. The message from the courts was that creationism or any efforts to undermine evolutionary theory were religious in nature and violated the 1st Amendment Establishment Clause.

In response to the court-mandated restrictions, creationists developed the concept of Intelligent Design. The campaign slogan of "Teach the Controversy" accompanied the new idea. This focused public attention on the perceived flaws or "gaps" in evolutionary theory while ignoring the flaws in Intelligent Design (Forrest, 2007; Forrest & Gross, 2004). An example of this approach can be seen in Jonathan Well's book *The Icons of Evolution* (2000) in which he claims to debunk ten foundational principles or "icons" of evolutionary theory that are present in college-level biology texts. Wells claims that these major concepts are either falsified or inaccurate, and therefore evolutionary theory must be false. The implicit message from Wells and other Intelligent Design theorists is that if evolutionary theory is wrong then Intelligent Design must be correct.

In order to understand the way in which Intelligent Design groups operate, it is instructive to examine the largest and most powerful Intelligent Design organization—the Discovery Institute—in Seattle, Washington. The Discovery Institute's official mission as stated on its web page <www.discovery.org> is to "make a positive vision of the future practical." In 1999, the Discovery Institute's true mission statement, the Wedge Strategy, was leaked to the public over the internet (Forest & Gross, 2004). The Wedge Strategy document delineates the following governing goals for the institute: defeat scientific materialism and its destructive moral, cultural and political legacies, and replace materialistic explanations with the theistic understanding that nature and human beings are created by God.

Despite the release of the Wedge Strategy, the Discovery Institute continues to actively campaign against evolution, and it still insists that it does not have a religious agenda (Forrest, 2007; Humes, 2007). In 2004, the Discovery Institute's Center for Science and Culture provided legal advice and experts in order to help the Kansas State Board of Education adopt standards critical of evolutionary theory (Forrest & Gross, 2004; Humes, 2007). The Center for Science and Society was also involved in the 2005 *Kitzmiller v. Dover* Case, during which it provided legal advice to members of the Dover School Board (Humes, 2007).

The Next Wave, Creationism Goes On the Air and Internet

Television, radio, the internet, and cinema have proven to be invaluable tools in creationists' grassroots efforts to inspire and recruit supporters. For example, Federal District Judge John Jones declared in his decision regarding the Kitzmiller case that Intelligent Design is not a scientific theory but a religious doctrine, and therefore it should be excluded from the public schools. On NBC's Nightly News, correspondent Robert Bazell's report focused on the judge's rationale for rejecting Intelligent Design as a religious doctrine and the judge's concern over the school board's religious motives (Bazell, 2005). However, if viewers changed the channel to watch Pat Robertson's *700 Club* or visited creationist and evangelical Christian web sites, they would have been exposed to the viewpoint that the judge overreached his constitutional authority (Lee, 2006).

Creationist programs can be on the air 24 hours a day and reach millions of viewers. Most of the programs are independently produced and broadcasted on local radio and cable access, but there is a growing number of international networks and programs (Larson, 2003). The public can view creationist television programs like *Creationism in the 21st Century* hosted by Dr. Carl Baugh, (Eve & Harrold, 1991) and listen to leading creationists like Phillip E. Johnson on radio programs such as Dr. James Dobson's *Focus On The Family* (Forrest & Gross, 2004).

Creationists are also adept at using the internet for disseminating their message and raising funds. A brief web search reveals hundreds of sites dedicated to diverse forms of creationism ranging from Young Earth Creationism to Intelligent Design. Creationist groups also use the web as an academic clearinghouse for articles on creationism and related subjects (Alters & Alters, 2001). Because mainstream academic journals reject Intelligent Design and other forms of creationism, creationists are now publishing their own articles and journals online. Web sites designed by the American Scientific Affiliation, Discovery Institute, Intelligent Design and Evolution Awareness Center, and other groups contain hundreds of articles that are written, reviewed, and edited by purported experts in the field of creationism. Because the creationist web-based articles resemble online academic articles, they can appear to be legitimate science papers to uniformed individuals seeking information on the internet.

Finally, in April 2008, creationism moved to the big screen with the premiere of the pro-Intelligent Design movie, *Expelled*. The movie features former Nixon speech writer and character actor Ben Stein. Throughout the film, Stein makes claims such as (1) excluding Intelligent Design from classes violates students' and parents' right to freedom of speech, (2) Darwin's ideas are responsible for the holocaust, and (3) scientists and educators who support Intelligent Design are unfairly persecuted (Rennie & Mirsky, 2008). Despite the public exposure of many inaccuracies and falsehoods in the film from diverse news sources (NCSE, 2008) it earned nearly $7.5 million at the box office and approximately $2.2 million from video sales and rentals (The Numbers.com, 2008).

III. Getting to Know the Creationists Movement

Scientists and science educators can not afford to take it for granted that creationism is a belief held by uneducated religious extremists or "Rednecks" as the biologist Richard Dawkins calls them (1986). Since the publication of Charles Darwin's *Origin of Species* (1859), evolutionary theory has become one of the most powerful explanatory theories in any academic field. However, despite evolution's triumph within the scientific community, courts and schools has concurrently selected for more virulent and robust forms of creationism. As a result, today's creationist groups are organized, inventive, and well versed in the tactics of advertising and political rhetoric.

In the public relations battle over teaching evolutionism or creationism in public schools, creationists have several advantages. First, they have greater financial resources to use in their campaigns against evolution. The two largest Young Earth Creationist organizations (Answers in Genesis and the Institute for Creation Research) each have an annual budget of $5 million and over 50 employees (Alters & Alters, 2001). In addition, the leading Intelligent Design organization, The Discovery Institute, has an operating budget over $7 million, and maintains a staff exceeding 50 individuals (Olson, 2006).

A second advantage the creationists have is that they are more organized at the national, state, and local levels. At the local level, creationists have a ready-made network of religious groups that may be affiliated with national organizations that officially support creationism (Answers in Creation, 2003). In the new creationist grassroots campaign, local religious groups are on the front lines lobbying local officials and running for local school boards in their efforts to get creationism back into public schools. It is this type of church-based campaigning that ignited and sustained the creationism/Intelligent Design conflict in Dover, Pennsylvania (Humes, 2007).

Creationists groups are also active on college and high school campuses where they have formed student chapters. For example, the Young Earth Creationists group, Answers in Genesis, claims to have 706 student chapters on 543 college campuses across the United States (Alters & Alters, 2001). Another creationist group, the Intelligent Design and Evolution Awareness Center, claims to have five high school and 22 college student chapters across the country (Intelligent Design and Evolution Awareness Center, 2007). The purpose of these student organizations is to recruit young supporters and to publicly confront experts on evolution in college and high school classes (Alters & Alters, 2001).

At the regional and state level, there are presently 132 creationist organizations across the United States (Northwest Creation Network, 2007). The purpose of these organizations is to assist smaller community-based groups by (1) providing attack strategies and legal advice, (2) establishing communications between local groups, (3) serving as the representative of the national creationist organizations, and (4) lobbying state and local officials (Alters & Alters, 2001). Even though their efforts occur in a limited geographical region, these organizations can make major contributions to the creationist movement. For example, the Intelligent Design Network located in Shawnee Mission, Kansas, has facilitated the development of standards that support Intelligent Design in several states. In 2002, John Calvert, the founder of the Intelligent Design Network, successfully convinced the Ohio State Board of Education to include a definition of science that could include Intelligent Design (Olson, 2006). In 2004, Calvert also led the effort to include Intelligent Design in Kansas' state science standards (Olson, 2006). As of 2006, both sets of standards now reflect the scientifically accepted view.

At the national level, there are at least 28 creationist organizations, some of which have considerable influence on national policies (Northwest Creation Network, 2007). In 2000, a delegation from the Discovery Institute briefed more than 50 Republican senators and congressmen about the purported flaws in evolutionary theory (Humes, 2007). Afterwards, Senator Rick Santorum and his collaborator, Center for Science and Society fellow Phillip E. Johnson, drafted an amendment to the *No Child Left Behind Act* that required teachers to address the gaps in evolutionary theory (Forrest, 2007; Forrest & Gross, 2004; Humes, 2007). Eventually, Santorum's amendment was removed from the law, but it was still included in the Senate's report about the legislation (Humes, 2007).

Relative to the vast networks of national, state, and local creationist organizations, the pro-evolution agenda is underrepresented and underfunded. The National Center for Science Education is the only full time organization dedicated to defending evolution (Humes, 2007; Olson, 2006). The National Science Education Center's annual budget of $700,000 and its staff of 12 are minuscule in comparison to the budgets of major creationist organizations (Olson, 2006). Additionally, there are only 18 state organizations dedicated to defending evolution (National Center for Science Education, 2008b), there are relatively few evolution-centered student organizations outside of college biology departments, and there are almost no local organizations to match the network of community-based religious groups (Humes, 2007).

One final disadvantage that scientists and science educators have is that they are not necessarily familiar with the creationists' true agenda. As stated in the Discovery Institute's Wedge Strategy, the ultimate goal is to "defeat scientific materialism and its destructive moral, cultural and political legacies." Statements like this and similar statements made by other creationist organizations indicate that their fundamental objective is to impart their values and beliefs on society (Forrest, 2007; Hunter, 1991; Jacoby, 2004). This moral agenda is exemplified by one of the central images of the creationist movement: the tree of secular humanism (Olson, 2006). Basically, it is the image is a fruit tree with its roots enveloping the earth. The tree represents secular humanism, and its fruits represent the products of secular humanism which include murder, hatred, abortion, homosexuality, drunkenness, witchcraft, and pornography (Ham, 1998).

In response to the charge that evolution leads to a belief in secular humanism, biologists like Kenneth Miller (1999) and Francis Collins (2007) have published books recounting how they can accept evolution and maintain their religious faiths. In addition, religious organizations such as the American Jewish Council, the Lutheran World Federation, the Presbyterian Church (U.S.A.), the Roman Catholic Church, and the United Methodist Church officially accept evolutionary theory (Sager, 2008).

Conservative organizations like the Heritage Foundation and the Thomas Moore Law Center attack evolution as part of their political, social, and moral agenda (Eve & Harrold, 1991). In addition, conservative activists and public personalities like Rush Limbaugh, Bill O'Reilly, and Ann Coulter dispense their conservative views which include critical comments about evolutionary theory. For example, the popular conservative author Ann Coulter attacks evolution because she perceives it to be the foundational theory of the liberal agenda.

> Liberals' creation myth is Charles Darwin's theory of evolution, which is about one notch above Scientology in scientific rigor. It's a make believe story, based on a theory that is a tautology, with no proof in the scientists' laboratory or the fossil record- and that's after 150 years of very determined looking. We wouldn't still be talking about it but for the fact that liberals think evolution disproves God (Coulter, 2007 pg. 199).

Scientists and science educators can learn from this conservative and creationist rhetoric that evolution is just one target in the much larger conflict over the values that will define American society (Sowell, 1987; Hunter, 1991). An individual's views on evolutionism or creationism are not isolated ideas but part of an intricate web of moral, social, and political beliefs (Haidt, Kohler, Dias, 1993; Hunter, 1991, 2006; Sowell, 1987). The conflict over teaching evolutionism or creationism is just one issue in a broader culture war (Hunter, 1991, 2006).

IV. Conclusion

One goal of this article is to provide science educators with a basic understanding of the creationist movement. Before engaging creationists, it is useful to know their specific views in order to adequately address their arguments. In addition, understanding creationist beliefs can improve student learning. Educational research demonstrates that addressing creationist views in class can positively impact perceptions of evolution and improve understanding of evolutionary theory (Blackwell, Powell & Dukes, 2003; Ingram & Nelson, 2006).

A second goal of this paper is to alert science educators of the consequences of losing the evolution/creationism conflict. As stated above, this is a battle about the values that will shape American society, and it has dire consequences for science. The majority of social conservatives are skeptical of science. For example, many conservatives tend to doubt the reality of global warming, and they tend to believe that the benefits of embryonic stem cell research are greatly exaggerated (Coulter, 2007; Mooney, 2006).

Presently, the creationists are in public favor as evidenced by a CBS News Poll in 2004 that found 82% of Americans believe that humans are the product of special creation (CBS News, 2004). Creationists have noted this shift in public opinion and utilize it in their grassroots campaigns. The objective of their efforts is to inspire citizens to vote for local, state, and federal politicians who will support creationist legislation and pro-creationism judges. In order to combat the creationist bottom-up strategy, science educators must become more ardent supporters of evolution on their campuses and communities. Although the acceptance of evolutionary theory in the scientific community is unquestionably widespread, its legal status may be subject to changes in popular opinion. A prime example of the way that public perception can shape government policy is the recent shift from a liberal to a more conservative federal court system. This ideological change is the result of public support of conservative senators who, in turn, confirm new conservative judges.

The current evolution/creationism controversy is analogous to the scene at the bookstore discussed in the introduction. The heterogeneous mixture of evolution and creationist titles is a microcosm of the malaise of religious, creationist, scientific, and evolutionary ideas within American society. In their books, television programs, web pages, and public talks, the evolutionists and the creationists proclaim they have the correct explanation, and it is the general public that is caught in the middle. If the creationists gain public confidence, they still have to contend with the nettling issue that there is no empirical evidence supporting creationism. Alternatively, if evolutionists can convince the general public to take their side, it is highly improbable that creationists will concede defeat. History indicates that when creationists lose in the courts and in the arena of public opinion, they simply re-invent themselves, create a new campaign, and continue the fight. For example, in 2008, anti-evolution bills were introduced in Alabama, Florida, Louisiana, Michigan and South Carolina under the pretense of defending teachers' academic freedom. Ostensibly, the new legislation is designed to protect teachers from legal actions or dismissal by providing training and guidelines for teaching controversial subjects like evolution or global warming (National Center for Science Education, 2008a). To date, all but one of the bills died in committees or failed to come up for a vote. However, Louisiana Governor Bobby Jindal signed into law his state's first anti-evolution bill in 27 years. If history is any indicator, Louisiana's pro-creation law will encourage politicians in other states to introduce their own creationist-friendly bills. The resurgence of anti-evolution initiatives in 2008 is just another indication that the evolutionism/creationism conflict will continue indefinitely into the future.

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