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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

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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.

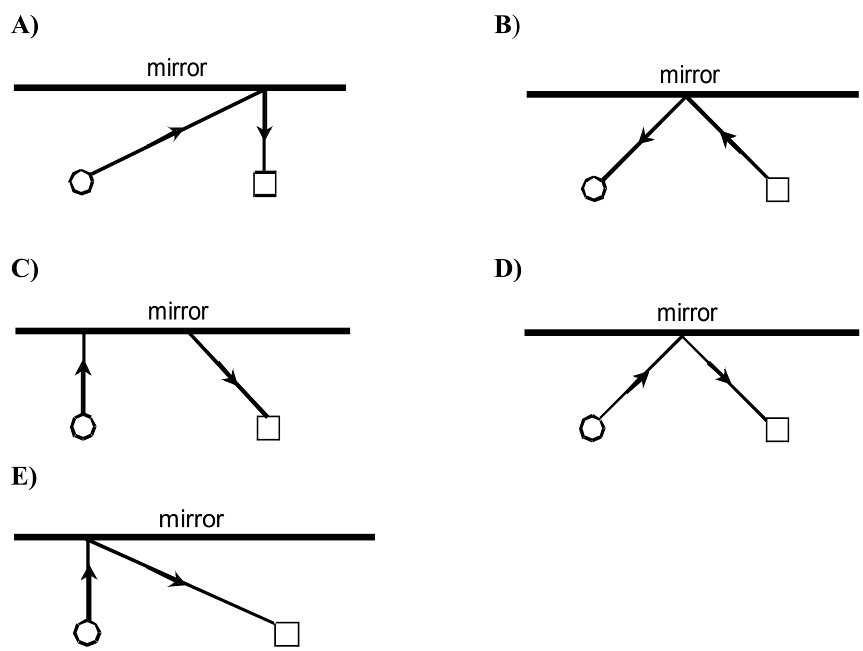
Data Analysis Procedures

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

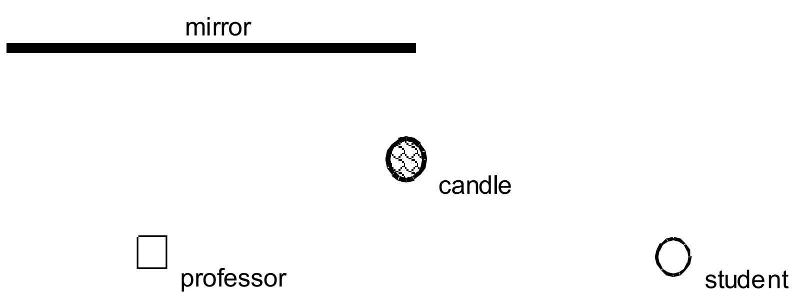
The first light task (Figure 1) assesses comprehension of the principle that light is reflected in a predictable manner by a plane mirror. Achievements of both the elementary and middle school groups can be seen in Table 1, which displays the results for Task 1, as well as the frequency with which each 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

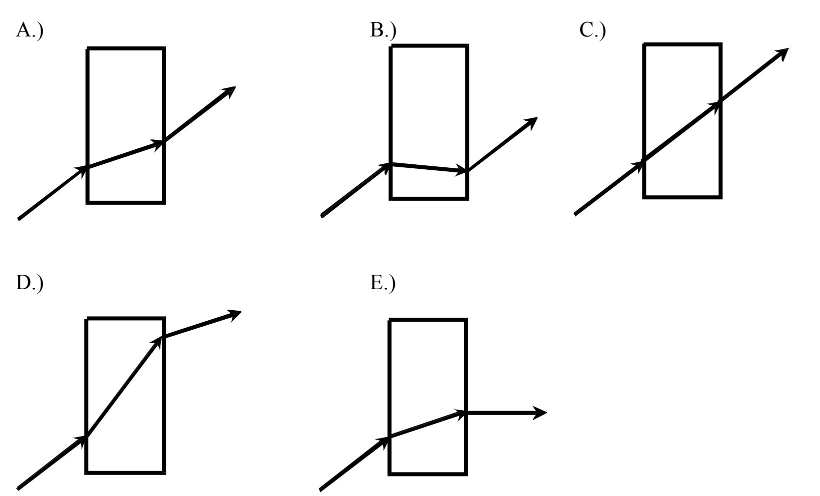
Table 2: Law of Reflection as Demonstrated by Candle Image in Mirror, Results for Elementary and Middle School Teachers Showing Response Frequencies by Performance-level Subgroups and Totals as Frequencies and Percents

	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.

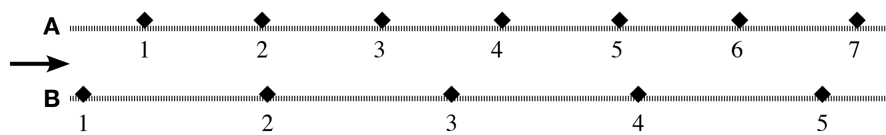
Teachers' conceptual difficulty identified in this task is consistent with previous research on university students enrolled in physics classes and with research on in-service elementary teachers (McDermott, 1984; Trowbridge & McDermott, 1980). Respondents in these studies tended not to differentiate 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

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.

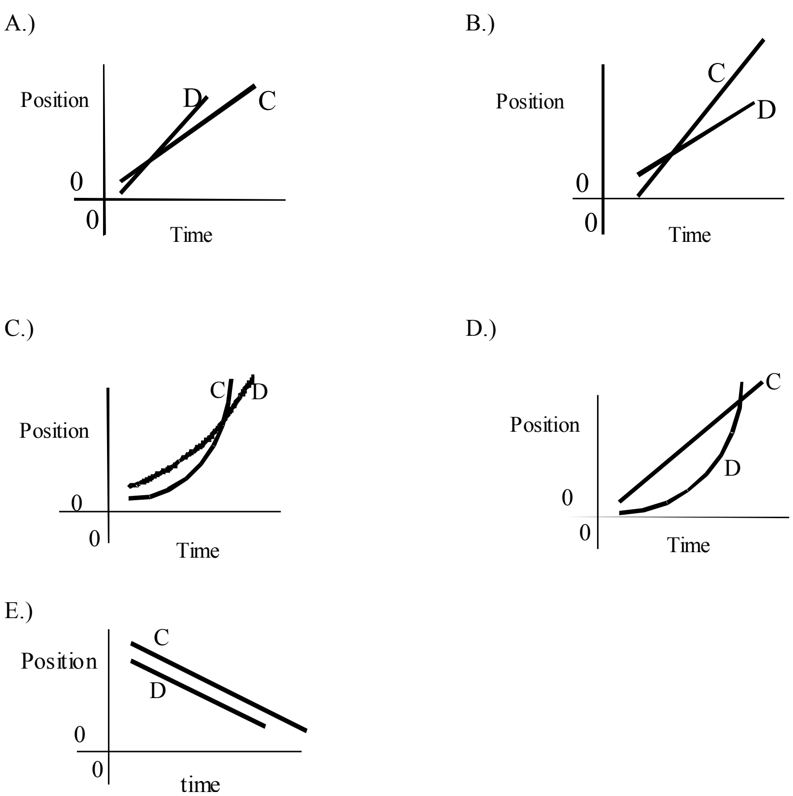
Table 4: ***Task 4***, Differentiating Position and Speed in Motion Diagram, Results for Elementary Teachers Showing Response Frequencies by Performance-level Subgroups and Totals as Frequencies and Percents

	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.

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?



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

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

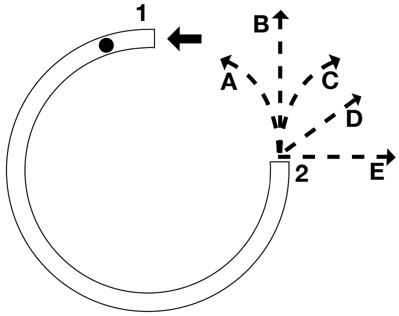
Both groups performed relatively well on this task when compared to performance on other tasks in the study. The roughly comparable performance of the two groups included 50 of 72 (69.4%) elementary teachers and 41 of 51 (80.4%) middle school teachers selecting the correct option, E. A chi-square of 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.

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



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.

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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