The Impact of Modeling Instruction within the Inverted Curriculum on Student Achievement in Science

Jennifer Dye
Pope John Paul II High School

Tom Cheatham
Middle Tennessee State University

Ginger Holmes Rowell
Middle Tennessee State University

Angela T. Barlow
Middle Tennessee State University

Robert Carlton
Middle Tennessee State University

Abstract

Achievement in science is a national concern, and graduating students who are college and career ready is a national imperative. In this study, we examine student achievement on the ACT science test as a high school transitioned from teaching biology, chemistry and physics with a teacher-centric pedagogy (the traditional instructional context) to the inverted curriculum (teaching physics, chemistry, then biology) to using the modeling instruction pedagogy (student-centric, inquiry-based) within the inverted curriculum. Data for students graduating over an eight-year period under these three instructional contexts were analyzed to determine if there were potential relationships between student achievement and the instructional context. This is an *in situ* study of the results of making an intentional change in the instructional context used to teach science. On average, ACT science scores and the percentage of students graduating college ready were higher for students learning in the two non-traditional instructional contexts.

Correspondence concerning this manuscript should be addressed to: Tom Cheatham, Box 82, Middle Tennessee State University, Murfreesboro, TN 37132, tom.cheatham@mtsu.edu.

Key words: modeling instruction, inverted curriculum

Introduction

Despite the recognized need for improvement in science education (ACT, 2009; Gonzales, et al., 2008; Machi, 2009; NRC, 2011), U.S. students continue to enter college underprepared in science (ACT, 2008, 2012). Of the 1.67 million ACT-tested graduates in 2012, only 31% (21% in the state) scored at least 24 on the science reasoning portion of the ACT, an indicator of their college readiness in science (ACT, 2012). The conclusion is that 69% of students nationally enter college with less than a 75% chance of succeeding (earning a grade of “C” or better) in freshman biology. Other college ready benchmarks are met at a higher rate—mathematics 46% and English 67%. This lack of preparedness in science results in too few students studying science and an overall failure to meet the needs of today’s workforce (Machi, 2009).

“The most direct route to improving mathematics and science achievement for all students is better mathematics and science teaching” (National Commission on Mathematics and Science Teaching for the 21st Century, 2000, p. 7). Improved science teaching hinges on significant changes in both instructional practices and the science curriculum (Machi, 2009; Pratt, 2012). Among the myriad of approaches that aim to improve science teaching, one strategy that has shown promise involves a teaching methodology known as modeling instruction (Wells, Hestenes, & Swackhamer, 1995). Another is curriculum-related and invokes a reversal of the historical order in which science courses are taken (inverted curriculum) with physics taken first and biology following chemistry.

Modeling instruction is a research-based instructional methodology/pedagogy that immerses science students in the practice of scientific processes and discourse that leads to conceptual understanding (Jackson, Dukerich & Hestenes, 2008). Originally designed for teaching high school physics, modeling instruction follows a guided-inquiry approach to learning (Banchi and Bell, 2008) where the teacher demonstrates a phenomenon or poses a research question. Students in each small group then collaboratively discuss, develop, debate and test a model to describe the phenomenon or answer the question. They may later apply the tested model to a new situation as a check for broader applicability—practicing science as a scientist. The term modeling instruction will be used, in this manuscript, to refer to an overall instructional methodology/pedagogy in which the teacher sets up the research question or problem, observes students’ processing of issues, asks questions to refine the inquiry, and attends to the student dialog as they construct their understanding and present their findings to the class. We use the term modeling to refer more generally to the learning environment and the process by which students work through the methodology, leading to conceptual understanding. Students work to develop a testable model by engaging in collaborative investigation and a give-and-take defense of their hypotheses (Wells et al., 1995), activities which have been found to support learning (Bransford, Brown, & Cocking, 2000). Additional information on this model development will be provided in the Background Literature section. Following the success of modeling instruction in physics (Brewe, Kramer, & O’Brien, 2008; Hestenes, 2000; Malone, 2008; Wells et al., 1995), similar instructional methodologies have been developed and deployed in chemistry (Barker 2012; Dugger, Principe, & Rudolph, 2012; Farrell, Moog, & Spencer, 1999; Lewis & Lewis, 2005) and in biology (Dye, Nolan & Rudolph, 2012; McDaniel, Lister, Hana, & Roy, 2007).

Whereas modeling instruction addresses the improvement of science education at the course level, the inverted curriculum addresses this improvement holistically, i.e., at the curriculum level. Rather than the biology–chemistry–physics sequence followed in traditional high school science curricula, the inverted curriculum follows a physics–chemistry–biology sequence. The “physics-first” approach rests on logic and the recognition that understanding fundamental biology mechanisms depends critically on a student having previously mastered physical and chemical concepts (Lederman 2001; NRC, 2001). Researchers have demonstrated the positive impact of the inverted curriculum on science achievement (Bess & Bybee, 2004; Lederman, 1995, 2001; Liang, Fulmer, Majerich, Clevenstine, & Howanski, 2012; Pasero, 2003; Taylor et al., 2005).

Purpose of Study

The purpose of this study was to examine the possible relationship between high school students' science achievement, as measured by ACT science subscores, and modeling instruction implemented within the inverted curriculum. Although modeling instruction and the inverted curriculum have been studied individually, studies of the two strategies combined are rare. To this end, the following research questions were posed.

Question 1: **Science Achievement:** What are the effects on *science achievement*, as measured by ACT science subscores, of shifts from a traditional science curriculum sequence that is teacher-centric, to an inverted curriculum sequence taught traditionally, and then to an inverted curriculum that also employs modeling instruction?

Question 2: **College Readiness:** What are the effects on *college readiness* in science, as measured by ACT science subscores, of shifts from a traditional science curriculum sequence that is teacher-centric, to an inverted curriculum sequence taught traditionally, and then to an inverted curriculum that also employs modeling instruction?

Significance of Study

Given the need to improve student achievement in science as well as the college and career readiness of high school students (Machi, 2009), the significance of this work lies in identifying the potential relationship between modeling instruction within the inverted curriculum and science achievement in the high school setting.

Background Literature

In this section, we present background literature that has served to inform our study. First, an overview of literature related to how people learn, known as *learning science*, will be provided that includes discussion of the traditionally taught (teacher-centric lecture and passive student learning) science classes and the alternative (active-learning) methodologies. Next, we present a description of modeling instruction, including the available research that supports its effectiveness. Finally, an overview of the inverted curriculum is provided along with its related literature.

Learning Science

Multidisciplinary research of the 1990s in the field of learning science produced a consensus that education for the knowledge economy must: include participatory or collaborative learning that is built upon prior knowledge, acknowledge and address misconceptions, and make use of learning environments more suited for reasoning about real-world problems (Bransford et al., 2000). In these learning environments, the effective teacher must be able to guide students in authentic practice that mirrors that of professionals in the field (Edelson & Reiser, 2006; Krajcik & Blumenfeld, 2006), i.e., learning by doing.

Traditionally taught college physics courses have often failed to include this “learning by doing” aspect. As a result, these courses have had little impact upon student understanding, with students leaving the course with their misconceptions unchanged (Hake, 1987, 1998; Halloun, & Hestenes, 1985a, 1985b; McDermott, 1984; van Heuvelen, 1991). The same is true in the other science disciplines. In the areas of physics, chemistry, and biology, educational research has confirmed that student attitudes, beliefs, and assumptions concerning course expectations can have significant consequences for learning (Barbera, Adams, Wieman, & Perkins, 2008; Perkins, Adams, Pollock, Finkelstein, & Wieman, 2005; Semsar, Knight, Birol, & Smith, 2011). In the move from passive to active learning, addressing and reordering those cognitive expectations can play a significant role in enhancing conceptual understanding. Additionally, as students make sense of science, they will develop beliefs that incline them toward its pursuit.

In recognition of this, at least a dozen constructivist-driven methodologies have been developed for physics (Hestenes, 1987; Laws, 1991; Mazur, 1997; McDermott & the Physics Education Group at the University of Washington, 1996; McDermott & Redish, 1999; van Huevelen & Etkina, 2005), including modeling instruction. In turn, a number of similar notable constructivist approaches have been developed for chemistry and biology (Gosser, Kampmeier & Varma-Nelson, 2010; Lord, 1998; Spencer, 1999). The formats differ but all are student-centered, inquiry-based, and consistent with how people learn. Conceptual gains, for a broad range of student demographics, have been demonstrated via concept inventories developed for each discipline (D’Avanzo, 2008; Hestenes, Wells, & Swackhamer, 1992; Mulford & Robinson, 2002).

Modeling Instruction

Modeling instruction is an inquiry-based pedagogy that has proven effective in improving learning in high school physics (Hake, 1998, 2009). Studies have shown that student performance on the physics Force Concept Inventory improves with the number of years of teacher training and experience using modeling instruction (Wells et al., 1995). In this research, physics has typically been taught in the junior or senior year, following courses in biology and chemistry and multiple high school mathematics classes.

High school chemistry and biology teachers have adopted modeling instruction more slowly. Yet, modeling has proven effective in teaching both chemistry (Barker, 2012; Dugger et al., 2012; Farrell et al., 1999; Lewis & Lewis, 2005) and biology (Dye et al., 2012; McDaniel et al., 2007) classes. Modeling has been successful with diverse student populations—from inner city, to magnet, to private schools—because this pedagogy is rooted in the way students learn and because the practice of all science disciplines is inquiry-based. In modeling instruction, lectures and traditional content units are replaced with modeling cycles in which small groups of students work collaboratively to collect data and construct a conceptual model to explain observations of a real-world system.

Jackson et al. (2008) provided an overview of the modeling process, which features two stages: development and deployment. During the development stage, groups of students engage in model analysis using whiteboards with emphasis on Socratic dialog, responding to challenges, and employing multiple representations (diagrams, graphs or equations). The teacher then guides their development of a generalizable model. During the deployment stage, students use the model they have developed to predict outcomes for new initial conditions or constraints. The modeling cycle concludes when a representative student from each group explains and defends their model of the real-world system to the class, again using whiteboards. The teacher is responsible for facilitating the ongoing Socratic dialog, challenging misconceptions, defining the real-world problem, guiding model development and deployment, and assessing student understanding.

Inverted Curriculum

The inverted curriculum describes a sequence reversal for the core science offerings in a high school curriculum, from biology-chemistry-physics to physics-chemistry-biology. This physics-first approach allows for building from the simple to the complex and replaces quantized, unconnected knowledge with an integrated learning continuum. Such an approach is logical and promotes deeper, richer understanding (Lederman 2001; NRC, 2001).

In physics, conceptual groundwork is laid in the concepts of matter, motion, forces, energy, and waves—all organized around a small set of basic models in ways that guide students to learn by inquiry. In chemistry, an explicit particle model is constructed to describe matter, and the role of energy in both physical and chemical change is a thread throughout the course. The curriculum includes matter, energy and states, moles, stoichiometry, temperature, and equilibrium. In biology, the models from physics and chemistry are applied to molecular interactions at the cellular level, including their role in cell structure, heredity, and energy. Like modeling instruction, the inverted curriculum has succeeded in improving science achievement (Glasser, 2012; Bess & Bybee, 2004; Lederman, 1995, 2001; Liang et al., 2012; Pasero, 2003; Taylor et al., 2005).

In summary, the call of the National Academy of Sciences, in the *Bio2010* report (NRC, 2003), for an integration of physics and chemistry in biology teaching is realizable through systemic transformation of the science curricula and the integration of these disciplines in a coherent learning sequence with explicit conceptual links across the courses. Modeling instruction within the inverted curriculum is an embodiment of this approach to learning with understanding. Although these two strategies have been studied separately, previous research has not examined the impact of the two in conjunction, which is the goal of our research.

Methodology and Results

Research Context

Located in a large, southeastern city, Catholic High School[1] (CHS) opened in 2002 and enrolled approximately 600 students in grades 9 through 12 (60% Catholic, 14% students of color, from 10 different counties and 50 different feeder schools). CHS features a classical, liberal arts curriculum, requiring four credits each of mathematics, English, theology, and history, three credits each of science, foreign language and fine arts, and one credit in a Christian Service Internship. As represented in Table 1, CHS students are quite diverse in terms of

[1] *The name of the high school has been altered in the interest of anonymity.*

academic ability, as measured by the ACT PLAN test (taken near the beginning of the 9th grade) and the ACT test (taken in the 11th grade).

Table 1. CHS PLAN and ACT Score Statistics for Students Graduating 2006-2013

Category	M	SD	MIN	MAX
PLAN Science	20.0	3.2	11	32
PLAN Composite	19.8	3.2	11	31
ACT Science	23.5	4.1	12	36
ACT Composite	23.8	4.2	11	35

N = 808 CHS students taking the ACT in 11th grade in the years 2005 through 2012 (graduating in 2006 – 2013) who also took the PLAN test in 9th grade. Only students who enrolled at CHS as freshman and graduated are included.

The first cohort to receive four years of instruction at CHS graduated in 2006. Before the fall of 2006, CHS's science program was traditional in that they did not utilize either the inverted curriculum or modeling instruction—science classes were ordered in the traditional biology, chemistry and physics sequence and teaching was a traditional teacher-centric, passive learner model. In fall 2006, CHS began phasing in the inverted curriculum, starting 9th grade students with a conceptual physics class, referred to within the state as Physical World Concepts (PWC), followed by chemistry in 10th grade and biology in 11th grade

Additional curriculum changes occurred in the 2009-2010 school year. In summer 2009, CHS science teachers received training in modeling instruction, for their area of certification, and began implementing the modeling instruction pedagogy within the inverted curriculum. Over the course of two summers, teachers attended two, two-week workshops conducted by expert modelers using the curriculum developed through Arizona State University. Teachers were immersed in the methodology—taking on the roles of student and teacher while conducting paradigm labs (i.e., labs that provide the framework for the scientific understanding), and engaging in discourse of those ideas. The teachers from CHS also met weekly to discuss the methodology and ensure fidelity in instruction. Pairs of teachers in each subject (physics, chemistry, and biology) worked collaboratively, often meeting daily but minimally for 70 minutes each week, to ensure courses were being taught using the modeling strategies and to provide support when uncertain about curriculum or methodology. Teachers engaged in refinement of strategies during their second summer of modeling training. The science department teachers also met weekly to discuss progress of students using the modeling strategies and conceptual threads between the courses.

To document and support fidelity of implementation, teachers were observed three times each year, for the length of the study, in both scheduled and unannounced observations by the department chair and an administrator. The department chair had received modeling training and the school administrator was familiar with the methodology, but had not been through the same training as the teachers. Formal feedback using the state-prescribed evaluation method was provided in written form and meetings were held with the individual teacher after each observation.

In fall 2009, CHS teachers implemented modeling instruction in chemistry, followed by biology and PWC starting fall 2010. Figure 1 pictures the phasing in of the inverted curriculum and modeling instruction at CHS. The rows show the order in which each student cohort took their high school science courses. The first column indicates the cohort number and the second column represents the year in which the students graduated. The top row is the academic year. For example, the students in our data set that graduated in 2010 were freshmen at CHS in the academic year 2006-07 and took PWC during their freshman year (06-07), chemistry in their sophomore year (07-08), biology during their junior year (08-09) and were seniors in the academic year (09-10), graduating in 2010. CHS accepted its first students in 2002-2003.

From this point forward, we will identify the students by cohorts representing the year they graduated, as shown in Figure 1, and the corresponding courses taught, by year, at CHS. Cohorts 1-4 used the traditional instructional context (traditional science sequence is biology, chemistry and physics with no use of modeling instruction), Cohorts 5 and 6 used the inverted curriculum alone instructional context (science sequence is physics, chemistry and biology with no use of modeling instruction), and Cohorts 7 and 8 used modeling instruction in chemistry and biology within the inverted curriculum instructional context. Cohort 9 will be the first class at CHS to

		Academic Year											
Cohort Number	**Graduation Year**	**CHS Opened 02-03**	**03-04**	**04-05**	**05-06**	**06-07**	**07-08**	**08-09**	**09-10**	**10-11**	**11-12**	**12-13**	**13-14**
Cohort 1	**2006**	B	C	P	Sr.								
Cohort 2	**2007**		B	C	P	Sr.							
Cohort 3	**2008**			B	C	P	Sr.						
Cohort 4	**2009**				B	C	P	Sr.					
Cohort 5	**2010**					PWC	C	B	Sr.				
Cohort 6	**2011**						PWC	C	B	Sr.			
Cohort 7	**2012**							PWC	C	B	Sr.		
Cohort 8	**2013**								PWC	C	B	Sr.	
Cohort 9	**2014**									PWC	C	B	Sr.

Figure 1. CHS Science Curriculum Sequence for Graduating Classes 2006-2013

Legend: B = biology, C = chemistry, P = physics, Sr. = Senior, PWC = physical world concepts

Traditional Curriculum | Inverted Curriculum | Modeling instruction within the inverted curriculum

experience the full treatment of both the inverted curriculum and modeling instruction. That is, they will have taken physics (9th grade), chemistry (10th grade) and biology (11th grade), all taught using modeling instruction. ACT scores are not yet available for Cohort 9 students.

Baseline Data

Both research questions for this study focus on the use of modeling instruction within the inverted curriculum. However, because this instructional context was not implemented all at once, the data will be presented in terms of a two-step treatment process. Treatment 1 is the inverted curriculum (alone), and Treatment 2 is the modeling instruction in chemistry and biology within the inverted curriculum. The participants for each of these groups are summarized in Table 2 by graduation year and cohort number. The corresponding sample sizes are also provided. The analysis that follows is a retrospective examination of the results of making an intentional change in the instructional context used to teach science at CHS.

Table 2. Treatment Group Summary by Cohorts

	Graduation Year	Cohorts	N
Baseline Group: Traditional context	2006-2009	1, 2, 3, 4	402
Treatment 1: Inverted curriculum context	2010, 2011	5, 6	214
Treatment 2: Modeling instruction within inverted curriculum context	2012, 2013	7, 8	192

This study has two types of baseline measurements. First, the students receiving the traditional instruction (teaching science in the order biology, chemistry and physics using a teacher-centric pedagogy) serve as a baseline, for comparison purposes, of the outcome measure for the two curriculum treatments. This traditional curriculum provides a baseline for what would have been expected to occur if there had been no treatments, that is, had the instructional context remained biology, chemistry, and physics with a teacher-centric pedagogy. Additionally, for this study each student has their own baseline scores provided by the PLAN science score. The primary outcome measure is the ACT science subscore.

Each of the 808 CHS students in the study completed the PLAN test which provided a measure of the students' preparation level when they entered CHS as freshmen. CHS administers the PLAN test at the beginning of October in students' freshman year. Table 3 disaggregates the overall average PLAN scores shown in Table 1 by cohort[2].

Table 3. Average CHS PLAN Scores by Cohort (Graduation Year 2006-2013*)

	Cohort							
	1	2	3	4	5	6	7	8
Sample Size (N)	101	83	101	117	104	110	80	112
PLAN Science	21.1	19.2	20.5	20.2	19.8	19.3	20.3	19.7
PLAN Composite	21.3	19.5	19.6	19.9	19.7	18.8	19.9	19.8

**Same 808 CHS students from Table 1*

The preparation in science of incoming CHS freshmen averaged 20 points as measured by the science subscore on the PLAN test. Since CHS administers the PLAN test in the 9th grade, there is not an exact state or national comparison for the PLAN scores, which are scored on a scale of 1 to 32. The closest reported national averages on the ACT PLAN website (ACT, 2010) are the averages for the students taking the PLAN test in the fall of their 10th grade year, which have a mean of 17.8 (*SD* = 3.9) for the science subscore and a composite mean of 17.2 (*SD* = 3.9) as shown in Table 4. By extrapolating (see note below Table 4) back to the fall of the 9th grade year, the estimated mean would be 17.4 for science and 16.7 for the composite. CHS students thus score, on average, 2.6 points higher than these estimated national averages on the PLAN science subscore and 3.0 points higher on the PLAN composite (or 2.2 and 2.6 points higher than the fall 10th grade scores for science and composite, respectively).

[2] For the purposes of this work, any student missing either a PLAN score or an ACT score was omitted from the study. Only students who started ninth grade and completed twelfth grade at CHS are included in the study.

Table 4. Comparison of CHS and National PLAN Scores

	CHS Scores Cohort 1 - 8		National Scores 10^{th} grade		Extrapolated* Scores 9^{th} grade
Group	M	SD	M	SD	M
PLAN Science	20.0	3.2	17.8	3.9	17.4
PLAN Composite	19.8	3.2	17.2	3.9	16.7

*ACT data shows a 0.2 change per semester for the science subscore and approximately 0.25 change per semester for the composite score when the PLAN test is given in consecutive semesters (ACT 2010). Extrapolated 9^{th} grade PLAN scores are based on this data.

Outcome Measures

Two professors from Iowa State University started the American College Testing (ACT) service over 50 years ago to provide an independent testing service for secondary school students. In 1996, this private, not-for-profit company changed its name to ACT. The components of the ACT are English, reading (social science), math, science, and a composite. The maximum score on any component of the ACT is 36. The ACT has a set of benchmarks based on longitudinal data that, on average, project for students a 75% chance of earning a “C or better” in an appropriate corresponding first college course. These benchmarks are called college ready benchmarks. Twenty-four (24) is the ACT college ready benchmark in science. If 21% of ACT test takers (in the state) meet the college ready benchmark in science, then 79% of college freshman are not prepared to succeed in their college freshman science course. State-wide, the other college ready benchmarks are met at a higher rate than science—46% meet the math benchmark, 52% meet the reading benchmark, and 67% meet the English benchmark , N=68,095 in 2012. ACT provides a suite of exams that track student progress toward career and college readiness—the EXPLORE exam is usually given in the 8^{th} grade, the PLAN exam is usually given in the 10^{th} grade and the ACT exam is given in the 11^{th} or 12^{th} grade. The maximum possible score on any component of the EXPLORE is 25 and PLAN is 32. For the EXPLORE and PLAN, college readiness benchmarks are projections of student achievement when completing the ACT exam in 11^{th} or 12^{th} grade. When this suite of exams is given on the timeline 8^{th}, 10^{th}, and 11^{th} grade respectively, the district has an opportunity to resolve deficiencies before the next test or graduation. The PLAN college ready benchmark in science is 21.

Although CHS students typically take the ACT multiple times, we utilized students’ ACT scores from the spring administration of the test during the junior year to be consistent with public school districts within the state. Table 5 features the ACT scores for the same 808 CHS students whose PLAN scores appeared in Tables 1, 3, and 4. Any student who did not start 9^{th} grade at CHS or left CHS before graduation was omitted from the study. The national data include the total test takers for each year. This could account for the national statistics shown in Table 5 (IES, 2013) having a higher standard deviation than that of the CHS students. The average ACT science scores for the CHS students are higher than the national average for all years 2006 - 2012.

Table 5. Comparison of CHS and National ACT Scores

	CHS Scores Cohort 1 - 8		National Scores* 2005 – 2012	
	M	SD	M	SD
ACT Science	23.5	4.1	20.9	4.9
ACT Composite	23.8	4.2	21.1	5.1

CHS: N = 808; CHS ACT years 2005-2012. For national scores, N=11.2 million.
**Calculated as a simple average of data provided in* http://nces.ed.gov/programs/digest/d12/tables/dt12_175.asp

Results for Research Question 1: Science Achievement

Having studied the differences in academic achievement in science among the entering freshman groups, ACT science scores were examined by group—traditional instructional context, inverted curriculum alone, and modeling instruction within the inverted curriculum. Table 6 summarizes the average PLAN Science scores, ACT Science Scores, and gains made for those same 808 CHS students (described in Tables 1, 3, and 4) based on the instructional context they experienced.

Table 6. Science Mean Scores by Treatment Group and Gains from PLAN to ACT

	PLAN Science			ACT Science			Gains
Group	N	M	SD	N	M	SD	$M_{ACT} - M_{PLAN}$
Traditional (baseline)	402	20.3	3.38	402	23.1	4.03	2.8
Treatment 1	214	19.6	2.83	214	23.7	4.03	4.1
Treatment 2	192	20.0	3.01	192	24.3	4.28	4.3

The mean PLAN science subscores for these students demonstrated similar trends for the three instructional contexts. From a baseline perspective, the students studying in the traditional instructional context were *not* less well prepared for studying science as compared to the two treatment groups. Students in Treatment 1 started out with a slightly lower mean PLAN science subscore (19.6) than the traditional (20.3) or Treatment 2 (20.0). Table 6 compares the mean ACT science subscores for the three instructional contexts for the 808 CHS students. On average, the traditional instructional context group scored the lowest (M=23.1), followed by the students with the inverted curriculum alone (M=23.7), and finally the students who experienced modeling instruction within the inverted curriculum scored the highest (M=24.3). A score of 24.3 on the ACT science is of particular importance since the ACT college readiness benchmark is a science subscore of 24. Students from the traditional instructional context gained only 2.8 points over their 9th grade PLAN science subscore. Students in Treatment 1 and Treatment 2 gained more than 4 points, on average, from the PLAN science subscore to the ACT science subscore (M_{diff} = 4.1and 4.3, respectively).

Comparing the groups in pairs, Cohen's *d* can be calculated as the difference in the sample means divided by the pooled standard deviation for different sample sizes (Cohen, 1988). A Cohen's *d* value of 0.2 was considered a small effect, 0.5 a medium effect, and 0.8 a large effect. Table 7 shows the largest difference (1.2 points) in average ACT subscores for the [Treatment 2 – Traditional] pair (students who experienced modeling instruction within the inverted curriculum context compared to the students who experienced the traditional instructional context), yielding an effect size of 0.29. Other differences between groups are approximately half as much. Cohen would consider that an effect of this size is one that could likely happen under normal circumstances.

Table 7. Effect Size to Compare Difference in Sample Means

Group	Difference in Means	Pooled *SD*	Cohen's *d*
Treatment 2* – Traditional (baseline)	1.2	4.11	0.29
Treatment 1* – Traditional (baseline)	0.6	4.03	0.15
Treatment 2 – Treatment 1	0.6	4.15	0.14

**Treatment 1 = inverted curriculum alone, Treatment 2 = modeling instruction within the inverted curriculum*

Results for Research Question 2: College Readiness

Many national leaders and organizations have set a goal for every high school student to be college and career ready upon graduation. Nationally, in the four areas tested by ACT (English, mathematics, reading and science), only 25% of all U.S. students tested meet all four college readiness benchmarks (ACT, 2012). In our state, only 16% of high school graduates meet college readiness benchmarks in all four areas. ACT notes that, based on their data, the most important factor in determining college readiness of a high school graduate is the level of college readiness (measured by the EXPLORE test given in the 8^{th} grade) when they enter high school (ACT, 2009).

EXPLORE test scores are not available for the CHS students since that test is usually taken in the 8^{th} grade and CHS includes only 9^{th} through 12^{th} grades. The PLAN test score matched, by student, with their corresponding ACT score was used to examine the CHS students' progress toward college readiness in science during high school at CHS. One measure of success was the movement of students who were *not* considered college ready in science when they completed the PLAN test (science subscore is less than 21) to being college ready in science when they completed the ACT (science subscore is 24 or higher).

The percentage of CHS students in each treatment group who met the college ready benchmark in science on the PLAN is less than the percentage of the baseline group who met the benchmark. As pointed out earlier, students in the treatment groups are less well prepared in science as they enter 9^{th} grade. The percentage of students who met the benchmark in science on the ACT is greater for both treatment groups (48.1 and 56.8 for Treatment 1 and 2, respectively) than in the traditional instructional context (45.3%). Figure 2 shows a steady growth in the difference between the percent of CHS students testing college ready in science on the PLAN and those testing college ready in science on the ACT (2%, 18%, and 21% for the Traditional baseline group, Treatment 1, and Treatment 2, respectively).

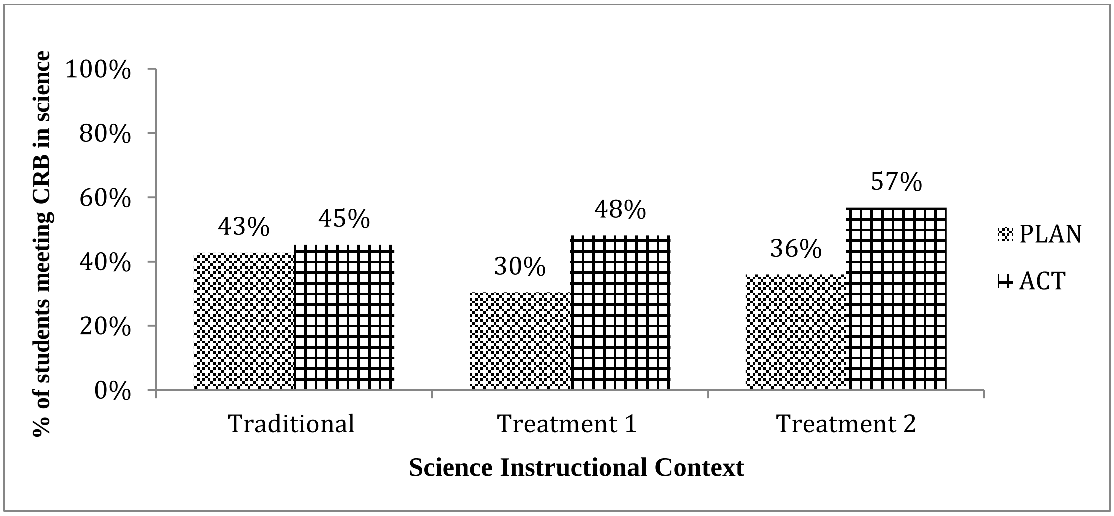

Figure 2. Proportion of Students who Met PLAN and ACT College Readiness Benchmark (CRB) of 21 and 24 in Science, Respectively, by Intervention Group

Although ACT does not provide a national comparison to this exact analysis (PLAN in 9th grade to ACT in 11th grade), they do have an assessment of student change from the 8th grade EXPLORE test to the 11th grade ACT test and from the 10th grade PLAN test to the 11th grade ACT test. ACT (2009) describes a scale for which expected growth ranges in science from EXPLORE to ACT are from 3 to 4 points based, not surprisingly, on how "close" to college ready the students were on the earlier test. ACT uses the phrase "off-target" to indicate that the student's subscore is more than 2 points below the corresponding subscore college readiness benchmark. "Close" means the student is below the benchmark by no more than two (2) points. Of the CHS students who experienced modeling instruction within the inverted curriculum instructional context, 59% of the students who were not college ready in science when they completed the PLAN test moved up one or more categories (from "off-target" to "close to college ready," from "close to college ready" to "college ready," or from "off-target" to "college ready"). ACT data from a sample of 150,000 students (ACT, 2009) show that students who do not test college ready at the time of the EXPLORE (8th grade) or PLAN (10th grade) are not likely to test college ready on the ACT in 11th grade. ACT (2007) data shows that some gain in college readiness in science occurs between 8th and 10th grade (EXPLORE and PLAN), but little gain occurs between 10th and 12th grade. The traditional instructional context for CHS conforms to these expectations (little gain), but this is not true for either of the treatment groups.

Since CHS students do not complete the EXPLORE test in 8th grade and complete the PLAN test in 9th grade instead of 10th grade, comparing PLAN scores to ACT scores is the closest comparison to ACT's (2009) college readiness growth description. Examining college readiness for each instructional context reveals large differences. For the 402 students in the baseline group, 43% were considered college ready in science on the PLAN. When those same students completed the ACT, 45% were considered college ready in science (a change of +2%). Thus, for CHS students, if the same traditional instructional context had been continued, it would be reasonable to expect an approximate 2.5% increase (Table 8) in the percent of students who were college ready in science on the ACT as compared to those who were college ready in science on the PLAN. In comparison, Table 8 shows that, for the two treatment groups, the increase in college readiness in science from the PLAN to the ACT is approximately 18% and 21% for Treatment 1 and Treatment 2, respectively.

Table 8. Students Testing College Ready in Science on PLAN and ACT

Treatment/Context	N*	PLAN-Science	ACT-Science	Difference (ACT - PLAN)
Traditional	402	42.8%	45.3%	2.5%
Treatment 1	214	30.4%	48.1%	17.8%
Treatment 2	192	35.9%	56.8%	20.8%

**Same 808 CHS students from Table 1.*

Table 9 examines incremental steps for students, regarding their college readiness status. For students in the baseline group who were off-target (more than two points below the college ready benchmark in science on the PLAN), only 8% were college ready in science when they completed the ACT. More than twice that percentage of students in the two treatment groups moved from being off-target in science on the PLAN to college ready on the ACT (18% and 21% for Treatment 1 and 2, respectively). As expected, the percent of students in all three groups who were "close to college ready" in science on the PLAN and moved to college ready on the ACT was higher than for those who were "off-target." Moreover, the improvement in college readiness is notably better for the two treatment groups. In Treatment 2 over 50% of the students who were close to college ready in science on the PLAN moved to college ready in science on the ACT.

Table 9. Number and Proportion of Students Achieving PLAN and ACT College Readiness Benchmark Scores (CRB) in Science by Treatment Group

		PLAN			PLAN to ACT				
Group	N	Off n	Close n	CR n	Off to Close n	Off to CR n (%)	Close to CR n (%)	CR to CR n (%)	CR to not CR n (%)
Traditional	402	116	114	172	27	9 (8)	38 (33)	135 (78)	37 (22)
Treatment 1	214	83	66	65	37	15 (18)	30 (46)	58 (89)	7 (11)
Treatment 2	192	52	71	69	25	11 (21)	37 (52)	61 (88)	8 (12)

CR = college ready in science (ACT science score >= 24); Off means off-target (more than 2 points below the CRB score; for PLAN, < 19), Close means below the CRB by 2 points or less—on PLAN, 19 ≤ score < 21, on ACT, 22 ≤ score < 24. In Table 8, "Off" applies only to PLAN; "close" and "CR" apply to both tests. CR alone applies to PLAN.

The last column of Table 9 shows the percent of students who were predicted by the PLAN to be college ready in science but who did not test college ready in science on the ACT. For the baseline group, 22% of the students who were on-target to be college ready in science at the time of the PLAN test did not test college ready in science on the ACT. This percentage decreases to approximately half in the two treatment groups. Thus, for the treatment groups, a smaller percentage of PLAN college ready students regress to *not* testing college ready on the ACT: 22% to 11% to 12% for the baseline and two treatment groups, respectively.

Discussion and Conclusion

Recognizing the role that curriculum and instruction play in improving science education (Machi, 2009), this research has examined the potential impact of instructional context (defined to be the sequence of science courses and the pedagogy used in teaching science) on (1) student achievement based on ACT science subscores, and (2) college readiness in science also measured by ACT science subscores.

This *in situ* study examined ACT science subscores collected from eight cohorts of students at CHS. CHS is not an exclusive high school. However, the average CHS freshman may be better prepared in science than the national average (CHS PLAN science score of 20.0 compared to an extrapolated 9th grade norm of 17.4, Table 4). We do not have an exact baseline comparison to state or national data for CHS because CHS administers the PLAN test in the fall of the 9th grade, and ACT recommends the PLAN test for fall of the 10th grade. In our analysis, we used the PLAN science score as a benchmark against which we measured progress. The other benchmark was the science scores from the PLAN and ACT for students in cohorts 1 - 4 who graduated before changes were made to the science sequence or the science pedagogy (traditional instructional context).

Prior research has shown that inverting the curriculum (Glasser, 2012; Liang et al., 2012; Lederman, 1995; Lederman, 2001) and using the modeling instruction pedagogy (Barker, 2012; Brewe et al., 2008; Hestenes, 1987; Hestenes, 2000; Jackson et al., 2008; Liang et al., 2012; Wells et al., 1995) have each proven successful when used independently. This study examined a combination of these two treatments. This retrospective analysis suggests that both treatments had a positive influence on student achievement in science as measured by the ACT science subscores at CHS. In particular, the gains in average science subscores (ACT – PLAN) of the treatment groups were 4.1 and 4.3 points for Treatment 1 and Treatment 2, respectively, and the baseline group only improved 2.8 points, on average (see Table 6). The improvement was modest but important. Despite the lower PLAN science scores of both treatment groups compared to the baseline group, their ACT science score improvements exceeded those of the baseline (traditional) group. Of the three groups (baseline and two treatment groups), treatment group 1 had the lowest entering PLAN science scores. We have no explanation for this anomaly. It is true that the percentage of Treatment 1 students who tested "off-target" in science on the PLAN test was at least 10% larger than the other groups. So, treatment group 1, for whatever reason, had a larger percentage of students who were poorly prepared in science upon entry into high school, making their increase in ACT science scores even more surprising. What growth in science subscore is reasonable from 9th grade to 11th grade? ACT (2009) suggests an expected growth in science subscore from 8th grade to 12th grade, ranging from 3.0 to 3.9, with higher growth for students who are better prepared in 8th grade. From 10th grade PLAN to 12th grade ACT test, the expected growth in science subscores ranges from 0.9 (for students who are off-target, more than 2 points below the PLAN science benchmark of 21) to 2.7 (for students who meet the PLAN benchmark). Either way (EXPLORE in 8th grade or PLAN in 10th grade), CHS students from each of the treatment groups (taken as a whole) exceeded the highest expected ACT gains in science (3.9).

Furthermore, for the modeling instruction within the inverted curriculum context (Treatment 2), the 11th grade ACT science subscore average was 24.3, which exceeded the ACT college readiness benchmark of 24. Thus, on average, Treatment 2 students graduated from high school prepared to succeed in freshman biology in college (college ready in science).

Improvements were also seen in science *college readiness* for the CHS students in the two treatment groups as compared to the teacher-centric baseline group (see Table 8). Before changing the instructional context, roughly the same percentage of students tested college ready in science at graduation (ACT science subscore of at least 24) as were projected to be college ready when they entered high school (PLAN science subscore of at least 21)—only a 2.5% difference from the PLAN projection to the actual ACT readiness result. Treatment 1 (inverting the curriculum alone) demonstrated an increase in readiness of 17.8% and Treatment 2 (modeling instruction within the inverted curriculum) demonstrated an increase of 20.8%, each more than seven times the increase in the baseline group. Although there are not direct comparisons nation-wide for this improvement in science college readiness because of the atypical administration date of CHS's PLAN test, the increase is worthy of further study. ACT data from a sample of 150,000 students (ACT, 2009) demonstrate that students who do not test college ready at the time of the EXPLORE (8th grade) or PLAN (10th grade) are not likely to test college ready on the ACT in 11th or 12th grade. In fact, ACT suggests that for students scoring below the college readiness benchmark on, say, the EXPLORE test, it is unreasonable to expect to make up more than half the difference to the benchmark by the next assessment (PLAN or ACT). For instance, a student with a PLAN science score of 17 (4 points below the PLAN science benchmark of 21) could expect an ACT science score of 22, two points (half) below the science benchmark of 24.

Neither ACT data nor the baseline group statistics predicted the growth in college readiness for students in the treatment groups who tested "off-target" or "close to college ready" in science on the PLAN test. Table 9 shows that 8% of the baseline group who were "off-target" in science on the PLAN, tested college ready in science on the ACT. Comparable numbers for Treatments 1 and 2 are 18% and 21%, respectively. As expected, a higher percentage of students who tested "close" to the science benchmark on the PLAN moved to college ready on the ACT, compared to students who tested off-target. As previously stated, ACT (2007) research showed little growth in the percentage of students testing college ready in science between 10th grade PLAN and 12th grade ACT. Table 9 shows that one-third of the baseline group who tested "close to college ready" in science on the PLAN were college ready when they completed the ACT. For the treatment groups the percentages were 46% and 52%, respectively, essentially improving from a third to a half.

To put the data from Figure 2 (or Table 8) into context, twenty-one percent (21%, N=68095) of students within the state meet the science college readiness benchmark on the 11th grade ACT test (ACT, 2012). From Figure 2, 57% of CHS students from Treatment 2 meet the science college readiness benchmark, up from 45% before any changes in science sequence or pedagogy. For CHS this translates to an additional tenth of their graduating class who graduated college ready in science under Treatment 2. Nationally, only 31% of students completing the ACT meet the college readiness benchmark in science. Comparing the 57% to the projected college readiness of entering freshmen, Figure 2 demonstrates that 21% more students tested college ready in science on the ACT than were projected to be college ready when they completed the PLAN test. This is a fifth of the graduating class.

Since this is an observational study, there could certainly be other variables that also changed during the treatment years at CHS, which affected the improvement in science ACT scores and college readiness. However, the entering students' achievement levels in science did not improve and there were minimal changes in school leadership and classroom teachers. Each new teacher was trained in modeling instruction before starting and was mentored by an experienced modeling teacher. Furthermore, CHS leadership and science teachers could not describe any other change in their school, which they believed could have produced such a positive change in the ACT science scores or science college readiness of their students. Clearly, additional study of how such changes in instructional context can improve college readiness is warranted.

Study Limitations

Having data from only one private high school is a limitation. The school is not exclusive, but science scores of entering freshman were higher than the national average. At CHS, the PLAN test was given in 9^{th} grade instead of 10^{th} grade as recommended by ACT, making state and national comparisons difficult. Data are still being collected in order to examine modeling instruction for all three science courses within the inverted curriculum (physics in 9^{th} grade, chemistry in 10^{th} and biology in 11^{th} grade). This is not a randomized experiment, but rather a retrospective examination of the changes in the instructional context in science of a small private high school over time. Inferences are not intended to be drawn from this study, but rather a description of results for this high school. The study does not allow the separation of potential variables which could influence the improvements in ACT scores. For example, we are not able to adjust for any improvement in teaching due to increased experience within a context or across contexts.

A large scale controlled study is needed to determine if the combination of modeling instruction within the inverted curriculum holds sufficient promise for meeting the demand for improvement in science education in the U.S.

References

ACT. (2007). Rigor at risk: Reaffirming quality in the high school core curriculum. Iowa City, IA: Author.

ACT. (2008). Measuring college readiness: The national graduating class of 2008. Iowa City, IA: Author.

ACT. (2009). How much growth toward college readiness is reasonable to expect in high school? *Issues in College Readiness*. Iowa City, IA: Author.

ACT. (2010). National Norms and Estimated ACT Composite Scores: 2010 National Norms, http://www.act.org/plan/norms/index.html.

ACT. (2012). *2012 ACT national and state scores.* Retrieved October 24, 2012 from http://www.act.org/newsroom/data/2012/benchmarks.html.

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and Children*, 46(2), 26-29,

Barbera, J., Adams, W. K., Wieman, C. E., & Perkins, K. K. (2008). Modifying and validating the Colorado Learning Attitudes about Science Survey for use in chemistry. *Journal of Chemical Education, 85*, 1435–1439.

Barker, J. G. (2012). *Effect of instructional methodologies on student achievement modeling instruction vs. traditional instruction.* Unpublished master's thesis, Louisiana State University.

Bess, K., & Bybee, R. (2004, June). *Systemic reform of secondary school science*. Paper presented at the AAS/UNESCO International Conference of Science & Technology Education: Systemic Approaches to Reform, Paris, France.

Bransford, J., Brown, A., & Cocking, R. (2000) *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press.

Brewe, E., Kramer, L., & O'Brien, G. (2008). CLASS shifts in modeling instruction. In C. Henderson, M. S. Sabella, & L. Hsu (Eds.), *2008 Physics Education Research Conference.* Melville, NY: American Institute of Physics

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2nd ed.*). Hillsdale, NJ: Erlbaum.

D'Avanzo, C. (2008). Biology concept inventories: Overview, status, and next steps. *Bioscience, 58,* 1079–1085.

Dugger, C., Principe, B., & Rudolph, D. (2012). *Alignment of Tennessee Standards with modeling-based curriculum and pedagogy (for chemistry).* Product of Project TIME grant funded by Tennessee Department of Education.

Dye, J., Nolan, M., & Rudolph, D. (2012). *Alignment of Tennessee Standards with modeling-based curriculum and pedagogy (for biology).* Product of Project TIME grant funded by Tennessee Department of Education.

Edelson, D., & Reiser, B. (2006). Making authentic practices accessible to learners: Design challenges and strategies. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 335-354). New York: Cambridge.

Farrell, J. J., Moog, R. S., & Spencer, J. N. (1999). A guided inquiry general chemistry course. *Journal of Chemical Education, 76,* 570–574.

Glasser, H. M. (2012). The numbers speak: Physics first support math performance. *Physics Teacher*, *50*, 53-55.

Gonzales, P., Williams, T., Jocelyn, L., Roey, S., Kastberg, D., & Brenwald, S. (2008). *Highlights from TIMSS 2007: Mathematics and science achievement of U.S. fourth- and eighth-grade students in an international context* (NCES 2009–001 Revised). Washington, DC: National Center for Education Statistics, Institute of Education Sciences and U.S. Department of Education.

Gosser, K., Kampmeier, J., & Varma-Nelson, P. (2010). Peer-led team learning: 2008 James Flack Norris Award Address. *Journal of Chemical Education*, *87,* 374–380.

Hake, R. R. (1987). Promoting student crossover to the Newtonian world. *American Journal of Physics, 55,* 878–885.

Hake, R. R. (1998). Interactive-engagement vs. traditional methods: A 6000 student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66,* 64–74.

Hake, R. R. (2009). *What is modeling?* Retrieved from http://modeling.asu.edu/modeling/WhatModlInstructionIs09.htm

Halloun, I. A., & Hestenes, D. (1985a). The initial knowledge state of college physics students. *American Journal of Physics, 53,* 1043–1055.

Halloun, I. A., & Hestenes, D. (1985b). Common sense concepts about motion. *American Journal of Physics*, *53,* 1056–1065.

Hestenes, D. (1987). Toward a modeling theory of physics instruction. *American Journal of Physics, 55,* 440–454.

Hestenes, D. (2000). *Findings of the modeling workshop, 1994 – 2000*. One section of an NSF final report. Retrieved from http://modeling.asu.edu/R&E/Research.html.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force Concept Inventory. P*hysics Teacher, 30*, 141–158.

Jackson, J., Dukerich, L., & Hestenes, D. (2008). Modeling instruction: An effective model for science education. *Science Educator, 17*(1), 10–17.

Krajcik, J., & Blumenfeld, P. (2006). Project-based learning. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 317-334). New York: Cambridge.

Laws, P. (1991). Calculus-based physics without lectures. P*hysics Today, 44*(12), 24–31.

Lederman, L. (1995). ARISE: American renaissance in science education. *FERMILAB-TM-2051*.

Lederman, L. (2001). Revolution in science education. P*hysics Today*, *54*(9), 11–12.

Lewis, J. E., & Lewis, S. E. (2005). Departing from lectures: An evaluation of a peer-led guided inquiry alternative. *Journal of Chemical Education, 82,* 135–139.

Liang, L., Fulmer, G., Majerich, D., Clevenstine, R. & Howanski, R. (2012). The effects of a model-based physics curriculum program with a physics first approach: A causal-comparative study. *Journal of Science Education and Technology, 21*, 114-124.

Lord, T. (1998). Cooperative learning that really works in biology teaching: Using constructivist-based activities to challenge student teams. *The American Biology Teacher, 60,* 580–588.

Machi, E., (2009). *Improving U.S. competitiveness with K-12 STEM education and training: A report on the STEM education and National Security Conference, October 21-23, 2008.* (SR-57). Washington, DC: The Heritage Foundation. Retrieved from http://www.eric.ed.gov/PDFS/ED505842.pdf

Malone, K. L. (2008). Correlations among knowledge structures, force concept inventory, and problem-solving behaviors. *Physical Review Special Topics – Physics Education Research, 4*, 020107 1–15.

Mazur, E. (1997). *Peer Instruction.* Upper Saddle River, NJ: Prentice Hall.

McDaniel, C. N., Lister, B C, Hana, M. H., & Roy, H. (2007). Increased learning observed in redesigned introductory biology course that employed web-enhanced, interactive pedagogy. *Cell Biology Education, 6,* 298–310.

McDermott, L. C. (1984). Research on conceptual understanding in mechanics. P*hysics Today, 37*, 24–32.

McDermott, L. C., & the Physics Education Group at the University of Washington. (1996). *Physics by Inquiry.* New York: John Wiley and Sons.

McDermott, L., & Redish, E. (1999). RL-PER1: Physics education research. *American Journal of Physics, 67,* 755–767.

Mulford, D. R., & Robinson, W. R. (2002). An inventory for alternate conceptions among first-semester general chemistry students. *Journal of Chemical Education, 79,* 739–744.

National Commission on Mathematics and Science Teaching in the 21st Century. (2000). *Before it's too late: A report to the nation from the National Commission on Mathematics and Science Teaching for the 21st Century*. Washington, DC: U.S. Department of Education.

National Research Council (NRC). (2001). *NRC report: Physics in a new era, overview*. Washington, DC: The National Academies Press.

National Research Council (NRC). (2003). *BIO2010: Transforming undergraduate education for future research biologists.* Washington, DC: The National Academies Press.

National Research Council (NRC). (2011). *Successful STEM education: A workshop summary*. A. Beatty, Rapporteur. Committee on Highly Successful Schools or Programs for K-12

STEM Education, Board on Science Education and Board on Testing and Assessment. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Pasero, S. (2003). The state of physics first programs. *FERMILAB-Pub-01/206.*

Perkins, K. K., Adams, W. K., Pollock, S. J., Finkelstein, N. D., & Wieman, C. E. (2005). Correlating student beliefs with student learning using the Colorado Learning Attitudes about Science Survey. In J. Marx, P. Heron, & S. Franklin (Eds.), *2004 physics Education Research Conference* (pp. 61–64). American Institute of physics.

Pratt, H. (2012). *The NSTA reader's guide to A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Arlington, VA: National Science Teachers Association.

Semsar, K., Knight, J. K., Birol, G., & Smith, M. K. (2011). The Colorado Learning Attitudes about Science Survey (CLASS) for use in biology. *Cell Biology Education, 10,* 268–278.

Spencer, J. (1999). New directions in teaching chemistry: A philosophical and pedagogical basis. *Journal of Chemical Education, 76,* 566–569.

Taylor, J. A., Powell, J. C, Van Dusen, D. R., Schindler, B. J., Pearson, B., Lavine, D., et al. (2005). Curriculum reform and professional development in San Diego City Schools. *The Physics Teacher, 43,* 102–106.

van Heuvelen, A. (1991). Learning to think like a physicist: A review of research-based instructional strategies. *American Journal of Physics, 59,* 888-897.

van Heuvelen, A., & Etkina, E. (2005). P*hysics Active Learning Guide*. Indianapolis, IN: Addison Wesley.

Wells, M., Hestenes, D., & Swackhamer, G. (1995). A modeling method for high school physics instruction. *American Journal of Physics, 63,* 606–619.