

High School Student Expectations after a Year of Constructing Physics Understanding

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Abstract

Students' expectations about learning physics are compared in two high school physics courses: a course taught in a traditional manner and a course taught using a concept-building, constructivist pedagogy. The Maryland Physics Expectations (MPEX) Survey was used to measure the students' attitudes, beliefs and assumptions about learning physics. After a year of learning physics, the students who were taught using a constructivist-based pedagogy held more expert-like views in Independence, Concepts, and Reality Link clusters of the MPEX survey than did students completing the traditional course. The results indicate that students who are guided in constructing their own physics understanding view themselves as more responsible for their learning, understand better the important role of concepts in learning physics and were more likely to connect the physics they learned to their experiences outside the classroom.

Introduction

High School students enter physics classes with a set of expectations about what it means to learn physics, and they exit a year of classes with those expectations either reinforced or altered. Some students believe that learning physics means receiving information about a collection of isolated information and formulas unrelated to real-world experience while other students view physics learning as a process of reconstructing their own understanding of a coherent system of concepts related to the real world (Hammer, 1994). Some student believe that learning is primarily learning facts and independent pieces of information while other students see learning as developing an understanding of how information is developed and how it all fits together.

Students in high school physics and introductory college physics can be categorized by their beliefs – their views about what it means to learn and understand physics. These beliefs play a critical role in how the students approach the coursework in a physics course and consequently, what they

learn in the course. Students who believe that they must memorize all the details of lectures and reading assignments will have different learning outcomes than students who spend their studying energies on trying to discern and understand the big concepts presented in the course and how these concepts are supported through observations. Student expectations about learning physics have been demonstrated to have a profound impact on the success of students in calculus-based, college-level physics classes. Students whose expectations match those of experts in the field experience greater success in learning, even when factors such as interest in science, mathematical aptitude, and socioeconomic status are controlled for (Schommer, 1993). Helping students gain understanding in the coherence and consistency, differentiating between rote memorization and deeper understanding will not only help them be better students academically, but is one of the main goals of science teaching.

High school physics teachers are in a position where they can have a great influence on their students' epistemological beliefs – their views about what it means to learn science. The instructor and the curriculum work together to foster a particular set of expectations. Many new models for high school physics curricula reflect an explicit goal of helping students to see connections and construct understanding. However, not much research has been conducted at the high school level to measure the effects of these curricula on student expectations. In addition, studies comparing the effects of two different curricula may lack internal validity due to the effects of different instructors. This paper presents the results of an experimental study comparing student attitudes and beliefs about learning physics in two different student populations: students who have completed a traditional high school physics course and students who have completed a conceptual physics course with a constructivist-based

pedagogy. Both courses were taught by the same instructor. The attitudes and beliefs of the students were probed using the Maryland Physics Expectations (MPEX) survey that was developed by Redish, Steinberg, and Saul (Redish, Saul, & Steinberg, 1998). Students' learning journals were also used to shed light on their attitudes and beliefs about learning physics. This paper focuses on the following research question: After a year of constructivist-based instruction in an introductory high school physics course, how do the students' expectations about learning physics compare to the expectations of students who completed a year of traditional introductory high school physics?

Background and Related Research

Research in physics education has grown over the past 25 years, and today there is a rich collection of research examining how students learn physics. Much of this research has centered on alternative conceptions that students hold prior to formal physics instruction (Arons, 1990; Clement, 1982; F. M. Goldberg & Bendall, 1995; F. M. Goldberg & McDermott, 1987; McDermott, 1993; Osborne & Freyberg, 1985; Posner, Strick, Hewson, & Gertzog, 1982). The implications for this research are well known: teachers should use this information about prior knowledge to plan experiences for their students that provide an opportunity for the students to construct their own knowledge. Many curricular and pedagogical advances have been made in the past ten years as physics education researchers have worked to use their findings to develop instruction that will be more effective in increasing students' understanding of the concepts being taught (F. M. Goldberg & Bendall, 1995; Hestenes, 1996; Redish, 1996). Physics pedagogy reform projects such as Constructing Physics Understanding (CPU), Modeling, and

Workshop Physics, Real-Time Physics, and Comprehensive Conceptual Curriculum Project (C³P) have been developed to help high school and college physics instructors to be more effective in helping students learn and understand physics concepts. These curricular developments help students to make careful observations and in turn make sense of these observations by constructing and testing consensus ideas. Of all of the curricular projects, CPU is focused more on consensus ideas and less on mathematical modeling of physical phenomena

The attitudes and expectations of high school and middle school students toward their classroom activities can shape their behavior in science class and have powerful consequences for their learning. Some educators argue that the most important goal of high school science courses should be to give student authentic science experiences, including immersion in a scientific community where ideas are built and tested through the inquiry process. A robust background in scientific thinking is expected to change students' attitudes and beliefs toward learning physics.

David Hammer (Hammer, 1994) proposed three dimensions that can be used to classify student beliefs about the nature of learning physics:

1. Independence – beliefs about learning physics; whether it means receiving information or involves an active process of reconstructing one's own understanding.
2. Coherence – beliefs about the structure of physics knowledge; as a collection of isolated pieces or as a single coherent system.
3. Concepts – beliefs about the content of physics knowledge; as formulas or as concepts that underlie the formulas.

Redish and his colleagues in the Physics Education Research Group at the University of Maryland, built upon Hammer's work and

developed a survey that probes some aspects of student expectations – the Maryland Physics Expectation (MPEX) survey (Redish et al., 1998). In addition to the three dimensions proposed by Hammer, the MPEX survey probes three additional dimensions:

4. Reality Link – beliefs about the connection between physics and reality; whether physics is unrelated to experiences outside the classroom or whether it is useful to think about them together.
5. Math Link – beliefs about the role of mathematics in learning physics; whether the mathematical formalism is used as a way of representing information about physical phenomena or mathematics is just used to calculate numbers.
6. Effort – beliefs about the kind of activities and work necessary to make sense out of physics; whether they expect to think carefully and evaluate what they are doing based on available materials and feedback or not.

The MPEX survey consists of 34 Likert-style questions designed to probe student expectations about learning physics by comparing the responses given by students to those of “experts” – College faculty familiar with current research-based physics instruction. This survey has been used and validated with college-level, calculus-based physics courses. In the original study using the MPEX survey, Redish *et al.* found that the cognitive attitudes of the students toward physics in introductory, calculus-based physics courses deviated significantly from “expert” views. They conclude that “the small fraction of students who enter our classes with expectations that match the instructors may be identified as ‘good’ students and achieve success,” while “the students who have inappropriate expectations may work extremely hard but still find themselves unable to succeed” (p. 220).

Methodology

Subjects

The subjects in this study were high school students enrolled in an introductory physics course in a suburban high school. The students were juniors and seniors in high school, generally in the top one-half of their class in academic standing. Each year, there were four sections of introductory physics at this school. In Year 1 three sections (55 students) were included in the study. In Year 2 four sections (87 students) were included in the study. The populations were equivalent in terms of grade point average and prior coursework. The instructor was the same for all students included in this study. During the two years, the curriculum and pedagogy changed, but the time allotted for the course remained the same.

The Curricula

In Year 1, the students completed a physics course that was based on the New York State Regents physics curriculum (New York State Board of Regents, 1988). This traditional algebra-level course had mandated units in simple mechanics, energy, electricity, waves, light, and modern physics. Much of the course centered on solving quantitative problems using equations given on a reference table. At the end of the school year, the students took a required state-wide physics examination. This curriculum will be referred to as “Traditional” throughout this study.

In Year 2, the students completed a physics course that was based on pedagogy and curricular activities developed through an NSF-funded project entitled “Constructing Physics Understanding in a Computer-Enhanced Learning Environment” (CPU) (F. Goldberg & Bendall, 1998). Four units were taught in this course: Light & Color, Static Electricity and Magnetism, Current Electricity, and Motion & Force. Because of

time constraints at the end of the school year, only half of the Motion & Force unit was completed. The focus in this course was on guiding the students through activities that are carefully designed to help the students develop Consensus Ideas. The activities required students to confront how their prior ideas held up to observations and then assisted students in gradually building more scientific, evidence-based, ideas. At the end of every learning cycle, the students would have a consensus discussion to come to agreement on what ideas best explain the observations made in the activities. Quantitative work was done in this course, usually introduced after the students had finished a cycle of developing ideas, but the emphasis was on conceptual understanding, not quantitative problem solving. At the end of this course, the students took a final exam designed by the instructor. This curriculum will be referred to as “CPU.”

Research Design

Expectations and attitudes were measured through post-tests given to both sets of students. Students completed the Maryland Physics Expectation Survey (MPEX) at the end of the school year. The guidelines suggested by Redish *et al.* (Redish, Steinberg, & Saul, 1996) were used to evaluate the MPEX surveys. The MPEX has been validated for students entering college; therefore, it was chosen as a reasonable measure for these students, graduating high school seniors.

Student writing

During Year 2, writing was a more prevalent part of the course. In one writing assignment, the students were asked to write about their experience in learning one particular consensus idea (of their choice) during the current electricity unit. This was an extensive piece of writing entitled a

Learning Commentary. In the Learning Commentaries, students described how they came to understand a consensus idea. This writing assignment is meant to help the students reflect on their own thinking by reviewing their own work, and looking for clues about when and how the final ideas were developed. The student writing from Year 2 is used in the Results section to articulate examples of the dimensions probed by the MPEX Survey.

Results and Discussion

MPEX Survey Results

The results of the MPEX survey are given in Table 1. To determine if the Year 2 results were different from the expected (Year1) results, a chi-square test was used. Significant differences were found in three of the six clusters: Independence ($\chi^2 = 8.45$, $df = 2$, $p = .019$) concepts ($\chi^2 = 8.28$, $df = 2$, $p = .0024$) and Reality Link ($\chi^2 = 6.25$, $df = 2$, $p = .026$). Following the lead of Redish *et al.* (Redish *et al.*, 1998) I present the results of the MPEX Survey using agree-disagree (AD) plots to display the results. In this representation, the mean percentage of favorable answers vs. the mean percentage of unfavorable answers is plotted. A data point in the upper left corner would represent a student that agrees with “experts”, and a data point in the lower right would represent a student that holds the opposite views and can be considered a “novice.” The distance from the diagonal line to a data point reflects the percentage of neutral responses. Figure 1 shows an AD plot for each of the MPEX Survey dimensions for both the Traditional and the CPU students.

Understanding the Differences

In the following sections, each cluster from the MPEX is examined more completely. The three clusters that evidenced significant differences between the two groups will be discussed. As the instructor

for both groups, I refer back to aspects of my practice in the two situations to develop hypotheses about the root of these differences. These sections are followed by a brief examination of the clusters that were not significantly different.

Cluster	Traditional course	CPU course	Statistical Significance
Independence	34/38	57/26	$p = .020$
Coherence	39/33	46/35	ns
Concepts	39/42	60/19	$p = 0.0024$
Reality Link	48/22	69/12	$p = 0.026$
Math Link	43/28	49/29	ns
Effort	41/32	49/30	ns

Table 1: Percentages of students giving favorable/unfavorable responses on overall clusters of the MPEX survey for students in the traditional course and the CPU course.

1. The Independence Cluster

The essence of this cluster is how students think they acquire knowledge and understanding about physics. Do they get it from the instructor or can they develop it on their own? If students believe that they can develop understanding of physics independently, they are more likely to take responsibility for their own learning in physics. The large difference between students in my traditional and CPU physics courses may be attributed to the role the students played in the course. In my traditional course, students were introduced to a concept with a lecture or demonstration. The instructor developed the concept, and sample problems were presented showing how the concept could be used to solve problems. The role of the student in all of this was mostly passive, taking notes, listening. When student were asked to do practice

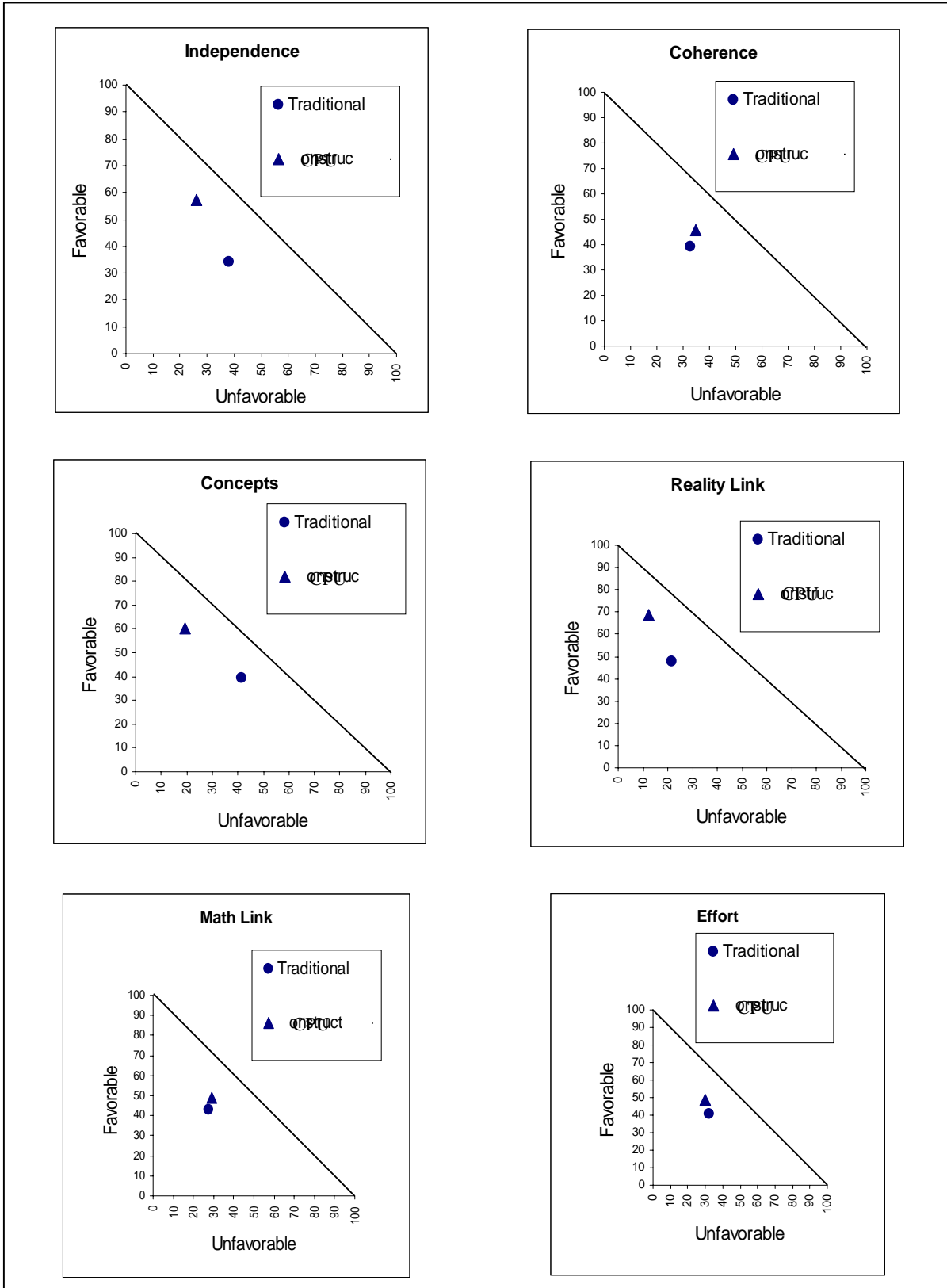


Figure 1: Traditional and CPU results of MPEX survey by Cluster

problems, they mimicked the sample problems.

In the CPU course, the students participated by working in groups doing activities to develop the concept. My role was more as a coach, facilitating the group discussion and experimentation and testing of ideas. The groups hypothesized ideas and tested these ideas for power by trying to use these ideas to make predictions and explain their observations. After completing the activities, the class came to a consensus on the ideas most useful. Then these ideas were used in additional activities and problems. By actually developing physics ideas themselves, students began to take responsibility for their learning, gaining independence. Two of my students in the CPU course articulated this in their learning commentaries as follows:

Student 1: Physics has proven to be one of the most challenging courses I've ever taken. Although I became very frustrated and discouraged at times, it benefited me greatly in the long run. Too many times, teachers expect students to learn by memorizing what we read out of a textbook or copied from a blackboard. Physics has gone beyond that style and forced me to Think. The teacher acted more as a guide than someone who just gives us the answers. I can't stress enough how much I've benefited from deriving initial ideas and confirming or changing them. Not only have I learned and proven ideas, I have developed important reasoning skills. This has been accomplished through being forced to find answers by observation and activities.

Student 2: All of the puzzle pieces had finally come together. The picture was right in front of me. I may not have expected the outcome of the experiments, but I will remember the results because I had seen and come up with the ideas on my own.

2. The Concepts Cluster

This cluster is intended to probe whether students are viewing the solving of physics problems as simply a mathematical manipulation of an equation, or if instead, they are aware of the more fundamental role played by physics *concepts* in complex problem solving. The significant difference between the traditional and CPU physics students might be explained by the exercises the students did for practice. In the traditional course, the students were asked to work on problems that are mostly quantitative in nature – using an equation to solve for an unknown.

In the CPU course the students were asked to make predictions about what would happen in different situations, explain why things happened, and to extend ideas to new situations. Less quantitative work was done in the form of using equations to solve problems, but the students did include quantitative ideas in developing many of the consensus ideas. Throughout the class activities, students were required to state explicitly how they perceived the emerging concepts and to explain and debate these conceptual understanding with their peers. The conceptual understanding came first, through great mental effort. The equations were added later for application activities. One student writes in her Learning Commentary:

My biggest discovery came when sitting in class listening to other students contemplate the working of electricity. It was then that my mind wandered to a previous unit, where we learned about the polarization of a conductor, involving conducting spheres which were able to polarize each other. With the connection between the two, I almost exclaimed out loud. I had answered my own questions.... [Then she went on to explain how a capacitor works].

This student clearly is using the concepts of physics to solve new problems, rather than looking for the right formula to use.

3. The Reality Link Cluster

One of the things this cluster measures is the likelihood of a student to think about the reality of a solution to a problem. In a traditional physics course, many students will calculate an answer and not think about whether the answer makes sense – even though we physics teachers love to preach the importance of doing so. In the CPU course, an effort was made to use everyday items in the activities. After developing the consensus ideas, the students applied these ideas to real-life problems. For example, after learning about capacitors, they were asked to analyze how a toy flashlight worked. When I taught the traditional curriculum, I felt that the time constraints of the state physics curriculum did not allow time for these types of activities.

4. Clusters that Did not Differ

There was no significant difference in the coherence, math link, and effort clusters between the two groups. The Coherence cluster is meant to determine whether students view science as a collection of facts or a single coherent system. In the CPU course, great emphasis was put on explaining and uniting observations with a few consensus ideas, which would imply greater coherence. However, the MPEX survey items included in the coherence cluster were based on the quantitative nature of physics, asking about “calculations” and “derivations and proofs” which did not correspond with their physics experience. In the CPU course there was no derivation of equations and just a few problems using calculations. Given a physical situation, students were expected to be able to make a prediction about what would happen and explain their predictions using the ideas developed in class. Phrases such as “my calculation” and “proofs of

equations” had few points of reference in the CPU class.

Because of the non-quantitative nature of the CPU course, the Math Link cluster is not a good lens for viewing this pedagogy. The CPU students rarely used mathematical modeling to either represent information about physical phenomena (the expert stance) or to just calculate numbers (the novice stance).

The Effort cluster is meant to measure the willingness of students to put forth effort to make sense of topics in physics. One would expect that the CPU students would show great strength in this area. In fact, my students talked often about the frustration involved in the course. For example, one student wrote:

When the answer finally came to me, I was so excited. I had come to the end of a very difficult process only to find out that the next day, my frustrations and confusions will reappear with a new lesson. Knowing that these activities are all steps to finding out the answer to my problems will help me to keep eager and open-minded the next time I start to get frustrated.”

The questions that are meant to uncover effort, though, use phrases such as “go over class notes,” go over “derivations and proofs,” and “read the text in detail and work through examples,” none of which were part of the CPU experience. These questions did not reveal the effort the CPU students were exerting in predicting, testing, explaining their thinking, and trying to understand the thinking of others.

Conclusions

The MPEX survey results suggest that high school student attitudes and expectations really do differ based on the pedagogy and curriculum used in the classroom. The significant differences between my two sets of students revealed that the students who

were taught using CPU responded more favorably in the clusters for Independence, Concepts, and Reality Link. The students that were allowed to argue ideas based on the observed evidence, forced to come to a consensus on the ideas used to explain the observations, and encouraged to reflect on their own learning became more independent learners, became more aware of the power of concepts in understanding physics, and connected what they learned in class to the reality outside of class.

Some limitations must be considered when interpreting the results of this study. I have argued that changes in the students' responses to the MPEX survey were the result of the shift to the CPU curriculum. One alternative hypothesis that could explain the results of the MPEX surveys is a change in teacher attitude. Perhaps I brought a different level of enthusiasm or engagement to the CPU curriculum than I did in the traditional course. Another alternative hypothesis concerns the number of topics taught during the course. During the year of CPU teaching, I taught about half as many topics compared to the traditional class the year before. Could the slower pace account for the difference in student expectations? One could imagine a traditional course that covers half the topics in the traditional state curriculum. These students might spend time doing more difficult quantitative problems, or doing long-term projects. I would argue that if the students are not actively involved in developing the concepts, it is not likely that their scores on the concept cluster would rise as significantly. A project-orientated class might be expected to raise students' score in the reality-link cluster, but not in the concepts or independence clusters. These predictions could all be examined in future research.

Finally, this investigation reveals the limitations of the MPEX survey in uncovering differences brought about through the CPU

instruction. In further studies examining nontraditional curricula such as CPU, items meant to reveal the coherence, math link, and effort may need to be re-designed to include phrasing that would be more effective in uncovering differences.

References

- Arons, A. B. (1990). *A guide to introductory physics teaching*. New York City: Wiley.
- Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics*, 50, 66.
- Goldberg, F., & Bendall, S. (1998). *Constructing Physics Understanding in a Computer Enhanced Learning Environment*, from cpuproject.sdsu.edu
- Goldberg, F., & Bendall, S. (1995). Making the invisible visible: A teaching/learning environment that builds on a new view of the physics learner. *American Journal of Physics*, 63(11).
- Goldberg, F., & McDermott, L. C. (1987). An investigation of student understanding of the real image formed by a converging lens or concave mirror. *American Journal of Physics*, 55, 108.
- Hammer, D. (1994). Epistemological beliefs in introductory physics. *Cognition and Instruction*, 12, 151-183.
- Hestenes, D. (1996). *Modeling method for physics teachers*. Paper presented at the Proceedings of the international conference on undergraduate physics education, College Park, MD.
- McDermott, L. C. (1993). Guest Comment: How we teach and how students learn -- A mismatch? *American Journal of Physics*, 61, 295-298.
- New York State Board of Regents (1988). *Regents Physics Curriculum*: New York State Education Department.
- Osborne, R. J., & Freyberg, P. S. (1985). *Learning in Science*. Birkenhead Auckland: Heinemann Education.

- Posner, G. J., Strick, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66(2), 211-227.
- Redish, E. F. (1996). *New models of physics instruction based on physics education research*. Paper presented at the Proceedings of the Deutschen Physikalischen Gesellschaft.
- Redish, E. F., Saul, J. M., & Steinberg, R. N. (1998). Student expectations in introductory physics. *American Journal of Physics*, 66(3), 212-224.
- Redish, E. F., Steinberg, R. N., & Saul, J. M. (1996). *The Distribution and Change of Student Expectations in Introductory Physics*. Paper presented at the International Conference on Undergraduate Physics Education (ICUPE), College Park, Maryland.
- Schommer, M. (1993). Epistemological Development and Academic Performance Among Secondary Students. *Journal of Educational Psychology*, 85(3), 406-411.