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# J P T E O

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## TOMORROW'S PHYSICS TEACHERS

Recently I received a message from one of our readers who appeared to be rather distraught about the prospect of ever recruiting enough candidates to meet the growing demand for high school physics teachers. The author cited a litany of factors that would appear make the teaching profession less than desirable - low pay, low status, low support, and low respect. He pointed out that women make up a growing percentage of all teachers, and that physics is a field populated mostly by men. And then, there's the potential for claims of child abuse... The reader went on to note that with the number of baby boomer teachers approaching retirement, that the situation was especially dire, and the prospect for having enough qualified high school physics teachers in the classroom is bleak.

Shortly thereafter I received another communication from a practicing engineer who had recently read the *Illinois Pipeline Project* report. He was optimistic that the teacher supply problem might be readily solved by taking advantage of all the layoffs in the engineering field. He suggested this is a most auspicious time to begin recruiting additional teacher candidates from among those displaced from the various engineering fields. Do this, and our supply problem will be solved.

Both of these viewpoints have been documented in several recent reports that are worthy of note. The National Education Association, writing in *Status of the American Public School Teacher*, mentions that only 21% of this nation's three million teachers are men. Over the past few decades this percentage has been declining. According to MenTeach, a not-for-profit organization promoting the recruitment of male teachers, there are problems with status and pay, and the perception that teaching is "women's work." Organizations such as these are working to eliminate social stereotypes and gender bias.

According to Public Agenda's report, *An Assessment of Survey Data on Attitudes about Teaching, Including the Views of Parents, Administrators, Teachers, and the General Public*, teachers want to see changes that will make them more effective in the classroom - smaller classes, better materials, stronger support from parents and administrators. Simply raising salaries is not the solution to getting the best teachers in the classroom. Salaries of the best starting high school teachers in large cities are on par with salaries of new Ph.D. faculty at many universities. Creative strategies are needed to attract qualified candidates.

My personal position is somewhere between the two divergent viewpoints express by those who wrote me for a variety of reasons. Granted, both of these writers had some very legitimate arguments substantiated by the reports cited, but I feel that neither of the writers has a good understanding of what drives individuals to become teachers - and helps them to remain committed to their chosen profession. Unless a person has what it takes to become a teacher, raises in salary and jobs for the jobless will not really help to solve the long-term problem of how best to supply our schools with teachers. Teachers who merely enter the profession on the basis of salary or job availability will soon depart once conditions on the outside that drive them into a teaching position change.

What really needs to be done to get more teachers for our classrooms is to take advantage of what drives those even today to become teachers despite the perceived low pay, low status, low status, and low respect - a sense of altruism, the desire to make a difference in the lives of others. We need to have high school teachers actually recruit candidates for teacher education programs which is something rarely done today in the area of physics. We also need to create teacher preparation programs that will attract students and of which we can be justifiably proud. The quality of such programs will help increase the number of tomorrow's teachers as work at several leading teacher preparation institutions has shown. Such programs actually exist today and are thriving. For more information about the reports cited in this article, visit the Illinois Pipeline Project website at <http://www.phy.ilstu.edu/pipeline/>.

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***JPTEO***

# A conceptual change approach to teaching energy and thermodynamics to pre-service elementary teachers

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*The article describes a use of conceptual-change theory to teach basic concepts related to thermal energy. The research was conducted in a university-level course for pre-service teachers that focused on one of the unifying themes in science (energy). The pedagogical approach, called misconception-guided instruction, involved five steps:*

*Step 1: identify the target areas for student learning*

*Step 2: assess prior understanding of targeted concepts*

*Step 3: analyze student understanding*

*Step 4: design instruction to address*

*Step 5: reassess student understanding to determine the impact of instruction on student understanding of targeted concepts.*

*The Thermal Concept Evaluation created by Yeo and Zadnik (2001) was used to assess prior understanding. Analysis of the pre- and post-instruction assessment data revealed that the combination identifying and targeting activities to confront student misconceptions was effective for targeted concepts and moved students to a more scientific understanding of thermal energy. Overall, the post-test scores were significantly improved. The average percentage of correct responses increased from 34.6% to 56.5%, resulting in a normalized gain  $\langle g \rangle = 33.4\%$ . Sample activities that were used in class are briefly described as well as limitations of the approach. Limitations described include student resistance to pre-assessment, student difficulty in applying concepts to related, but non-targeted situations, and the instructional and preparation time required to use this approach.*

## Introduction

Two of the most significant reform documents in science education are *Project 2061: Science for All Americans* (American Association for the Advancement of Science, 1989) and the *National Science Education Standards* (NSES) (National Research Council, 1996). Both documents recommend that science educators at all levels focus on deeper study of fewer concepts. One way to achieve this goal is to center content on common themes of science that transcend disciplinary boundaries such as energy, change and constancy, models or scale and structure (American Association for the Advancement of Science, 1989). A second recommendation contained in both Project 2061 and NSES is a description of how to teach science. The advocated inquiry-based pedagogy builds upon the learners' previous conceptions and provides links to everyday experiences. Despite these recommendations, very few pre-service teacher education programs prepare teachers to teach common or unifying themes with an inquiry-based approach. This article will describe one model for doing this with the theme of energy. Energy was

selected because it is frequently included in state benchmarks and school curricula, despite general agreement that teaching energy concepts is hard and thermodynamics is even harder (Cotignola, Bordogna & Punte, 1992; Duit, 2004; Trumper, 1998; Solomon, 1992).

Physics educators do not agree on how to teach concepts related to energy and thermodynamics. Some educators believe that conservation of energy (First Law of Thermodynamics) should be taught first, while others believe that it is more effective to teach the second law first. Traditionally, students are taught that energy changes form, but Swackhamer argues that this language suggests that there are different kinds of energy. He states that rather one should emphasize that there is only one kind of energy, although it may be stored in different ways (Swackhamer, 2003).

A fundamental reason these concepts are difficult to teach may be that we experience energy and thermodynamics in our everyday life. As a result, everyone has, to a certain extent, constructed a belief system that often is in conflict with scientifically correct understandings of identical phenomena (Wiser & Amin, 2001; Lewis & Linn, 2003; Solomon, 1992). Even scientists cannot explain everyday phenomena easily. In one study, two of the eight scientists interviewed could not easily explain the difference between heat energy and temperature, one could not apply his or her scientific knowledge to the question of relative insulating properties of aluminum foil and wool, and

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all gave different answers to the complex problem of the relative roles of convection, conduction, and radiation in the cooling of silver and pottery platters (Lewis & Linn, 2003).

Given students' perception that energy and thermodynamics are difficult to understand and the physics education community's disagreement about how to teach these concepts, how should educators teach energy and thermodynamics to pre-service teachers? Conceptual change theory is one model to bridge the gap between everyday knowledge and scientifically correct concepts. Broadly speaking, this theory of learning places emphasis on conceptual development or change rather than acquisition of isolated facts (Scott, Asoko, & Driver, 1991). Theorists describe three conditions necessary for change in conception to occur: the new conception must be intelligible, plausible, and fruitful (Posner et al., 1982). The more conditions that are met, the more likely conceptual change will occur.

We developed a pedagogy, called misconception-guided instruction, based upon conceptual change theory. The process, guided by student misconceptions, is used for introducing each science concept:

- Step 1: identify the target areas for student learning (what concepts do we want students to understand)
- Step 2: assess prior understanding of targeted concepts (resulting from everyday life experiences or formal instruction)
- Step 3: analyze student understanding (identify misconceptions or areas with lack of knowledge identified on the assessment)
- Step 4: design instruction to address (remediate) misconception(s)
- Step 5: reassess student understanding to determine the impact of instruction on student understanding of targeted concepts.

### Our Approach

This paper describes how we used conceptual change theory to teach concepts related to thermal energy and includes some activities used to address selected concepts related to energy and thermodynamics.

To make students' alternative frameworks in thermal energy explicit we chose the Introductory Thermal Concept Evaluation (TCE) described by Yeo and Zadnik (2001). The TCE targeted several of the concepts we wished to include, was based on misconception research, and posed questions in the context of everyday situations. The TCE consists of 26 multiple-choice questions that assess students' conceptions of four basic thermal energy concepts: heat, temperature, heat transfer and temperature change, and thermal properties of materials. Each question consisted of a scenario followed by statements that included common misconceptions relating to thermal energy (see Table I for sample questions). The TCE asks students for the 'best' rather than 'right' answer.

The students participating in the study (n=47) were elementary education students enrolled in a science capstone course at University of Michigan-Dearborn during the fall 2003 term. All students were either seniors or post-baccalaureates (five) earning their K-8 teaching credential. The students ranged in age from 21-45 years. Ethnicity was representative of our local area with nearly 10% of the students of middle-eastern descent. Typically, students take the capstone course the semester before they student teach although ten students in our sample enrolled in the course concurrent with student teaching.

All elementary education students are required to complete six science courses that combine content and pedagogy. The coursework, specifically created for these students, includes a prerequisite course focusing on science process skills and science as a way of knowing. Three science content courses (one each in physical science, earth/space science and life science) and one

Table I. Sample Questions from Thermal Concept Inventory

Question #8	<p>Jim believes he must use boiling water to make a cup of tea. He tells his friends: "I couldn't make tea if I was camping on a high mountain because water doesn't boil at high altitudes."</p> <ul style="list-style-type: none"> <li>a. Joy says: "Yes it does, but the boiling water is just not as hot as it is here."</li> <li>b. Tay says: "That's not true. Water always boils at the same temperature."</li> <li>c. Lou says: "The boiling point of the water decreases, but the water itself is still at 100 degrees."</li> <li>d. Mai says: "I agree with Jim. The water never gets to its boiling point."</li> </ul> <p>Who do you agree with?</p>
Question #19	<p>Ron reckons his mother cooks soup in a pressure cooker because it cooks faster than in a normal saucepan but he doesn't know why. (Pressure cookers have a sealed lid so that the pressure inside rises well above atmospheric pressure)</p> <ul style="list-style-type: none"> <li>a. Emi says: "It's because the pressure causes water to boil above 100 °C."</li> <li>b. Col says: "It's because the high pressure generates extra heat."</li> <li>c. Fay says: "It's because the steam is at a higher temperature than the boiling soup."</li> <li>d. Tom says: "It's because the pressure cookers spread the heat more evenly through the food."</li> </ul> <p>Which person do you most agree with?</p>



science methods course follow. The sequence culminates in the science capstone course that we developed.

The science content in the capstone course is centered on a common theme or “big idea” of science. As described in *Science for All Americans* (American Association for the Advancement of Science, 1989), “big ideas” include scale and structure, systems and interactions, and energy, among others. When energy is the “big idea” of the capstone course, student learning focuses on formulating a scientific definition of energy and understanding five sub-concepts of energy: forms, conversion, transformation, conservation and entropy. Elementary teachers in Michigan are mandated to teach the content described in the Michigan Curriculum Framework - Science (MCF-S) (Michigan Department of Education, 2000), which is based on the NSES (National Research Council, 1996). The five energy-related subconcepts were based on the MCF-S and the NSES for K-8.

While we acknowledged the general aims of the TCE, we wanted to know how close our students came to selecting the ‘best’ answer in order to identify student misconceptions (Step 3). Two natural sciences faculty (a chemist and a physicist) created a rubric of the ‘best’ answers. Student responses ranged from a minimum of five (19%) to a maximum of 15 (58%) correct answers. The overall score was low ( $m = 9$ ;  $s.d. = 2.46$ ). Further examination revealed that the students had the most difficulty with questions relating to thermal properties of materials. Within this subsection, 10.6% and 8.9% of the students correctly answered questions 8 and 19 respectively (Table I). Both questions probed student understanding of the relationship between boiling point of a fluid (water) and atmospheric pressure. Twenty-three students (49%) chose ‘b’ (“Water always boils at the same temperature.”) for question 8. The next highest response was ‘c’ ( $n = 18$ , 38%), (“The boiling point of water decreases, but the water is still at 100 degrees”). For question 19, 34% ( $n = 16$ ) of the students chose ‘b’ (Pressure cookers cook faster because “. . . the high pressure generates extra heat.”) and 21% ( $n = 10$ ) chose ‘c’ (Pressure cookers cook faster because “. . . steam is at a higher temperature than the boiling soup.”). Students may have answered the questions incorrectly because they had never boiled water at higher elevations or because they were unfamiliar with a pressure cooker. First hand experience with the question context may have improved choice of a best response, however they probably have never considered the possibility that the boiling point of water could vary. If they did know that the boiling point could vary, they had not considered what factors might cause the variability.

These results allowed us to identify areas where students’ conceptualization was very different from an expert’s, whether from lack of knowledge or because they possessed a misconception. We first presented the frequency of each response to the class and asked the students, “given these different answers to the same question, how could you find out the scientifically correct answer?” We then had the students explore each scientific concept.

The next section will provide examples of concepts we identified as needing clarification and how the misconception-guided instructional process was used to assist students in developing the scientifically correct concept.

### Activities

Our goal for each of these activities was for students to develop and carry out explorations that were relevant to them and that would link their interpretation of everyday phenomena and the scientific concept. Therefore for Step 4 we sought inquiry-based learning experience(s) that would confront their misconceptions and/or lack of knowledge. Students needed to explore some aspects of thermal properties of ice, boiling water and steam; they needed to explore at least one factor affecting boiling point. We designed and implemented a learning experience to address the particular misconceptions we identified, that is, that pressure affects the boiling point of a fluid.

The learning experience began with small group exploration of the thermal properties of ice, boiling water and steam. None of the activities were unique except perhaps the use of Dry Ice to demonstrate that ice temperature could be lower than 0°C. Although the experiments are not complicated and could easily be done at home, it appeared that no student had left a thermometer in boiling water to see if the temperature increased with time, nor left a thermometer in ice in a freezer to determine the temperature. Evidently, the students do not try these simple experiments on their own at home or in most science classes.

In addition to having the students explore thermal properties, we investigated one factor affecting boiling point: pressure. We developed two criteria to guide our selection of an activity: the supplies must be readily accessible to K-8 teachers with limited budgets and the activity must be easily conducted within a single class session. The activities that we employed met both criteria of cost and time. We used a plastic 60-ml syringe with a plastic locking device and boiling water to illustrate the qualitative relationship between pressure and boiling point. Students drew up a small amount of boiling water in the syringe, locked the syringe and saw that boiling ceased. They agreed that the boiling water had cooled, and, using prior knowledge, they also agreed that pressure inside the syringe was reduced as the volume expanded when the barrel of the syringe was withdrawn. As the barrel was withdrawn, students saw that boiling recommenced. They concluded that reducing the pressure reduced the boiling point of water. For this activity to be successful, we found it important that air, at least 5 ml, be in the syringe before drawing up the boiling water.

To demonstrate the effect of high pressure on boiling points, we used commercially available, clear, cubic-shaped plastic ice cubes partially filled with water. The cubes visibly expand in boiling water thus demonstrating increased internal pressure. Students measured the boiling point of the water, observed the expansion of the cubes and noted that the water in the cubes was not boiling. The students derived the qualitative relationship that an increase in pressure raised the boiling point.

Table II. Pre and Post Test Scores on the Thermal Concept Evaluation

Question	% Correct Pre	% Correct Post	df	t
1. Likely temperature of ice cubes in a freezer.	25.5	37	45	1.22
2. Likely temperature of water in glass with ice.	25.5	60.9	45	4.11**
3. Likely temperature of ice cubes in puddle of water.	23.4	60.9	45	4.60**
4. Likely temperature of rapidly boiling water.	34.0	65.2	45	2.97*
5. Five minutes later, temperature of still boiling water.	25.5	63.0	45	3.69*
6. Temperature of steam above the boiling water.	27.7	34.8	45	0.72
7. Temperature of mixture of unequal volumes of different temperatures of water.	83.0	82.6	45	0.000
8. Reason behind water boiling and high altitude.	10.6	50.0	45	4.60**
9. Likely temperature of plastic bottle and can of cola.	40.4	84.8	45	5.42**
10. Reason counter under cola can feels colder than rest of counter.	43.5	71.7	44	3.10*
11. Equal volumes of water and ice in freezer, which loses greatest amount of heat?	44.7	47.8	45	0.44
12. What are in bubbles in boiling water?	27.7	37.0	45	1.16
13. Explanation of cooling process of boiled eggs.	74.5	76.1	45	0.26
14. Reason metal chairs feel colder than plastic chairs.	13.0	91.3	44	12.41**
15. 5°C twice as cold as 10°C?	48.9	73.9	43	2.88*
16. Explanation for metal ruler feeling colder than wooden ruler.	37.0	69.6	44	3.30*
17. Likely room temperature given wet and dry washcloth temperatures.	31.1	21.7	43	-1.07
18. Reason cold carton from refrigerator feels colder than one on counter.	28.3	45.7	44	1.64
19. Reason pressure cookers cook faster than normal saucepans.	8.9	30.4	43	3.17*
20. Explanation for cooking on top shelf in oven.	12.8	47.8	45	3.90**
21. Sweating cools you down because...	45.7	60.0	43	1.63
22. Reason bike pump becomes hot.	76.6	86.7	44	1.43
23. Why do we wear sweaters in cold weather?	40.4	52.2	45	1.63
24. Wooden Popsicle sticks higher temperature than ice part?	17.8	80.4	43	7.03**
25. Maximum lowest possible temperature.	28.3	43.5	44	1.94
26. Reason dolls in blankets don't warm up.	37.0	47.8	44	1.77
<b>Pre-Post Test Comparison</b>	<b>34.6</b>	<b>56.5</b>	<b>46</b>	<b>7.89**</b>

Note: \*  $p < .01$ ; \*\*  $p < .001$

### Outcomes

The final step in our method was to reassess student understanding of thermal energy by re-administering the TCE. On the post-test, 50% of the students answered question #8 correctly, compared to 10.6% on the pre-test. The question about why pressure cookers cook food faster (question #19) was only answered correctly by 9% of the students on the pre-assessment, while 30% answered it correctly on the post-assessment. This equates to gain scores of 44% and 23.6%, respectively.

Overall, the post-test scores were significantly improved: the average percentage of correct responses increased from 34.6% to 56.5%, resulting in a normalized gain  $\langle g \rangle = 33.4\%$ . Students gained significant knowledge on half of the questions (see matched pairs t-test scores in Table II). The number of questions answered correctly by 50% or more of the students increased from 3 to 16. This improvement is consistent with knowledge gains when inquiry-based learning pedagogy strategies are

employed instead of traditional lecture formats (Hestenes, Wells, & Swackhamer, 1992; Lawson, et al, 2001). However, it was disappointing to see many misconceptions persist (i.e., question #23; “why do we wear sweaters in cold weather?”) Although course activities did target this misconception, nearly half of the students answered this question incorrectly on the post-test. These results, like other research (Duit & Treagust, 1998) demonstrate how difficult it is to alter deeply held conceptions.

### Discussion and Conclusion

Because elementary teachers' attitudes toward science affect the amount of science they teach their students and the pedagogy they employ, we were interested in knowing how our students responded to this instructional approach. In addition to student comments given informally during instruction, students were asked to participate in a short interview conducted by an external evaluator at the end of the semester. Student response to

instructional approach was generally positive. Most students viewed their wrong answer as an opportunity to learn and did not view it as a personal judgment. One student described how the pre-assessment made her realize she had a misconception about the temperature of water containing ice, “We had a survey that we had to fill out [about] temperature. Talking about the different degrees . . . concerning the ice. If you left it over time, would it get warmer or colder. I had a lot of misconceptions when I first filled that [pre-assessment] out, and then when we went and experimented with it the following week, I realized wow, you know that really does work.” In addition students recognized that we were modeling the approach we hoped they would use in their classrooms. As one student explained, “I just think that like the...., it really is a good course to take, the capstone class, because the fact that we do the experiments, too. It’s kind of like a, a model... for what you’re supposed to be doing [in your classroom].”

A few students vocally proclaimed their displeasure with the pre-assessment. These students said they felt humiliated and “stupid” even though we told them the assessment was to inform our lesson objectives and to make them aware of their own misconceptions or lack of knowledge rather than an exercise that would be graded. One student expressed this frustration by stating, “I have a tendency sometimes, that I feel really stupid in this class. And I think, one part that I thought was really frustrating was they gave us this big huge test. Ok, it wasn’t really a test, but it was, it was a test. You know, they gave you like 5000 questions, or something like, it was a lot of questions, based on energy, and just kind of getting to see what you knew... I already felt like such a moron.”

Instructor response to the misconception-guided instructional approach was generally positive. This method assisted students in improving their understanding of concepts related to thermal energy when the TCE questions identified specific misconceptions or areas of lack of knowledge and we developed inquiry activities to target these areas. The approach seemed less effective when we asked students to apply their knowledge to similar (to experts’ eyes) situations, such as question #1 where students were to choose the response for the most likely temperature of ice cubes in a freezer. Although we had measured the temperature of ice cubes in class, students did not know the temperature of the freezer. In these situations, students were unable to discern salient features in questions; they became distracted by non-relevant parts or had gaps in their knowledge of important features of the question (e.g., the temperature of a freezer). It should not come as a surprise that misconceptions remained despite instruction. Campanario (2002) describes how resistant even scientists are to changing their ideas about scientific concepts. One other limitation to this instructional approach is that it is very time consuming (during class and in preparation). As a result, we were only able to address a restricted number of concepts related to energy and thermodynamics.

We have the following recommendations for instructors interested in using this pedagogical approach:

- Focus instruction on a few crucial concepts, because you will not be able to cover everything you hope to
- Assess students on broad conceptual knowledge as well as specific concepts in order to determine what level of knowledge students possess; this will enable better targeting of activity objectives
- Adapt existing assessments to your own contexts
- Have students practice application of concepts to different and progressively complex situations

Our research and classroom experience have demonstrated that while teaching energy is hard, it is possible to teach/learn concepts like thermodynamics. In addition, the five-step misconception-guided instructional process was an effective way to identify and correct student misconceptions. What remains to be seen is how durable the knowledge is and how transferable it is to similar contexts. We intend to study these topics in the future.

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# *JPTEO*



# Implementing inquiry-based instruction in the science classroom: A new model for solving the improvement-of-practice problem

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*Getting student teachers and traditional in-service teachers to regularly implement inquiry-oriented pedagogical practices in their science classrooms is more difficult than it appears. The general thinking among many science teacher educators tends to be that teacher candidates and traditional in-service teachers who learn how to conduct scientific inquiry will, in fact, teach science using an inquiry approach. Unfortunately, experience has shown that merely learning about scientific inquiry in methods courses and professional development workshops does not automatically translate to implementation of inquiry-based instruction. A number of important and neglected external factors influence whether or not and to what extent inquiry is implemented in the classroom. Unless these impediments are confronted and resolved, it is highly unlikely that even teachers who possess a good understanding of science inquiry will regularly implement inquiry-based instruction in their classrooms.*

One of the leading goals of the science education reform movement in the United States is getting teachers to effectively and regularly employ inquiry-oriented pedagogical practices in science instruction (AAAS, 1990; NRC, 1996, 2000a; NSTA, 2003). Unfortunately, even after years of reform efforts, widespread progress has not been made in this area. If the science education reform movement is to make significant improvements in the way science is taught in schools, a better understanding of the relationship between the way teachers are educated and how they perform in the classroom must be had. How American school students learn science will depend strongly upon adequate teacher preparation and professional development that is based on a knowledge of the relationship between teacher understanding of scientific inquiry and the social context of teaching. Teacher candidate preparation and professional development for traditional in-service teachers must provide instructors with the ability and disposition to teach science via inquiry, as well as a means for dealing effectively with confounding factors such as personal teaching concerns, concerns about students, instructional and curricular concerns, and strongly-held didactic teaching philosophies. Such factors can at times be more influential than any intrinsic beliefs developed from a formal education (Young, 1991). It is the author's contention that failure of teacher preparation models to take into account the social context of teaching has, to date, left the science education reform movement languishing. A new model is desperately needed to help solve the long-standing improvement-of-practice problem.

## The Improvement-of-Practice Problem

For more than a century there have been repeated calls to improve the procedures used in the preparation of science teachers so that they would more effectively provide students with experiential learning. To this end John Dewey (1904) noted with great concern that there was inadequate consideration of the proper relationship between theory and practice as far as the preparation of teachers was concerned. He expressed his concern that too much time and effort were being spent on "methods," and far too little expended on the theory that might guide practice

in a more enlightened fashion. Dewey later (1916, 1938) repeated his call for reform. His pleas for changes in teacher preparation, however, fell on deaf ears. Teachers graduating from colleges and universities continued to teach using expository methods. For many science teachers today, didactic teaching remains the status quo despite growing evidence that "teaching by telling" is not highly effective in inculcating the content knowledge and process skills that are part and parcel of good science instruction (Costenson & Lawson, 1986; McDermott, 1993; NRC, 2000a, 2000b, 2005).

Shortly after the USSR launched Sputnik in 1957, broad-based work was begun in the United States to change the practice of science teachers and thereby improve the scientific literacy of American students. Up to that time the practice of many (if not most) teachers concentrated on imparting content knowledge. Pedagogy often consisted of drill and practice, and assessment focused on fact-laden tests. Under the sponsorship of the National Academy of Sciences, thirty-four psychologists and research scientists met at Woods Hole, Massachusetts, in September 1959, "to examine the fundamental processes involved in imparting to young students a sense of the substance and method of science" (Dow, 1991, p. 33). Jerome Bruner, a psychologist who headed the ten-day conference, strongly promoted conceptual learning and de-emphasized rote memorization. All the attendees appeared to agree that there should be a greater emphasis on inquiry practices, thereby including a spectrum of cognitive approaches – logic, intuition, and creativity. Other topics of discussion at the meeting included the evolving stage theory of cognition, child growth and development, and pedagogical strategies for promoting the "new science" following insights of psychologists Kurt Lewin and Jean Piaget. The discussion revolved around such questions as intellectual ability at various developmental levels, and what implications this might have for pedagogy. One major problem overlooked by the reformers was consideration to create an effective implementation model. Their model did not include such things as personal, social, and political factors that could support or impede progress toward the goal of revised classroom practice.

Failing to see the possible problems associated with implementation, Jerrold Zacharias, a physicist present at the Woods Hole meeting and now chair of the President's Science Advisory Committee, plunged blindly ahead to reform public school science in America. From 1962 through 1963 he hosted a series of meetings at MIT's Endicott House to hear the thoughts of educational theorists and practitioners. Zacharias was an outspoken critic of those who begged to differ with his views on educational practice, "and some of the nation's best-known educators left those meetings shaken by the encounter" (Dow, 1991, p. 41). There were many academicians to whom Zacharias listened, but most of these were university science faculty with little knowledge of what was happening in the nation's elementary and secondary schools. This latter group agreed among themselves that the dissemination of "predigested" summary information was intellectually and pedagogically wrong, that education of youth should consist of students taking a critical look at evidence in a detached manner, and drawing conclusions of their own. Knowing how to employ facts, concepts, and relationships was just as important as knowing them. According to the reformers, students should draw their own conclusions from evidence, much like a scientist working with data. Based upon this and similar efforts, large-scale curriculum development projects such as PSSC Physics, BSCS Biology, and CHEM Study were initiated. Years later, Dow would carefully document how deficiencies in planning and implementation, a lack of concern for suitable teacher preparation, and even a regard for social and school issues, resulted in the overall failure of the 1960s science education reform movement. These projects had run their course by the mid-1970s and the status quo of teaching using traditional expository methods had returned. Still, the science education reform movement was not dead.

The National Commission on Excellence in Education, writing in *A Nation at Risk* (1983), recommended that the "teaching of science in high school should provide graduates with an introduction to (a) the concepts, and processes of the physical and biological sciences; (b) the methods of scientific inquiry and reasoning; (c) the application of scientific knowledge to everyday life; and (d) the social and environmental implications of scientific and technological development." Subsequently, the National Research Council, the American Association for the Advancement of Science, and the National Science Teachers Association have indicated that science should be taught using inquiry-based instructional practices (AAAS, 1990; NRC, 1996, 2000a, 2000b, 2005; NSTA, 2003). The NRC in *Inquiry and the National Science Education Standards* dedicated a whole chapter to making the case for teaching via inquiry. Ideally, science teacher candidates will be educated in ways that are well aligned with the *NSTA Standards for Science Teacher Preparation* that place a strong emphasis on inquiry practice. As will be seen, this alone constitutes inadequate preparation for teachers to regularly implement inquiry-based instruction in their classrooms.

A large amount of research, reviewed by Costenson and Lawson (1986), and later by the National Research Council (2000a, 2005), has shown that helping students construct

intellectual understanding through inquiry is the most effective way of getting students to accurately learn content knowledge, a wide array of intellectual process skills, and appropriate scientific dispositions. Further, they indicate that expository methods of teaching are comparatively ineffective in overcoming preconceptions, teaching a range of intellectual process skills, and inculcating appropriate values and attitudes. According to the NRC (2000b, p. 116), there is now a broad consensus about how learning occurs. "The report synthesized research from a variety of fields, including cognition, child development, and brain functioning. It also drew on research across content areas, with important contributions from the research on science learning." The report strongly supported the use of inquiry-based instructional practices. Still, many instructors of science continue to use expository methods.

Mary Kennedy (1991, p. 662) clearly enunciated the need for a new form of instructional practice if, indeed, teacher educators and professional development providers are going to have a significant influence on the way teachers teach. It would pay dividends to keep her words of wisdom in mind:

"The improvement-of-practice problem boils down to this: if we know that teachers are highly likely to teach as they were taught and if we are not satisfied with the way they were taught, then how can we help them develop different teaching strategies? And how can we create schools and policies that will support the use of these strategies?"

How serious is the improvement-of-practice problem? I judge it to be very serious. We are caught in a vicious circle of mediocre practice modeled after mediocre practice, of trivialized knowledge begetting more trivialized knowledge. Unless we find a way out of this circle, we will continue re-creating generations of teachers who re-create generations of students who are not prepared for the technological society we are becoming."

Even after a century of demand for change, and after making clear the importance of teaching with the use of inquiry, there remains a significant difference between how many school instructors teach science and how university science educators say they should do so. With strong arguments for and evidence in favor of the inquiry approach, as well as repeated calls for improvement in science instruction, why don't more new and established science teachers use inquiry-oriented teaching methods?

### **Established Models for Implementing Inquiry-Based Instruction**

Over the course of the years, informal models to explain why it is that science teachers fail to implement inquiry-based pedagogical practices in their classrooms have been proffered. Predominant among these models is an idea captured in the following quote:

“An unprepared teacher is likely to teach in the way that he or she was taught. When a powerful teacher education process does not intervene, new knowledge does not have an opportunity to transform teaching across generations. Yet prospective teachers cannot profit from these insights if they have no opportunity to encounter them” (Darling-Hammond et al., 1995, p. 21).

The National Research Council in *Inquiry and the National Science Education Standards* (NRC, 2000a) recently propounded an implementation model that suggests what it takes for science instructors to be able to teach using inquiry practices. The NRC has in effect suggested that the reason for teachers failing to implement inquiry-oriented instruction has to do primarily with the lack of adequate preparation. The NRC (p. 87) argued, “For students to understand inquiry and use it to learn science, their teachers need to be well-versed in inquiry and inquiry-based methods. Yet most teachers have not had opportunities to learn science through inquiry or to conduct scientific inquiries themselves. Nor do many teachers have the understanding and skills they need to use inquiry thoughtfully and appropriately in their classrooms.” The NRC implementation model further posits that four factors account for teachers’ understanding of scientific inquiry: (a) having learned science through inquiry, (b) having learned to teach science through inquiry, (c) having been lifelong inquirers, and (d) having followed a professional development plan that has inquiry-based instruction as its focus. Understanding of scientific inquiry is then positively correlated with implementation of inquiry-based instruction. The supposed NRC implementation model is shown diagrammatically in Figure 1.

Even though understanding of scientific inquiry is a prerequisite for implementing inquiry-based instruction in the classroom, it is not the only factor that influences its implementation. The NRC model is deficient to the extent that it

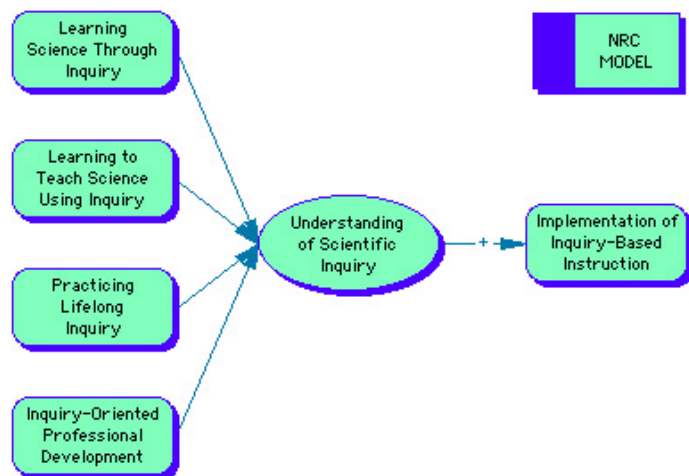


Figure 1. *The implementation model of the NRC. This model suggests that teachers’ understanding of scientific inquiry, as well as those educational experiences that lead to this understanding, are positively correlated with implementation of inquiry-based instruction.*

fails to account for the human condition and the social context of teaching. As Kennedy (1991, p. 11) noted, “Although it is all too easy to do, let us not lose sight that causal laws in the social sciences refer to people.” Unfortunately, this is what the NRC model appears to do; it makes the same mistake as the science education reformers did in the 1960s. The NRC model fails to take into account confounding variables - those factors that tend to be negatively correlated with the implementation of inquiry-based instruction.

Costenson and Lawson (1986), during interviews with teachers dedicated primarily to the lecture mode of instruction, identified ten major confounding factors to explain why these teachers failed to include inquiry practices in their teaching. While Costenson’s and Lawson’s 1986 work is now nearly two decades old and refers to biology teaching, these points are broadly applicable to all science teaching today. The following list encapsulates the major impediments teachers cited as the reasons teachers fail to regularly employ inquiry-oriented practice in their classrooms:

- *time and energy* – It is difficult and time consuming to produce high quality inquiry lessons; it is difficult to sustain the high level of energy required to use active learning.
- *too slow* – Inquiry takes more time than teaching by telling; the school curriculum requires coverage of broader spectrum of content than is possible with inquiry.
- *reading too difficult* – Students have difficulty translating textbook knowledge into active inquiry.
- *risk too high* – The school administration does not support inquiry practice due to a lack of sufficient content coverage; the teacher might be perceived as not doing his or her job.
- *tracking* – Classrooms filled with lower-performing students do not contain the right type of population needed to conduct inquiry effectively.
- *student immaturity* – Students are too immature and waste time in unstructured settings; they do not benefit from inquiry-oriented teaching.
- *teaching habits* – Established expository teaching habits are hard change after long periods of use; teachers do not have knowledge and skills required for inquiry teaching.
- *sequential text* – The textbook constitutes the curriculum; chapters are not skipped because too much important material is included in each.
- *discomfort* – It is uncomfortable not to be in control of the lesson; being uncertain of the outcomes that might result from inquiry-oriented teaching is disturbing.
- *too expensive* – Inquiry requires active engagement, and many classrooms are not equipped with sufficient teaching materials suitable for hands-on learning.

None of these ten teacher-identified confounding variables is included in the NRC model. In addition, there are other important considerations missing. Such things as the explosive growth of textbook contents, the quality of student teaching experiences, the lack of teacher mentoring, the unintended effects of high-stakes testing and No Child Left Behind legislation attended by calls to return to “direct instruction” (Cavanagh, 2004). All play a crucial role in determining whether or not inquiry is implemented in the classroom.

With regard to the factors identified by the NRC as positively correlated with teachers’ understanding of scientific inquiry, not all are equally important or even necessary. For instance, teacher candidates who have been prepared with the knowledge, skills, and dispositions necessary to support sustained inquiry practice can successfully employ inquiry without ongoing professional development. Additionally, even novice science teachers – so long as they are well prepared – can implement inquiry without having been lifelong inquirers. As a result of these limitations, the NRC model is incomplete at best, and inaccurate and misleading at worst. A more complete and accurate implementation model is called for so that teacher candidates and in-service teachers can be properly prepared or retrofitted to teach science employing inquiry in an effective and sustained manner.

### A New Model for Implementing Inquiry-Based Instruction

The NRC model for implementing inquiry-based instruction, while appearing logical, does not address factors that confound the implementation of inquiry-based instruction. This model therefore cannot serve as the basis for the “powerful teacher education process” called for by Darling-Hammond. If a more complete implementation model is developed, curriculum planners, instructional developers, teacher educators, professional development providers, and in-service teachers can be provided with a better understanding of the relationship between pertinent educational factors associated with the implementation of inquiry-based instruction. In educating/reeducating teachers, efforts can be made to galvanize them to resist confounding factors.

The author proposes for the first time a hypothetical model to explain more completely and accurately the observed disconnect between teacher preparation/professional development and teacher performance. This new model replaces the four positively correlated factors of the NRC model with three somewhat different factors essential for the implementation of inquiry-based instruction: knowledge, skills, and disposition. In addition, educational experiences (e.g., student teaching and professional development) are also incorporated. Finally, the new model groups the 10 negative factors identified by Costenson and Lawson into four major (if somewhat overlapping) groups that are all negatively correlated with implementation of inquiry-based instruction: personal teaching concerns, concerns about students, instructional and curricular concerns, and didactic teaching philosophy. The new model is depicted in Figure 2.

Experience has shown that there is a significant relationship between the dependent variable in this model (implementation

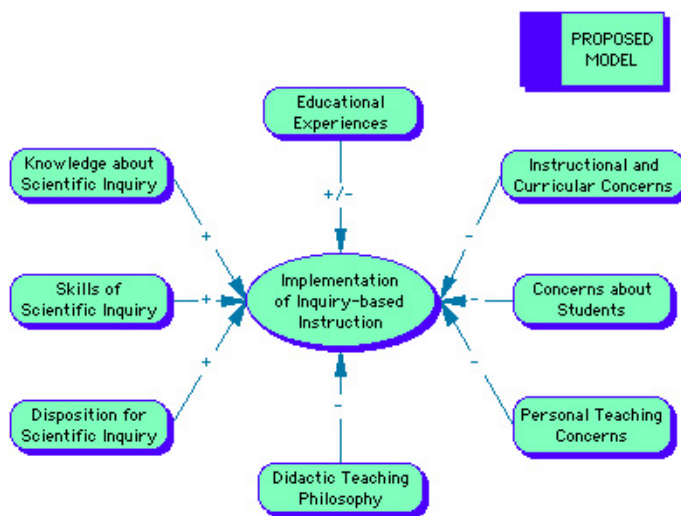


Figure 2. *The proposed model including confounding variables to more fully explain the degree to which science teachers implement inquiry-based instruction in their classrooms. This model suggests that teachers’ understanding of scientific inquiry is not the only factor that affects the implementation of inquiry-based instruction.*

of inquiry-based instruction) and the multiple independent variables (understanding of science inquiry in three different dimensions, didactic teaching philosophy, personal teaching concerns, concerns about students, instructional and curricular concerns, and educational experiences). Other contributory factors might also negatively or positively influence the degree to which inquiry-based instruction is implemented. These factors could be grouped together in the model and appear as “specification error.” They are, however, not included in Figure 2. According to this new model, when positive correlates exceed the negative correlates, inquiry teaching takes place. When the opposite occurs, little if any inquiry teaching occurs. This more complete implementation model, then, appears to explain the disconnect between teacher preparation and implementation of inquiry practice.

While no empirical evidence has been provided or cited by the author to validate the proposed model, it seems that reason and anecdotal evidence support it. Nonetheless, it would behoove science education researchers to conduct a path analysis of this model to determine if empirical evidence can be found either to support or reject the hypothesis. This would prove to be a daunting task due to the complexities associated with operationally defining and accurately measuring each of the model’s factors. Another, but admittedly less satisfactory way, to test this model would be to create a teacher education/professional development program based on the assumptions of the model, and then determine to what extent that program’s graduates actually implement inquiry-based teaching practices.

Failure to employ a real-world model for promoting and implementing inquiry-based instruction will impede any solution to the improvement-of-practice problem. As history has shown,



the difference between educational practices that are influenced by a well-thought-out model and those that are not, can be profound in both their implementation and effects. The difference will be to the extent that an educational process is conducted blindly under the control of unexamined traditions or take into account personal, social and political factors.

### “A Powerful Teacher Education Process”

If teacher preparation is to have a significant and lasting impact on teacher candidates' performance, teacher educators must keep in mind that candidates' beliefs and experiences have a strong influence on their decision-making processes as new teachers (Short, 2003). In the teacher preparation process, it is not at all uncommon to find little emphasis placed on teacher candidate thinking and great emphasis placed on methodology and materials (Schubert, 1991). As a result, there is more than adequate data to show that many teacher education programs contribute little to change prior beliefs about teaching and learning (Kennedy, 1991). A similar case can be made for the professional development of traditional in-service teachers.

The proposed implementation model calls for an educational process that might be thought of as analogous to the teaching of bicycle riding. Much can be gleaned from a study of the metaphor of teacher candidate as neophyte bicyclist. A parent (teacher educator) wishes to teach a child (teacher candidate) to safely ride a bicycle (teach via inquiry). Consider the following line of reasoning. In order to learn how to ride the bicycle, the child must be outfitted with the following: (1) a knowledge of how a bicycle is ridden (the parent describes the process of riding), (2) the skill of riding the bicycle (learn the process through practice), and (3) an understanding of the utility of bicycle riding (pointing out the benefits of doing so). In addition, the child needs to be (4) forewarned of the dangers associated with riding a bicycle, and (5) forearmed with the rules of the road as they apply to bicyclists. The metaphor of teacher candidate as neophyte bicyclist is quite apt; the parallels between learning to teach using inquiry and riding a bicycle are numerous. As conscientious teacher educators seeking to promote the use of a complex educational process, should we do anything less for our teacher candidates than a parent does with a son or daughter learning to ride a bicycle? The preparation process for new teachers must provide candidates with the required knowledge, skills, and dispositions related to inquiry practice. Candidates must be forewarned about teacher concerns and other dangers to their intended inquiry practice, and they must be forearmed to respond appropriately to attacks on that practice.

**Initial Teacher Preparation** – The inquiry practice of science teacher candidates will strongly benefit from preparation programs that follow a seven-step educational process (Wenning & Short, 2004) aligned with the proposed implementation model. This process, as several case studies have shown (Short, 2003), is effective in preparing physics teacher candidates to employ inquiry-oriented pedagogical practices in their classrooms. Teacher candidates also benefit from a program that includes aspects that serve to forewarn and forearm candidates so that

they can start their teaching careers with the use of inquiry-based practices and continue doing so effectively throughout their professional lives. The following steps could well be incorporated into undergraduate physics teaching methods courses:

- **Prepare teacher candidates to use inquiry-based instruction:**

Ideally, the model teacher education process includes a systematic treatment of inquiry practices incorporated in several physics teaching methods courses taught over the course of several years. The educational process also includes student teaching and first year teaching in the educational process. The seven-steps of the inquiry learning process promulgated by Wenning and Short are the following: introducing, modeling, promoting, developing, practicing, deploying, and supporting inquiry-based teaching practices.

*Introducing* inquiry consists of having teacher candidates visit the classrooms of expert high school practitioners of inquiry and comparing what they observe there with the commonly didactic teaching taking place in the university classroom. The differences in teaching styles are readily observed once students know what to look for.

*Modeling* inquiry consists of having teacher candidates play the role of high school students in a science methods course in which several exemplary inquiry lessons are taught by the university instructor.

*Promoting* inquiry consists of helping students come to know the reason for and benefits derived from the use of inquiry practice in the science classroom. Discussions of readings taken from *Inquiry and the National Science Education Standards* and other sources form the bulk of the promotion.

*Developing* an inquiry lesson plan using the Lesson Study approach modeled after the description by Stigler and Hiebert (1999) is the next step in the educational process. Students create a model inquiry lesson plan under the critical eye of an experienced inquirer.

*Practicing* inquiry comes next by teaching the lesson study lesson plan to high school students. The approach consists of teaching, revising, and then reteaching the lesson. This activity is then followed by a series of inquiry-oriented lessons that students develop and implement on a rapid-fire basis so as to gain greater experience working with inquiry.

*Deploying* inquiry comes with the start of student teaching. Teacher candidates prepare and teach inquiry lessons with the advice and assistance of their cooperating teachers.

*Supporting* inquiry teaching continues throughout student teaching and the first years of professional practice by continuing contact between the novice teacher and high school and university mentors.

This seven-step inquiry learning process has been shown to develop a strong understanding of inquiry practices and pedagogical processes related to inquiry-based instruction (Short, 2003). Integrated with this seven-step process are



activities that help teacher candidates develop a strong philosophical disposition toward teaching via inquiry.

- Forewarn teacher candidates about potential impediments to inquiry-based instruction: Teacher candidates are made aware of the fact that there will be resistance to the implementation of inquiry. The ten main influences working against teaching via inquiry and identified by Costenson and Lawson (1986) are reviewed and discussed. Not among this listing, but today perhaps the most striking form of resistance to inquiry that teacher candidates will experience, comes from the high school students themselves. This is especially so for student teachers who take over courses that have previously been taught didactically. It's not uncommon to hear students complain under such circumstances that they "would rather be told" what they need to know rather than to have to construct knowledge from experience.
- Forearm teacher candidates to resist impediments to inquiry-based instruction: Teacher candidates are made aware of the wide variety of very real threats arrayed against inquiry practice. They address each of the arguments posed against inquiry based on the work of Costenson and Lawson (1986), as well as recent attacks against it by strong proponents of the No Child Left Behind initiative (Cavanaugh, 2004). Teacher candidates are galvanized with personal and professional resources with which to identify, confront, and resist or change confounding factors.
- Support teacher candidates and mentor novice teachers as they use inquiry-based instruction: Student teaching takes place using cooperating teachers who are open to and supportive of teacher candidates using inquiry-based practices even if they themselves have a didactically-oriented teaching philosophy. Better yet is to place student teachers with cooperating teachers who are strong proponents of instruction incorporating inquiry. Provide ongoing support to novice teachers during the transition period from the university through the first year of teaching. It should be well noted that a very significant fraction of novice teachers are lost to careers other than teaching during the first few years of classroom experience. To what extent this occurs as a result of conflicting messages between what teacher candidates are told in their university science teaching methods courses and what they experience in their own classrooms is unknown with certainty. Nonetheless, providing novice teachers with the transitional support they need for conducting inquiry is, without a doubt, a factor in solving the improvement-of-practice problem.

***In-Service Professional Development*** – If the teacher reeducation process is to have a significant and lasting impact, it must take into account the fact that many experienced science teachers are likely have somewhat entrenched didactic teaching philosophies. Professional development probably will always be less effective than teacher preparation unless it identifies, confronts, and resolves the problems associated with expository teaching. Professional development activities must be of high

saliency and prolonged if expected practices are to become the "coin of the realm." Activities should include placing teachers in the role of students as well as that of teacher so that they can see both sides of the coin. These practices must be backed up with sustained periodic mentoring by professional development providers. The improvement-of-practice problem for in-service teachers must, at the root, influence teaching philosophies. It is from philosophies that beliefs arise, and beliefs give rise to decisions. Decisions bring about actions, and actions have consequences. Hence, to influence outcomes, professional development providers need to give attention to teaching philosophies.

### **Turning Educational Theory into Practice**

As noted educational philosophers John Dewey and James McLellan once stated, "The value of any theory is, in the long run, determined by practical application." (1895, p. 195). Years later, educational psychologist Kurt Lewin similarly stated, "Nothing is more practical than a good theory" (1951, p. 169). These dicta hold considerable truth when applied to the current situation. Our understanding of the relationship between theory and practice is critical if teacher educators are to make significant progress toward the goals of reforming teacher preparation and professional development. It is instructive to note how wide the gap is between theoretical sufficiency and practical efficacy as far as teacher preparation and professional development are concerned. Without reasonable theoretical underpinnings, it is likely that today's teacher preparation and professional development processes will continue to be less than entirely effective. To paraphrase Dewey's question, are teacher educators still spending too much time and effort thinking about "methods" and far too little time reflecting on the theory that might guide their own instructional practice in a more enlightened fashion? If we fail to turn educational theory into practice, our work will ultimately and always be a series of ad hoc initiatives that result in failure to make appropriate progress toward the goal of improving how teachers perform in their classrooms. Only if teacher educators establish a clear agenda based on an adequate theory base for teacher preparation and professional development can we hope to achieve our goal of solving the improvement-of-practice problem. The measure of our success will be found in the extent to which in-service teachers have adopted, are guided by, and utilize the methods of scientific inquiry in their pedagogical practice.

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# JPTEO

# Examining the professional growth of out-of-field physics teachers: Findings from a pilot study

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*This article reports the findings of a pilot study where the self-efficacy, concerns, and classroom practice of out-of-field physics teachers were examined. Data collected during the study indicate that when the out-of-field teachers were asked to implement new curriculum, adopt new teaching practices, and teach content outside their major field, their self-efficacy for teaching physics suffered. Similarly, as a result of these teaching demands, the out-of-field teachers' concerns tended to lie mostly in the realm of materials and time management. On the other hand, the data collected in this study suggest that with the support of ongoing professional development, out-of-field teachers can learn to implement curriculum materials as the developer intended (i.e., with fidelity). The authors recommend that professional development for out-of-field teachers focus on the curriculum materials they use every day and that these curriculum materials be coherent, research-based, and provide built in teacher support.*

## THE PROBLEM

Professional development for out-of-field teachers has become extremely important in recent years. In a 1999-2000 study for the Consortium for Policy Research in Education, Ingersoll clearly indicates that a great deal of teaching of core courses in the sciences is done by out-of-field teachers. He found that nearly twenty-seven percent of all public school students enrolled in science classes in grades 7-12 were taught by teachers without a major or minor in science (Ingersoll, 2003). The situation is even worse when one looks specifically at the physical sciences. Fifty-nine percent of all public school students enrolled in physical science classes in grades 7-12 were taught by teachers without at least a minor in physics, chemistry, geology, or space science (Ingersoll, 2003). The issue of out-of-field teaching has come to the attention of educational policy makers, lawmakers, and the general public. The issue is not new, but in light of the teacher quality requirements of No Child Left Behind legislation, the issue has intensified.

What are the consequences of so many teachers teaching out of the fields for which they are trained? One negative consequence is likely to be low scores by students on state, national, and international assessments of educational progress (e.g., TIMSS). Another negative consequence for students is the inability of out-of-field teachers to focus on inquiry abilities and critical thinking skills in a discipline they do not understand well themselves. Out-of-field teachers must rely heavily on textbooks and often cannot elaborate on scientific knowledge beyond what textbook authors have written. And, most textbook programs, outside of those developed with NSF funds, do not incorporate scientific inquiry into the instructional materials. In addition, out-of-field teachers often shortchange all students, even those in the courses for which they are well-prepared, because they must spend so much of their preparation time on the subject for which they are least prepared. Naturally, such teaching loads will have negative consequences on teachers' morale and commitment to teaching when they often feel inadequately prepared and unsuccessful with students in areas outside of their

expertise. This study examines the initial impact of one school district's professional development efforts aimed at avoiding these potential consequences.

## CONTEXT FOR THIS STUDY

In the spring of 2001, the San Diego City Schools (SDCS) Board of Education adopted comprehensive science graduation requirements for all students that included physics (Grade 9), chemistry (Grade 10), and biology (Grade 11). *Active Physics* was adopted as the 9<sup>th</sup> grade physics curriculum and was taken by all entering freshman beginning in 2002-2003.

As the district prepared for these changes, the science leaders realized they faced a complex curriculum implementation challenge. Part of the challenge stemmed from having just adopted a "physics-first" high school science sequence. Now, instead of a relatively small number of elite students taking physics (1200 annually), physics was now a required course for all freshmen in twenty-three schools (10,000 students annually). As a result of this dramatic increase in physics enrollment, SDCS needed to augment their existing physics faculty (~40 teachers) by asking an additional 40 district science teachers who held a credential in a science discipline other than physics to teach ninth-grade physics. Of these 40 teachers 25 were certified to teach biology, 10 were certified to teach chemistry, and 5 were certified to teach general science. In addition, the majority of the out-of-field teachers were not highly experienced teachers (40% had 5 years experience or less). Consequently, an urgent need emerged for "out-of-field" teacher professional development.

## THE SDCS PROFESSIONAL DEVELOPMENT MODEL: *Translating Research into Practice*

Establishing a structure for cultivating powerful instructional leadership was an essential strategy of the district's overall reform effort. SDCS formed a curriculum leadership team consisting of science administrators and physics teacher-leaders from within the district to design and implement the professional development

program. The curriculum leadership team, in response to the recommendations of professional development research, developed a sustained, curriculum-focused professional development program for its 9<sup>th</sup>-grade physics teachers. The professional development program brought colleagues together on a regular basis to develop a community of physics teachers who understood inquiry, student learning, and issues related to the implementation of *Active Physics*.

This professional development program consisted of four major components: 1) summer institutes supported by monthly follow-up workshops, 2) content courses for out-of-field teachers, 3) common planning periods to promote collaboration, and 4) curriculum support materials. The purpose of the following section is to describe each component in more detail.

### **1. Summer Institutes and Monthly Follow-Up Meetings**

The Summer Institute, usually held in August, “kicked off” the professional development program each academic year at SDCS. The primary purpose of the intensive summer institutes was to prepare teachers to begin implementing *Active Physics* by helping them understand the instructional approach used in the program as well as broader issues such as inquiry learning and teaching (as described in the *National Science Education Standards*). During the summer institute, the facilitators modeled exemplary teaching, used activities from the instructional materials to engage teachers as *learners* of physics, and challenged teachers’ existing beliefs about physics and student learning. These adult learning strategies are strongly recommended in the professional development literature (e.g., Loucks-Horsley et al., 1998; NRC, 1996; Thompson & Zeuli, 1999).

These same goals and strategies applied to the monthly meetings. However, in addition to these goals, the monthly meetings brought colleagues together on a regular basis throughout the academic year to address relevant issues in a timely fashion. Since implementation had begun, the monthly meetings allowed time for reflection on current teaching practice and sharing of implementation experiences and expertise. The ongoing nature of the monthly meetings also allowed the facilitators to engage teachers in extended activities and discussions that spanned one or more meetings. These extended activities are, as suggested in the *National Science Education Standards* (NRC, 1996), conducive to helping teachers, over time, develop deep understandings of content and pedagogy.

### **2. Content Courses for Out-of-field Teachers**

The district’s sensitivity to the diversity in content knowledge and pedagogical skills among its physics teachers resulted in the development of the course sequence *Physics for Educators* (Physics 496 I-IV). This course sequence was approved as a means for SDCS teachers to obtain a supplemental authorization in physics by the California Commission on Teacher Credentialing. Credits for completing the course were granted through San Diego State University. This four-semester sequence was intended to augment the content preparation provided in the

summer institutes and monthly follow-up meetings. The instruction in this course was similar to that provided in the summer institutes and monthly meetings in the sense that it modeled inquiry-based teaching strategies from *Active Physics* and engaged teachers as learners of physics content. Since activities from *Active Physics* were not designed to fully engage adult learners in the study of physics; course instructors also used materials from *Physics by Inquiry* (McDermott, 1996), a course designed for pre-service and practicing teachers.

### **3. Common planning periods at the building level**

SDCS modified high school schedules around the district so that teachers implementing *Active Physics* at each building would share a common planning period. The intention of this structural change was to promote collaboration and sharing of expertise among colleagues. Secondly, this structural change was intended to convey the district belief that professional development is valued and should be an integral part of each teacher’s workday.

### **4. Curriculum Support Materials**

A support guide for each module of *Active Physics* was developed to assist teachers in the pacing, planning, implementation, and evaluation of instruction. In addition, SDCS maintained a comprehensive website to support teachers implementing *Active Physics*. The site contained downloadable resources and materials such as lesson plans, assessments, and scoring rubrics. The site also contained archived discussion threads related to implementation issues as well as contact information of district support personnel.

In a broad sense, SDCS attempted to make its curriculum-based professional development effective by incorporating ongoing experiences that engaged teachers as physics learners and helped develop robust understandings over time. These experiences were embedded within a timely support and feedback cycle that allowed teachers to: 1) surface issues that arose from actual classroom implementation of *Active Physics*, 2) collaboratively discuss and come to understand the issues better, and 3) translate these new understandings into improved classroom practice.

### **OBJECTIVE OF THE STUDY**

The primary objective of this study was to document several different ways in which out-of-field teachers can grow professionally when involved in comprehensive, curriculum-based professional development. More specifically, this study examined the following indicators of professional growth:

- Teachers’ **efficacy** for teaching physics and inquiry-oriented instruction,
- Teachers’ **concerns** about implementing a new, inquiry-oriented curriculum, and
- The **fidelity** of teachers’ use of the curriculum. In this context, implementing the curriculum as it was envisioned by the developers – which includes teaching



**Table 1. Stages of Concern**

STAGES OF CONCERN	Typical Expressions of Concern about the Innovation
6 Refocusing	I have some ideas about something that would work even better.
5 Collaboration	I am concerned about relating what I am doing with what other instructors are doing.
4 Consequence	How is my use affecting students?
3 Management	I seem to be spending all my time in getting materials ready.
2 Personal	How will using it affect me?
1 Informational	I would like to know more about it.
0 Awareness	I am not concerned about the innovation.

Adapted from Hall & Hord, 2001

the activities as designed and in their intended order, would be described as teaching with fidelity.

**RESEARCH METHODOLOGY**

In this study, a mixed-methods approach was used. Specifically, teacher efficacy and concerns were measured and analyzed quantitatively using rating scales in a pretest-posttest design. Implementation fidelity was measured and analyzed qualitatively through interviews and direct observation of classroom practice. Approximately 40 out-of-field physics teachers, divided into two cohorts, participated in the study.

**Description of the Measures**

The Science Teaching Efficacy Belief Instrument (STEBI) developed by Riggs and Enochs (1990) was used to measure science teaching efficacy. This instrument is composed of two subscales identified in the literature as important components of teacher efficacy: Outcome Expectancy (OE) and Personal Teaching Efficacy (PTE). Outcome expectancy refers to the whether the teachers believe that student learning can be influenced by effective teaching, and personal teaching expectancy refers to whether they have confidence in their own teaching abilities.

In addition to the STEBI, we administered the short form of a Teacher Efficacy Scale (TES) developed by Hoy and Woolfolk (1993). This 10-item scale was administered because we thought it would be a reasonable validity check on the STEBI but also because it measures teacher efficacy in general and not just in science teaching. We thought that teachers may feel efficacious in teaching in their own discipline but may not feel that way teaching in a discipline in which they have little preparation. This measure was used to provide an indicator of that factor.

Teacher concerns were measured using the Stages of Concern Questionnaire (SoCQ) which is based on

the Concerns-Based Adoption Model (see Hall, George, & Rutherford, 1998). The questionnaire is a 35-item rating scale instrument where respondents rate themselves on a continuum from “not true of me” to “very true of me now.” In the Concerns-Based Adoption Model, there are seven developmental stages of concern numbered 0 to 6 (Awareness, Information, Personal, Management, Consequence, Collaboration, and Refinement). In the literature on systemic change, a teacher’s stage of concern about an innovation (or curriculum in this case) has been strongly linked to his or her quality and fidelity of implementation. The Stages of Concern and their brief descriptions are provided in Table 1. Fidelity of use was determined by triangulating the following data sources: data from the research team’s classroom observations, teacher interviews, and comments from the Physics 496 course instructor (a SDCS district employee who also conducted classroom observations).

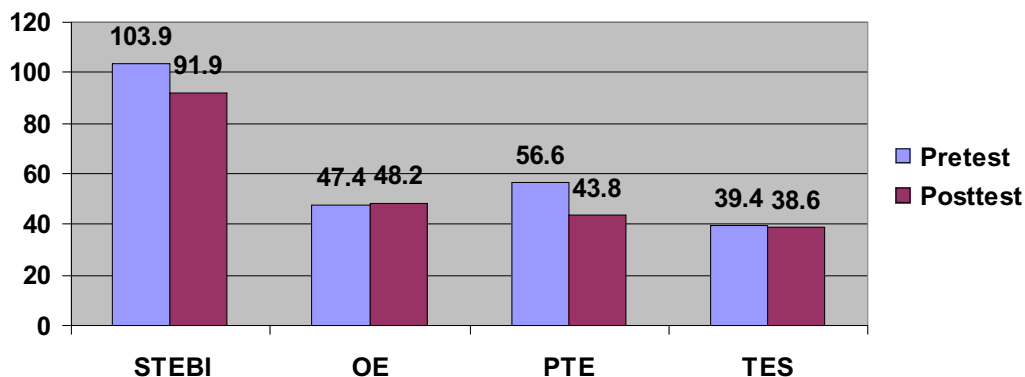
**FINDINGS AND DISCUSSION**

**Teacher Efficacy**

The STEBI (including its subscales OE and PTE) and the TES were analyzed to compare pretest scores obtained at the beginning of the semester (Fall, 02) to posttest scores obtained at the end of the semester. The pretest and posttest means are shown in Figure 1.

The results appear somewhat surprising at first glance, with the efficacy scores much the same or lower in the posttest, after the professional development. However, this pattern in efficacy beliefs is consistent with the research of Fullan (2001) who has

**Figure 1: Pretest & Posttest Means for the STEBI, Subscales, and the Teacher Efficacy Scale**





suggested that all successful schools experience an “implementation dip” where performance and confidence decrease as teachers encounter an innovation that requires new skills and new understandings. An implementation dip makes sense in this context as well when one considers that initially most of the SDCS teachers had high expectations of their abilities and estimates of their efficacy, often based on experience in their own fields. It is likely that once they became engaged with the new innovation (teaching unfamiliar content in an inquiry-based fashion), there was a realization of the professional growth that was necessary to be successful, so efficacy suffered.

**Out of Field Teachers’ Concerns about Implementing Active Physics**

Cohort I

We administered the Stages of Concern Questionnaire (SoCQ) twice to out-of-field teachers from Cohort I. The survey was first administered in September 02, and then again in December 02. An identical questionnaire was administered each

time. Cohort I teachers were in the third semester of Phys 496 – *Physics for Educators* and had completed one year of *Active Physics* implementation. To determine the prevalent stage of concern for this cohort of teachers, an average intensity was calculated that took into account each individual teacher’s intensity of concern at each stage. The average intensities can be plotted to provide a graphical view of the cohort’s concerns as a whole (see Figure 2a). A parallel analysis of the questionnaire data from the December 02 administration yielded the relative intensity graph in Figure 2b.

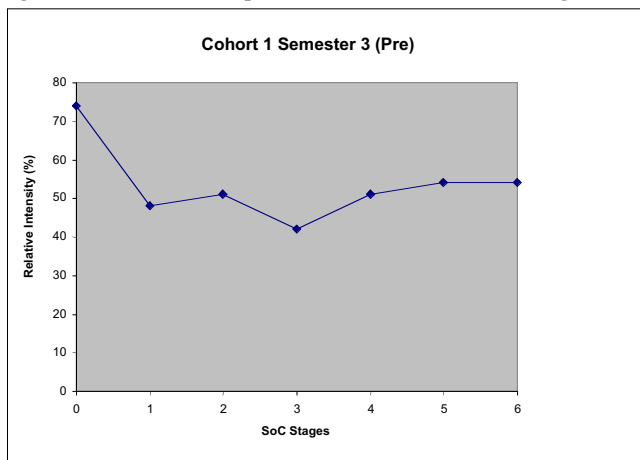
Our interpretation of the Cohort I data centers on two critical features of the relative intensity graphs. These were the high level of “nonconcern” (stage 0) in both September 02 and December 02, and the Stage 6 (Refocusing Stage) “tail up” apparent on the December 02 graph.

The high relative intensities found for Stage 0 (Awareness) actually suggest a lack of concern about implementing the curriculum. For example, two items from the Stage 0 subscale are

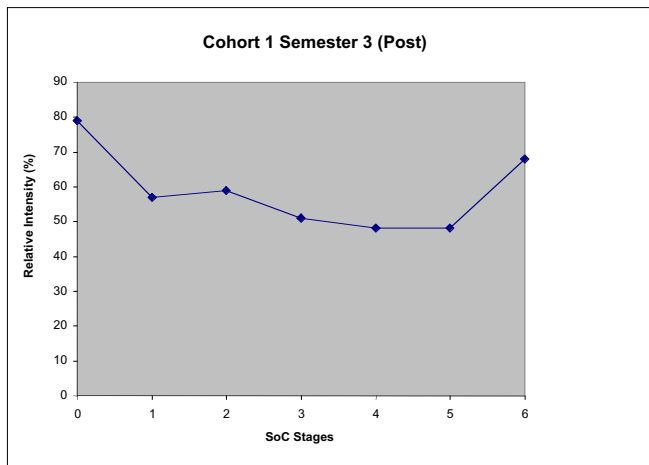
Item 12. I am not concerned about this innovation.

Item 21. I am completely occupied with other things.

**Figure 2a. Cohort I – 02 Sep.: Relative Intensities for each Stage of Concern**



**Figure 2b. Cohort I – 02 Dec.: Relative Intensities for each Stage of Concern**



If teachers were to rate these two items as a “7” indicating that these were “very true of me now” this would indicate a lack of concern about implementing the curriculum but would result in a higher relative intensity for this stage. The lack of concern about implementing the new curriculum was not surprising given that these teachers were now in their third semester of implementation support through the Phys 496-*Physics for Educators* course sequence and had enjoyed a full year of comprehensive, ongoing implementation support that was provided to all physics teachers in the district. We assert that this lack of concern about using the new curriculum, as indicated on the questionnaire, is evidence that the teachers have become more experienced implementers of the curriculum. These teachers may still have concerns about teaching physics in general or about physics for ninth graders, which would affect their efficacy scores; but concerns related to the curriculum seem to have faded.

The Stage 6 (Refocusing Stage) increase or “tail up” observed in the December 02 data suggests that the teachers developed many ideas for enhancing the effectiveness of the new curriculum. This finding is consistent with one of the primary goals of the professional development program, which was to support teachers in implementing the curriculum by (in part) helping them adapt the curriculum for optimal use in SDCS. In some cases, a high Stage 6 score can indicate that the respondents are considering the replacement or drastic modification of the innovation. Our classroom observations suggest, however, that the teachers were implementing the new curriculum with some degree of fidelity and that most adaptations were done without compromising the integrity of the new curriculum’s instructional model (see Implementation Fidelity section).

Cohort II:

The SoCQ was also administered twice to the out-of-field teachers from Cohort II. The questionnaire was identical to that used with Cohort I where the innovation was defined as “implementing *Active Physics*.” The SoCQ was administered in September 02 and December 02. Cohort II teachers were beginning their first semester of Phys 496 – *Physics for Educators* and had not begun implementing the new curriculum. The analysis of Cohort II SoCQ data was conducted as it was with Cohort I data yielding relative intensity graphs for both the September 02 and December 02 administrations (see Figures 2c and 2d).

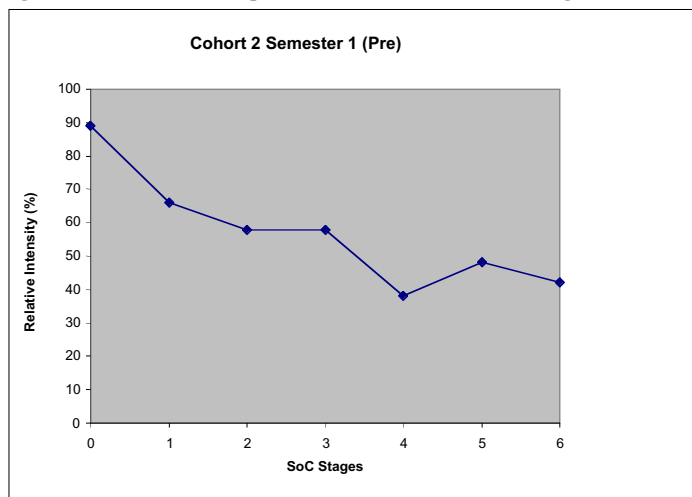
The September 02 SoCQ administration yielded a relative intensity pattern that is very similar to the pattern of concerns typically held by “non-users” of an innovation (see Hall, George, & Rutherford, 1998; p. 37). This is a reasonable result since, in September 02, the teachers in Cohort II had just begun using the new curriculum. In the September 02 SoCQ administration, Cohort II teachers were characterized by a high degree of

awareness and concern about the new curriculum (Stage 0). It is likely that the teachers were interested in being positive and proactive as they learned more about the curriculum (Stage 1 – Information slightly higher than Stage 2 - Personal). At this point, Management concerns were moderate (medium intensity Stage 3), and concerns about consequences for students were low (relatively low intensity on Stage 4 - Consequence). The decreasing Stage 6 (Refocusing) score indicates that the teachers did not have many ideas about teaching physics that would necessarily compete with those embodied in the new curriculum. Hall et al. (1998) summarize that “This overall profile suggests and reflects the interested, not terribly over-concerned, positively disposed nonuser” (p. 36).

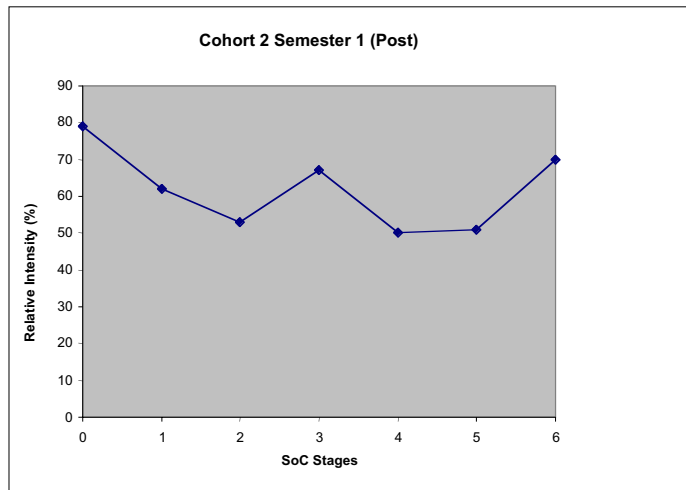
Our interpretation of the Cohort II data from the December 02 centered on two critical features of the relative intensity graph. These were the increase in Stage 3 (Management) concerns, and the increase in Stage 6 (Refocusing) concerns. It is clear that, in their first semester of implementing the new curriculum, the Cohort II teachers encountered management issues (e.g., time, materials, logistics) related to implementing the curriculum. These management issues would have been difficult to anticipate in September 02. Therefore, the increase in management concerns is not surprising since these concerns are focused on the processes and tasks of using the curriculum and issues of efficiency, organization, scheduling, and time are paramount.

Our interpretation of the Stage 6 (Refocusing Stage) increase is similar to that of Cohort I’s Stage 6 increase in that it suggests that the teachers developed many ideas for enhancing the effectiveness of the new curriculum. Again, this finding makes sense given SDCS’s efforts to support teachers in implementing the curriculum by (in part) helping them adapt the curriculum to optimize student learning. Again, a Stage 6 increase can also suggest that the teachers were ready to completely abandon the curriculum program, but the data around implementation fidelity (see following section) indicate otherwise.

**Figure 2c. Cohort II – 02 Sep.: Relative Intensities for each Stage of Concern**



**Figure 2d. Cohort II – 02 Dec.: Relative Intensities for each Stage of Concern**



### Implementation Fidelity

We based the preliminary analysis of teachers’ fidelity of use of *Active Physics* on a set of interviews and observations conducted in September 02 and December 02. In general, the out-of-field teachers were using *Active Physics* with fidelity. In September 02, most of the implementation was at the mechanical level. That is, the teachers were staying true to the basic design of each module and using the various elements as the developers intended. The modifications that were being made to the curriculum appeared to be aimed at aligning use of the curriculum with more familiar teaching approaches and materials. By December 02, more modifications were being made. Most of these modifications were consistent with the goals of the curriculum program. Table 2 summarizes the changes between the September 02 and December 02 observations.

The comments made by out-of-field teachers during their interviews were quite compelling in their support for both the adoption of curriculum materials that include strong teacher support and professional development that is tightly linked to

**Table 2: Observable Indicators of Fidelity**

September 02	December 02
Most out-of-field teachers sticking closely to program as designed. Modifications tend to be aimed at wedding new curriculum with more familiar approaches and teaching materials. Some modifications were ill-advised.	<p>All teachers are making some modifications or supplementing the program.</p> <p>Modification and supplements are generally more consistent with goals the curriculum.</p> <p>Conceptual flow in some out-of-field teachers' classrooms is still somewhat disjointed. Teachers question if this is a result of the curriculum's design or their own lack of knowledge.</p>

that curriculum. Most teachers indicated that they could not imagine teaching out-of-field without this combined support. Their conviction that the curriculum and professional development were vital to their survival in the classroom seems to have increased the likelihood of teaching with fidelity. The out-of-field teachers did not trust their ability to teach physics so they put their trust in the curriculum. Then, because they had strong support for learning to use *Active Physics*, they were able to stick with the curriculum at times when they were struggling. This support increased their familiarity with the program and therefore their willingness to teach it with fidelity. Table 3 summarizes the comments made during interviews that indicated high fidelity. There was only one comment made during an interview that indicated anything other than an intention to use the program with fidelity. One person raised questions about the amount of support any set of curriculum could provide for him as an out-of-field teacher, but this same teacher also said he would not have moved to this new teaching assignment had *Active Physics* not been in place.

**SUMMARY AND DIRECTIONS FOR FURTHER RESEARCH**

One finding from this study suggests that many of the teachers' efficacy levels for physics teaching stayed the same or declined in the early stages of implementation of the new curriculum, despite ongoing professional development. This was not a surprising result given the radical change in beliefs and practice that some teachers underwent during the implementation process. Further study of this group of teachers might investigate whether teacher self-efficacy reaches a minimum and then rebounds to a level more indicative of experienced implementers of the curriculum.

Another finding of this study indicated that the teachers' implementation of the curriculum was done, in general, with fidelity. However, early on, the implementation was often mechanical in the sense that the teachers were following directions about how to teach the program rather than understanding it in depth. Thus, modifications were sometimes ill-advised. Future research might explore the teachers' use of the new curriculum to determine whether the implementation continues to have fidelity as teachers personalize and internalize

**Table 3: Interview Excerpts Suggesting Fidelity**

Cohort I	Cohort II
Like having a curriculum to give direction to the course.	I would not teach without it [ <i>Active Physics</i> ] and would have accepted the position if it were not in place.
Kits make it possible to run labs that would have been impossible to conduct before.	Without it [ <i>Active Physics</i> ] I would have stuck strictly to the outline of some text and that would not have been best for the kids.
The teacher support materials helped me develop background knowledge (about how to implement).	All teachers should have to learn about how <i>Active Physics</i> is sequenced and organized.
This curriculum has the same constructivist teaching strategies used by Dan ( <i>Physics 496</i> instructor)!	Professional development that helps teachers understand the structure of the program (such as the instructional model) is worthwhile.
The tight link between the curriculum and the professional development made this possible.	Professional development should engage teachers with actual activities from the program.
Liked having an established curriculum because it helped balance what teachers like to teach with what students should know. That is, the teachers were forced to teach topics that they did not necessarily like or excel at.	

the program. If so, one would expect to see modifications that refine the implementation for greater impact on students. Further, future research should examine whether a refined level of implementation coincides with increased self-efficacy.

Finally, in this study we found that the teachers had many management-type concerns, especially the teachers in Cohort II. Future research might also examine changes in the teachers' concerns as the implementation progresses. If teachers' curriculum use becomes routine and more refined, it would be important to investigate whether this new level of use coincides with teacher concerns that leave the realm of logistics and management and begin to focus on the curriculum's optimal use and impact on student achievement.

### **RECOMMENDATIONS FOR THE DESIGN OF PROFESSIONAL DEVELOPMENT PROGRAMS FOR OUT-OF-FIELD PHYSICS TEACHERS**

It is clear from all sources of data in this study that out-of-field teachers need ongoing professional development that is tightly coupled with the curriculum materials they are using every day. Further, curriculum-based professional development programs can have an enhanced impact on out-of-field teachers when the curriculum materials being used incorporate a research-based instructional model/learning cycle, have a coherent conceptual flow, and have built-in teacher support (e.g., questioning strategies, ideas for addressing misconceptions). In short, we recommend that quality, research-based curriculum materials be put in the hands of out-of-field teachers and that their use of the materials be supported by long-term, thoughtfully designed, professional development programs.

Further, we encourage teachers and district leaders to stay the course in their reform efforts. This study illustrated a decrease in performance and efficacy that is very common when innovations are first introduced. This study also documented signs of a reversing trend. Fullan (2001) urges science leaders to be patient and suggests that the "implementation dip" will be overcome by providing teachers with comprehensive professional development programs whose time lines are measured in years. The reward for this patience can be a level of implementation and confidence that far exceeds previous standards.

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# *JPTEO*

# High school physics students' conceptions of position, velocity, and acceleration during a computer-based unit on kinematics

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*Students have long had difficulty grasping physics concepts. This difficulty has largely been attributed to tightly held misconceptions. Basic concepts relating to motion, such as velocity, acceleration, and force, all are introduced early in K-12 schooling, yet display some of the most consistent discrepancies from proper physics understanding. While these misconceptions have been observed for some time, new methods and technologies are constantly being implemented in the classroom to correct for these ideas. This study focused on the use of MBL activities in both a typical classroom and an online environment. It was hypothesized these misconceptions would begin to dissolve through increased student and teacher familiarity with this type of equipment and pedagogy through time. Unfortunately, it was found that while the students did display growth in their physics learning, they showed nearly identical levels of misconception as similar students from previous studies.*

## Introduction

Students typically enroll in physics classes during either their junior or senior year of high school, if at all. Students will therefore undergo around 16-18 years of observation about physical phenomena before they receive extensive formal training about these phenomena. Unfortunately, much of the observation of the natural world by students leads them to formulate incorrect schema about the nature of motion. Hidden from their observation are forces that help define motion according to Newton, whose beliefs are accepted for the motion of most objects. Research has shown that typical physics instruction has generally proven ineffective at rooting out these alternative conceptions (also called preconceptions or misconceptions in the literature) as to the nature of motion. New techniques and new technologies are now available to aid teachers' efforts to change students' conceptions. Before these can be effective, however, one must have a clear picture of the conceptual understanding of students with regards to motion.

## Literature Review

In one of the early studies on student preconceptions, Clement (1982) videotaped students as they solved problems in mechanics. His analysis showed students often believed that motion implied force. Students would depict a force acting in the direction of the motion regardless of the situation. He determined that the pattern of responses by students was very similar to a Galilean point of view of mechanics. Students were also tested after the completion of a mechanics course, and while there was some improvement in the conceptual understanding of the problems, still less than 20% of the students answered correctly. In 1987, Gunstone attempted to replicate the measures of alternative conceptions produced by Clement. Over 5500 high school students completed an examination after a year of physics instruction. While the results revealed similar misconceptions as first shown by Clement, these were not as drastic. Gunstone hypothesized the differences may have been caused by physics teachers being more aware of the alternative conceptions of

students, or that this exam was given in multiple choice format to facilitate a large population.

The other seminal studies on student conceptions in physics were completed by Halloun and Hestenes (1985a; 1985b). The results were reported in a pair of articles detailing the level of student conceptions in mechanics and what alternative conceptions the students held. First, they administered a mechanics test to about a thousand high school and college physics students. They found that pre-instruction high school physics students' levels of understanding were barely above the level of guessing. Post-instruction high school students were able to answer 44-52% of the questions correctly. This was roughly the same level as the pre-test for university physics students, who had taken physics in high school. After instruction, these university physics students averaged 64% correct. To them, this was a very disappointing increase. In fact, Halloun and Hestenes (1985b) noted,

A low score on the physics diagnostic test does not mean simply that basic concepts of Newtonian mechanics are missing; it means that alternative misconceptions about mechanics are firmly in place. If such misconceptions are not corrected early in the course, the student will not only fail to understand much of the material, but worse, he is likely to dress up his misconceptions in scientific jargon, giving the false impression that he has learned something about science. (p. 1048)

Halloun and Hestenes (1985a) went on to examine what alternate conceptions of mechanics were possessed by students. One of the main discoveries was again similar to Clement. Students believed that motion is proportional to force. Acceleration was only associated with an increasing force. They also found that students had very loose and inconsistent definitions of simple concepts such as distance, velocity, and acceleration. Only 17% of the students surveyed,  $n=478$ , could be classified as having a primarily Newtonian view of mechanics.



Because the alternative conceptions of mechanics held by students are so prevalent, they have been examined at all ages and stages. In an effort to determine the origin of alternative conceptions Bliss and Ogborn (1994) studied infants. They categorized the stages and observations related to motion as follows; 0-4 months- notice movement, 4-9 months- make effort to move, 9-12 months- move objects and self, 12-18 months- walk/run, and 18+ months- jump, carry and throw. In another study of young children, pre-school and kindergarten students outperformed school aged students on motion concepts, possibly due to the lack of well-formed alternative conceptions (Pine, Messer, & St. John, 2001).

Students in grades 4-9 were found to have a 'straight down' belief system as to how objects would fall (Shemesh & Eckstein, 1993). This was particularly strong for students in the lower grades. In this same age group, over 75% of the students were classified as providing intuitive, correct answers with incorrect reasoning, or logical, incorrect answers but with systematic reasoning, to a mechanics scenario (Eckstein & Shemesh, 1989). The percentage of students in these categories remained constant across age levels until students received instruction. A study of fifth grade students revealed that over 90% held misconceptions and no correlation existed between how the teachers ranked the students according to ability and the students' misconceptions (Weller, 1995). Slightly older students, prior to physics instruction, also demonstrated a belief in the influence of shape and weight on the motion of an object (Fischbein, Stavy, & Ma-Naim, 1989).

Other studies of middle and high school aged students found similar patterns of alternative conceptions. A study of seven sixteen-year old students uncovered a difference in the description of motion based on the animation of the object (Whitelock, 1991). If the object was living, students were more likely to believe in impetus theory, and if it was an inanimate object, they were more likely to subscribe to straight down theory. In an examination of ten seventeen-year old students, Marioni (1989) found alternative conceptions based on an absolute frame of reference and, once again, the relationship of force and motion. Research consisting of interviews with twenty-five 11-18 year old students found they also had alternative conceptions related to the support of objects, prevention of motion, and effort to move objects (Bliss, Ogborn, & Whitelock, 1989).

A survey of college-bound high school seniors enrolled in a physics class revealed similar alternative conceptions (Sadanand & Kess, 1990). These students deemed a constant force is required for constant motion and that no force was necessary for inanimate objects to support other objects, but forces were required if animate objects were supporting other objects. Interviews with students revealed alternative conceptions including the personification of inanimate objects (Gilbert, Watts, & Osborne, 1982). These interviews also revealed that students constructed parallel conceptions, one for the classroom and one for the outside world. "The students, therefore, has (sic) views but the learned science viewpoint is not one that is used outside the formal learning situation" (Gilbert et al., 1982, p.64).

Velocity is a concept frequently appearing in the literature with associated alternative conceptions. In a review of literature, McDermott (1984) compiled data showing students had difficulty distinguishing between position and velocity, distinguishing between velocity and the change in velocity, and neglected the time change over which changes in velocity occurred. Another literature review revealed that alternative conceptions in physics were similar in the United States, England, Japan and Israel (Van Hise, 1988).

Another phase of physics education research involves discovering effective ways to correct the alternative conceptions held by students. Some believe as students matured, their conceptual frameworks would become more difficult to modify. A study of Australian year 6 and year 10 students, however, refuted this notion (Palmer & Flanagan, 1997). In this study, both age levels showed similar amounts of conceptual change after intervention. One intervention that was studied to bring about conceptual change was deductive reasoning (Park & Han, 1993). This method was only shown to be effective if the interviewer assisted the students in removing a series of roadblocks, such as not reading or using the premises and rejecting logical conclusions.

A more common and effective method to induce conceptual change is through the use of refutational texts (Guzzetti, 2000; Hynd, McWhorter, Phares, & Suttles, 1994). These texts confront student ideas, present scenarios where these ideas will no longer explain the phenomena, and then present accepted explanations and concepts. Use of these texts is only effective when combined with teacher-led discussions. If students are allowed unmoderated discussions, dominant students can reinforce alternative conceptions. In an examination of four different methods to realize conceptual change in physics, Eryilmaz (2002) concluded that such teacher-led discussions provided both a decrease in alternative conceptions as well as an increase in the understanding of correct conceptions.

A variety of methods using computers in the classroom to achieve conceptual change have been studied. In one case, students were given a game-like simulation to learn mechanics concepts (Flick, 1990). Unfortunately, students' gaming skills were higher than their level of understanding, as they were able to solve the game without demonstrating conceptual change. In other cases, computer programs have been specifically designed to confront and remediate students' alternative conceptions in mechanics (Tao, 1997; Tao & Gunstone, 1999). While these have proven to be effective, they have also shown that students' new scientific conceptions are often context dependant (Tao & Gunstone, 1999). Students will apply their correct new conceptions to the computer or in the classroom, but have difficulties applying these correct conceptions to real world scenarios.

Specific computer interventions using prediction to understand one dimensional motion (Monaghan & Clement, 1999) and using remediation to clear confusion between position and velocity (Zietsman & Hewson, 1986) have proven effective at achieving conceptual change, but are time intensive. One of

the methods to harness the capabilities of computer remediation is to use the computer to first assess a student's alternative conceptions and then present remediation directly related to the individual needs of the student (Hewson, 1984; Pek & Poh, 2000). Hewson (1984) states, "The ability of the microcomputer to allow a student to interact actively with instructional material and to follow an individualized path at his or her own pace is very useful in designing instruction." (p. 17).

In analysis of tasks and interviews Trowbridge and McDermott specifically assessed college students' conceptions of velocity (1980) and acceleration (1981) in one dimension. With regards to velocity, they discovered that nearly every error by students related to confusing velocity and position. They also found after instruction students were much more capable of completing the task correctly, as nearly 70% of the students demonstrated success after instruction. Acceleration, however, was a much more difficult concept for students to master. Students confused acceleration with position, and more often with velocity. Students would also examine the change in velocity, but with no regard to the change in time. After instruction the majority of students still held these alternative conceptions. Similarly, in assessing high school honors physics students after instruction, Peters (1982) determined that only 30% of the students accurately described a velocity-time event in one dimension and this dropped to 10% for an event in two dimensions.

### Research Questions

This research project aimed to assess the conceptual understanding of high school physics students with regards to position-time, velocity-time, and acceleration-time graphs. The conceptual understandings of the students were measured both before and after a short duration, two to four week, treatment. The second goal of this project was to assess if the students achieved any conceptual gains due to the treatment. The students were in two groups. One group received the treatment in a normal classroom setting, and the other group received the treatment online. The last focus of this study was to determine if there was a difference, in the conceptions or in the conceptual gains, between the students in the two groups.

### Population

This study was completed with 150 high school physics students from five different high schools in North Carolina. The high schools were from a variety of geographic and demographic regions of the state. For all but four of the participants, this was the first physics class they had taken. All of the instruction for this unit took place within the first two months of the school year. This was the first instruction that the students had received on motion.

The group of students who completed the instruction in a traditional classroom setting was from three high schools and had 95 members. They were 60% male, 78% Caucasian, and 13% African-American. Their ages ranged from 15-18 and all but one student were either juniors or seniors in high school.

The group of students who completed the instruction in an online environment was from two high schools and had 55 members. They were 50% male, 75% African-American, and 8% Caucasian. Their ages ranged from 15-18 and they were all either juniors or seniors in high school.

### Method

The curriculum used for this research project was the Tools for Scientific Thinking- Motion (TST) curriculum developed by Sokoloff and Thornton (1998). This is microcomputer-based laboratory (MBL) curriculum. The students move themselves and carts in front of motion detectors and display, in real-time, graphs of the motion on the computer screen. Beichner (1990) showed the kinesthetic portion of this type of lab was critical to students gaining understanding. Thornton (1986) first experimented with creating curriculum using the motion detectors with sixth grade students. He was quick to realize this style of curriculum could be applied to physics learners with naive concepts at any age. When the curriculum was further developed and used with non-physics major college students, these students were able to perform equally well on a series of motion graphing questions as were physics majors who had also completed the material in a traditional physics course.

Thornton (1987) felt MBL activities, when properly used in the classroom, could provide numerous pedagogical advantages. The MBL activities encourage inquiry and allow students to easily engage in the scientific process, as the computer handles the drudgery of the data collection. The technology aptitude necessary for MBL activities is easily mastered and can be readily applied to extension investigations that students find personally interesting. Thornton (1986) concluded,

...it would seem that MBL is effective for teaching science to students with a wide range of abilities and ages. MBL gives students an opportunity to investigate their "common sense" understandings of science. When MBL proves are well designed with good user interfaces and used properly as tools to aid scientific thinking, microcomputer-based laboratories can be a powerful adjunct to science instruction.

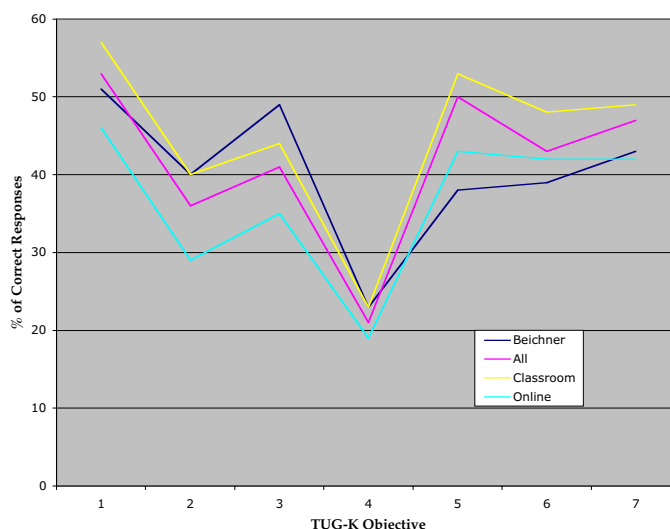
The first six investigations of the TST curriculum were given to all 150 students in the project. Ninety-five of the students completed the investigations in a normal classroom setting. They were given paper copies of the activities and worked in groups of two to four students at laptop computers with motion detectors. The teachers in these classrooms were available to assist the students with misconceptions and difficulties they might encounter.

The online students,  $n= 55$ , also completed the same six activities in groups of two to four students with computers and motion detectors. These students, however, were not given paper copies of the activities or given assistance from their classroom teachers. These students were directed to a website designed by the researcher that presented the same investigations and

completed the activities entirely in an online environment. When these students answered questions, the answers were emailed to the researcher who graded them and returned scores back to their classroom teachers. The only time these students used paper was in instances where they were directed by the website to print graph axes so they could make predictions. The teachers in these classrooms were asked not to assist in concept development. The students were to gain understanding from peer interactions, the investigations, the website, and its related links.

### Instrument

The instrument used to assess the conceptual understanding of the students was the Test for Understanding Graphics-Kinematics (TUG-K) by Beichner (1998). This test was originally developed to investigate the importance of the kinesthetic aspect of MBL activities (Beichner, 1990). The TUG-K was further refined to be an instrument for generically testing MBL activities in kinematics (Beichner, 1994). The KR-20 reliability statistic for the TUG-K was .83, well above the .70 required for a reliable test. The Point-Biserial Coefficient of .74, was well above the .20 required for reliable items. Fifteen science educators established the validity. The test contains 21 multiple-choice questions to test seven objectives (see Table 1). The final version



**Figure 1. Comparison of Post-Test Achievement on TUG-K Objectives (% correct)**

subsequent comparisons, ‘all’ represents the entire student population of the project, ‘classroom’ is the group that completed the activities in a normal classroom setting, and ‘online’ represents the group that completed the activities online. This table shows

students in the present study were at similar conceptual levels as the combination of high school and college students tested by Beichner. There is a significant difference,  $p = .01$ , between the online and classroom groups’ post-test which may suggest the classroom group has a slightly higher conceptual understanding. The classroom group, however, also started at a

significantly,  $p < .001$ , higher level. There was not a significant difference,  $p = .14$ , between the gain scores for the two groups.

To inspect the student responses in greater detail, the seven objectives of the TUG-K can also be examined (see Figure 1). To calculate the percentages given in the table, all the correct responses on each question for an objective were divided by the

total number of responses to the questions for that objective. Once again, there appears to be a great deal of similarity

**Table 1. Objectives of TUG-K\***

*Given:*

1. Position-time graph
2. Velocity-time graph
3. Velocity-time graph
4. Acceleration-time graph
5. A Kinematics Graph
6. A Kinematics Graph
7. Textual Motion Description

*The student will:*

- Determine Velocity
- Determine Acceleration
- Determine Displacement
- Determine Change in Velocity
- Select Another Corresponding Graph
- Select Textual Description
- Select Corresponding Graph

\*(Beichner, 1994)

of the test was given to over 500 high school and college students after instruction on kinematics.

### Results

To assess the conceptual level of the students in this project, the pre- and post-test scores on the TUG-K in this project were compared with Beichner’s results (see Table 2). In this and

**Table 2. Comparisons of Means on the TUG-K**

	<i>Pre-test Mean (SD)</i>	<i>Post-test Mean (SD)</i>	<i>p-value for Post-test*</i>
Beichner	n/a	8.5 (4.6)	
All	4.9 (3.5)	8.8 (4.2)	.45
Classroom	5.9 (3.8)	9.4 (4.3)	.06
Online	3.3 (2.2)	7.6 (3.8)	.10

\*p-value from t-test with Beichner

**Table 3. Comparison on Achievement on TUG-K items (as % correct)**

Objective	Item	Beichner	All	Classroom	Online
1	5	73	76	80	68
1	13	61	63	62	64
1	17	21	20	27	6
2	2	63	60	67	47
2	6	25	16	19	12
2	7	31	33	35	28
3	4	28	21	24	16
3	18	46	41	45	34
3	20	72	61	64	56
4	1	16	29	33	20
4	10	30	27	25	30
4	16	22	9	10	6
5	11	36	45	49	38
5	14	48	64	68	56
5	15	29	39	42	35
6	3	62	60	63	55
6	8	37	53	55	48
6	21	18	24	25	22
7	9	24	31	33	28
7	12	67	71	76	62
7	19	37	38	40	35

between the students in this project and those tested by Beichner. The range of correct responses on the seven objectives for Beichner was 23-51%, and for the students in this project, it was a nearly identical 21-53%. For both Beichner and this project, the objective with the highest rate of correct responses was objective one, to determine velocity given a position-time graph. The most difficult objective was objective 4, to determine the change in velocity given an acceleration-time graph.

One more level of comparisons can be made, and that is to compare the responses on a per item basis (see Table 3). Once again, the trends between the students in this project and those in Beichner's are quite similar. On only five items was there a difference of 10% or more between the whole groups. On items 1, 8, 14, and 15, students on this project scored higher, and on item 16 students in Beichner's groups scored higher.

Given the similarity at all levels of examination between the students in this study and those that participated in establishing the baseline data for the TUG-K, it seems likely students in this study share the same six difficulties that Beichner (1994) identified. These difficulties are: 1) graph as picture errors, 2) slope/height confusion, 3) variable confusion, 4) non-origin slope errors, 5) area ignorance, and 6) area/slope/height confusion.

### Discussion

The mean scores on the pre- and post-TUG-K test for students in this project suggest many alternative conceptions still exist. The pre-test scores were essentially at the level of random guessing; suggesting students' understanding of these graphs was woefully inadequate at the beginning of the unit. While the scores increased significantly after instruction, given the research in

kinematics that shows how difficult it is to change students' alternative conceptions, it is not surprising the scores remained relatively low. In fact, in a similar study, Eryilmaz (2002) designed an 18 item post-test and the mean score was between four and five. Despite changes in technology and pedagogy, physics misconceptions appear stable over time.

In trying to examine what alternative and correct conceptions the students held after the unit, the achievement on the TUG-K can be furthered examined by objective and item. Students were most successful on the objective stating, given a position-time graph determine velocity. Even this objective, however, is somewhat ambiguous when examined at the item level. One of the items under this objective was question five. This was the highest scoring question on the test. Students were asked to find the velocity at two seconds from a distance-time graph that depicted a constant velocity that rose from the origin. Students could correctly solve for the slope and find the correct answer, however, they could also make the common mistake of confusing position and velocity. In this case, students would divide the position at the given two second mark, divide by two, and also arrive at the correct answer. Item 17 also tested objective one. This question was the third lowest scoring item on the exam. These questions asked essentially the same thing, to solve for the velocity at a given time on a distance-time graph. This graph, however, was irregular in shape and had a negative slope through the time referred to in the question. Confusing position for velocity on this question would not result in the correct response. If this was students' confusion they would select choice B. In fact, 46% of the students in both the classroom and the online



group selected that choice, the most frequent answer for both groups.

A sampling of some of the responses that were emailed to the researcher as part of the work to complete the investigations online reveals some of the same ambiguity. Some students' answers showed clear understanding of the concept that the slope on the distance-time graph depicted velocity. A sample student response illustrates this, "The quicker you move the faster you cover distance so the graph whold (sic) have a larger slope. The slower you move the more horizontal the line would be in the graph so the slope would be smaller." A common alternative suggestion involved the 'wavy-ness' of the lines. This was created by the students' steps as they walked in front of the motion detector. Students related the frequency of these waves with velocity, "If I moved faster there would be more curves in the graph or the graph would go up and down more. If I moved slower the the (sic) graph would have less curves or go up and down less." Another group stated, "if it is faster then the curves in the lines a much shorter than those of if you were walking slower. When walking slower the curve is more stretched (sic) out".

The objective, given a kinematics graph select another corresponding graph, had the second highest frequency of correct responses. The three items, numbers 11, 14, and 15, for this objective asked the students to choose the corresponding velocity-time for a displacement-time, acceleration-time for a velocity-time, and velocity-time for an acceleration-time graph respectively. There was much less ambiguity about the achievement of the students on this objective. For all three questions, the students scored between 39-64%. This is a skill that is practiced repeatedly throughout the TST curriculum. Somewhat surprisingly, the highest scoring question was not the item where the corresponding displacement-time graph was chosen for a given velocity-time graph, but was instead when the corresponding velocity-time graph was chosen for given acceleration-time graph. A closer inspection of the questions reveals that for the velocity-time graph answers, there are two graphs with the correct shape. To answer the question correctly, judgment must also be made as to the magnitude of the velocity depicted on the given displacement-time graph.

The objective, given an acceleration-time graph determine the change in velocity, produced by far the lowest achievement of the students in this project. While not more than 30% of the students answered any of the three questions for this objective correctly, item 16 was by far the lowest scoring item on the test. In this item the students were given an acceleration-time graph and asked to calculate the change in velocity over the first three seconds. On this item, students overwhelmingly committed what Beichner called area/slope/height confusion. Instead of calculating the area under the curve, 45% of the students calculated the slope, and 35% of the students reported the height of the graph at that point as the correct answer. Responses from the online group indicate that some students seem to understand the relationship of acceleration-time and velocity-time graphs, "if the velocity slopes down then the acceleration is negative. If the velocity slope is posive (sic) then the acceleration is positive."

Other groups had a more mixed signal, being able to recite the definitions but not understanding all the possibilities, "If the velocity is increasing so is the acceleration and if the velocity is decreasing so is the acceleration because acceleration equals the change of velocity over the change of time." Still other groups appeared to be more confused, "Yes the acceleration and the velocity did agree because they started off medium fast and then slowed to a complete stop. The sign can be represented by the sign of the velocity, if the velocity is positive then the acceleration will also be positive." As the students progressed through the acceleration section of the activities, the quality of work received began to decline. It is possible students began to tire of the unit and had to expend considerably more effort to understand the concepts. Moving from an acceleration-time graph to understanding the change in velocity of the object is not a skill emphasized in the TST curriculum.

Much has been said about the comparison between students in this project and Beichner's research but little mention has been made about differences between the two groups for this project, the classroom and online groups. In examining the data there is quite nearly a mirror effect, as the largest and smallest percentages of correct answers are the same by objective, and nearly so by item. Most of the differences between these two groups can be traced to the level of initial understanding demonstrated by the classroom group. This group started at a higher level and at the end of instruction was able to gain the same amount as the online group, thereby retaining an edge in the level of understanding.

Two items stand out for consideration, two and seventeen, as there is a greater than 20% increase by the classroom group over the online group. At first glance there appears to be little in common between the questions, item two addresses objective two, and item 17 addresses objective 1. The only commonality in the questions, which may or may not be related to the differences in scores, is that for the part of the graph in question, the slope is negative. As to whether it is more difficult to comprehend negative slopes and their meaning in an online environment would call for additional study.

In conclusion, students completing this unit were able to make conceptual gains as illustrated by their TUG-K scores. Inspection of these tests, however, reveals that even post-instruction the students retain several of the entrenched alternative conceptions about motion that are prevalent in the literature. The students display confusion selecting the correct variables: displacement, velocity, or acceleration. There is also confusion as to which operation to use with a given graph: determining height, slope or the area under the curve. While MBL units have proven here and in other studies to be effective at inducing conceptual change, there is still difficulty in changing students alternative conceptions about motion to levels that would be considered educational success, students 'passing' the assessment. This calls for more research on MBL's, both in the classroom and online, in combination with other methods of conceptual change, such as refutational texts, and for longer durations.



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