The Influence of Model-Based Science Teaching on Female High School Students' Attitudes and Confidence Levels

Grant Williams
School of Education – St. Thomas University

John Clement
College of Education - University of Massachusetts, Amherst

Abstract

In this study, we set out to investigate whether model-based teaching can have an influence on the interest, attitudes, and confidence levels of high school physics students compared to their traditionally instructed counterparts, and particularly whether there were any differences by gender. Statistical analysis of students' self-reported pre/post instruction problem solving confidence levels indicated that students who learned about electricity through model-based instruction experienced significantly greater gains in their levels of confidence about scientific reasoning. We also conducted an exploratory survey which indicated that the students in the model-based classes, particularly the females, gave responses to a science learning survey that were significantly more positive than students in the control group in regard to four factors: interest in science, use of imagery, the experience of active learning, and curiosity about science. The purpose of this exploratory study was to generate interesting hypotheses. It is hypothesized that the latter four differences originated in the whole class discussions during which students in the model-based classes were encouraged to cooperatively generate, evaluate and modify their explanatory models, and that the four differences led to deeper comprehension and consequently higher confidence in conceptual problem solving. Research indicates females are less likely than males to pursue post-secondary study and careers in STEM disciplines. We hope that this study and further studies in the future may contribute to finding solutions to this inequity.

Purpose

In this study, we set out to examine whether model-based teaching can have an influence on the interest in, attitudes about, and confidence levels of high school physics students compared to their traditionally instructed counterparts, and particularly whether any differences by gender may exist. Since research indicates females are less likely than males to pursue post-secondary study and careers in many STEM disciplines, we wanted to explore whether model-based science instruction has characteristics or features that have potential to ameliorate these inequities; possibly by increasing females' interest in and comprehension of science, and confidence in their science abilities. This exploratory study aims to examine the effects of model-based teaching on these aspects of students' learning experiences, particularly for females.

Theoretical Framework

Research indicates females are considerably less likely than males to pursue post-secondary study and careers in STEM disciplines (Valian, 2007; Blickenstaff, 2005; Zeldin, et al., 2008; Hill et al., 2010; Dasgupta & Stout, 2014). In the study of life sciences (biology, human and veterinary medicine, environmental science, etc.) as well as chemistry at the university level, males and females participate in approximately equal numbers. However, in physics, engineering, and computer science, males outnumber females 3 to 1 in the completion of university degrees (Wang, 2013). Further to this, while women make up 50% of the overall workforce in the United States, they compose only 24% of the STEM employment ranks (Beede et al., 2009). This leads to questions of why this is so, and whether there are types of science instruction that may either contribute to or mitigate the situation.

Halpern et al. (2007), Brotman & Moore (2008), and Lavy & Sand (2015) identify teaching practices that many K-12 educators employ that may unknowingly be discouraging girls in the study of science and their eventual choices to pursue careers in STEM fields. For example, studies have shown that many science teachers tend to: a) call on boys more frequently than girls during class discussions, b) allow boys to dominate science class talk, c) encourage boys to manipulate the apparatus and materials in experiments more so than for girls, d) grade boys' science tests and assignments more favorably than those of girls, e) and make more references to males as role models in STEM fields than they do to females.

There are, however, studies that have identified teaching strategies that have been shown to encourage the participation in and success of females in learning science (Burkam et al.,1997; Alexakos & Antoine, 2003; Sinnes & Loken, 2014). These include: a) developing a non-competitive classroom environment since competitiveness in class usually favors male students, b) allowing students to work frequently in collaborative small group settings since this has been shown to encourage increased female participation, c) providing extended wait time after calling on students since girls tend to think longer and more critically before responding, d) linking science lessons to societal/ environmental issues since research indicates that female students benefit by having meaningful contexts for the science content they learn, and e) varying the types and formats of assessments used to evaluate conceptual understanding since short answer and multiple choice style test questions that require forced choices make little use of females' abilities to synthesize information, make connections, and use their practical intelligence.

The characteristics and goals of model-based science instruction align particularly well with many of these latter kinds of teaching strategies which leads us, at this point, to a brief examination of models and modelling. The term model has many uses; however, in the context of this study, a model is considered to be a simplified representation of a system, which concentrates attention on specific aspects of the system (Ingham & Gilbert, 1991; Johnson-Laird, 1983). Models are a central component of scientific theories as recognized by the NGSS. They include concepts such as planetary motion, human respiration & circulation, erosion and continental drift, cellular reproduction, chemical reactivity, magnetic fields, electric circuits, etc.

As used here, model-based teaching is instruction designed to support the development and evolution of learners' *explanatory* models. Explanatory models can be described as mental representations of causal or functional mechanisms that are often hidden and that can explain why phenomena in a system occur (Clement, 2008). Model-based science instruction intends to be student-centered, inquiry-based, and constructivist in its approach, differing from what we refer to in this paper as "traditional" science teaching which tends to be more teacher-centric, didactic, and confirmatory in nature. In traditional science instruction, models are usually viewed as pre-developed, external representations of accepted ideas and theories that are used to show students how things work. In model-based science teaching, as represented by the classes studied here, the teacher takes students' prior knowledge into consideration, models are collaboratively constructed by the teacher and students; both in the shared social space and in the students' minds, and students are encouraged to generate, evaluate and modify their explanatory models for accuracy and completeness, much in the way science extends our understanding of the world around us.

Research Questions

While research exists to support the positive impacts of model-based science instruction on students' conceptual understanding (Vosniadou, 2002; Lehrer & Schauble, 2006; Windschitl et al., 2008; Schwarz et al., 2009; Gilbert, 2011; Williams & Clement, 2015), there is very little research that examines the impact of this type of teaching on students' attitudes about, interest in, and confidence in their abilities in science. This study endeavors to contribute to this area of science education research by examining the effects of model-based teaching on these aspects of students' learning experiences, particularly for females.

We asked the following research questions:

1) What is the influence of model-based teaching on high school physics students' (particularly females') levels of confidence in their conceptual science understanding?

2) What is the influence of model-based teaching on high school physics students' (particularly females') interest in and attitudes about science?

Study Context

In the initial phase of the research (Williams, 2011) we examined high school physics students' experiences learning about electric circuits through model-based instruction of Steinberg et al.'s (2004) CASTLE (Capacitor Aided System for Teaching and Learning Electricity) curriculum. The CASTLE curriculum utilizes the introduction of large non-polar capacitors into basic electric circuits as a means for focusing students' attention on the transient states of potential differences that exist throughout the circuit. By using the analogy of voltage as a type of "pressure" that exists in the "compressible electric fluid" of a circuit, students are encouraged to generate explanatory models of dynamic pressure changes occurring throughout the circuit as these capacitors go through their charging and discharging cycles. The CASTLE curriculum employs the extensive use of analogies, color-coded diagrams, and discrepant events to engage students and their teachers in the incremental co-construction of explanatory mental models for circuit electricity.

A group of approximately 270 high school physics students who were learning about electric circuits through the model-based CASTLE curriculum and an equally sized control group who learned through traditional instructional methods completed a 20 question conceptual, non-quantitative pre-test to gauge their understanding of and reasoning about electric circuits. The questions were multiple choice and were often accompanied by diagrams of circuits to provide visual context. An identical post-test was administered after the period of instructional, which lasted from 6-8 weeks. The groups were formed of 13 control classes taught by five teachers and 14 experimental classes taught by six teachers. Both groups had approximately equal distributions of male and female students.

A repeated measures analysis of variance (ANOVA) with an alpha value of 0.05 determined that overall, and when separated by gender, the students in the model-based learning group experienced significantly greater gains in their levels of conceptual understanding over the course of instruction than their traditionally instructed counterparts. (See also the section on Limitations for comments on the unit of analysis.)

The results of the pre and post-tests by treatment group and gender are displayed in the following tables and graphs:

Control Group (Traditional Curriculum and Instruction)

	Raw Score	**Percentage**
Overall Mean Pre-Test Problem Solving Score	6.59 / 20	32.9%
Overall Mean Post-Test Problem Solving Score	7.75 / 20	38.8%
Overall Mean Problem Solving Score Gain	1.17 / 20	5.9%
Males Mean Pre-Test Problem Solving Score	6.53 / 20	32.7%
Males Mean Post-Test Problem Solving Score	7.89 / 20	39.5%
Males Mean Problem Solving Score Gain	1.36 / 20	6.8%
Females Mean Pre-Test Problem Solving Score	6.64 / 20	33.2%
Females Mean Post-Test Problem Solving Score	7.61 / 20	38.1%
Females Mean Problem Solving Score Gain	0.97 / 20	4.9%

Table 1 - Pre/ Post Test Conceptual Understanding Scores by Gender – Control Group

Experimental Group (Model-Based Curriculum and Instruction)

	Raw Score	**Percentage**
Overall Mean Pre-Test Problem Solving Score	6.70 / 20	33.5%
Overall Mean Post-Test Problem Solving Score	11.61 / 20	58.1%
Overall Mean Problem Solving Score Gain	4.91 / 20	24.6%
Males Mean Pre-Test Problem Solving Score	6.76 / 20	33.8%
Males Mean Post-Test Problem Solving Score	11.53 / 20	57.7%
Males Mean Problem Solving Score Gain	4.77 / 20	23.9%
Females Mean Pre-Test Problem Solving Score	6.65 / 20	33.3%
Females Mean Post-Test Problem Solving Score	11.69 / 20	58.5%
Females Mean Problem Solving Score Gain	5.04 / 20	25.2%

Table 2 - Pre/ Post Test Conceptual Understanding Scores by Gender – Experimental Group

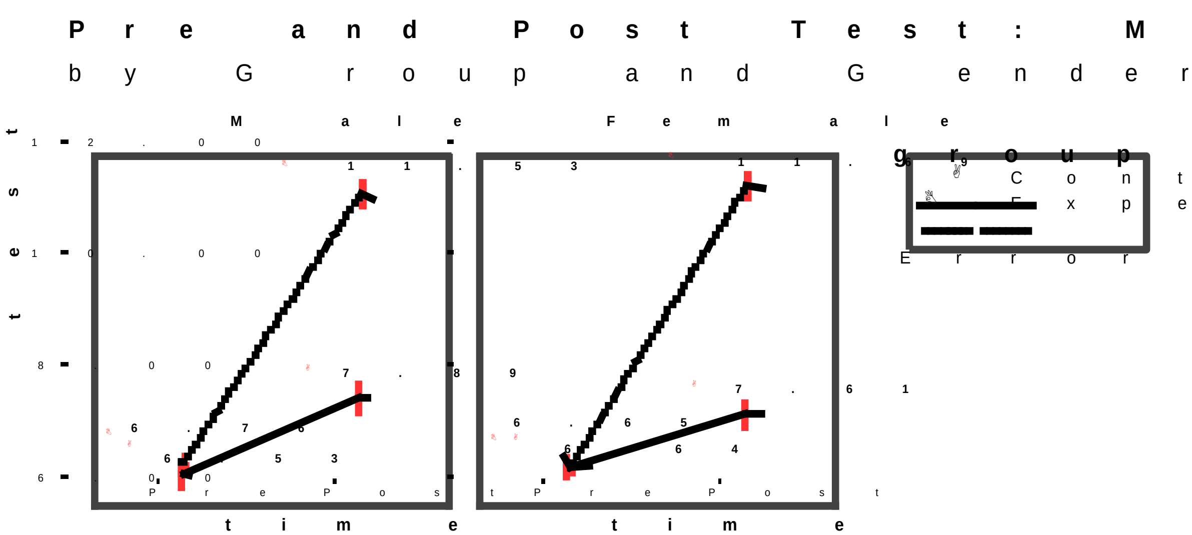


Fig.1 – Pre/ Post Test Conceptual Understanding Scores by Treatment Group and Gender

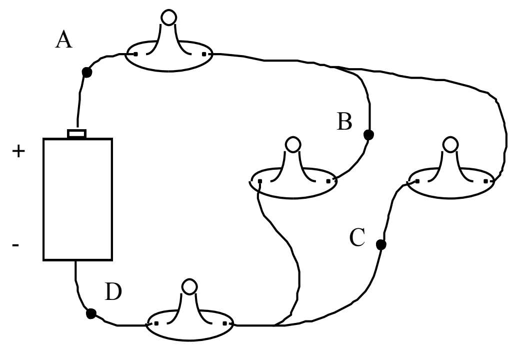
Methodology

For the phase of the study reported on in this paper, additional data from a) students' self-reports of pre/posttest circuit problem solving confidence levels and b) post-instruction science learning surveys for the same two groups were analyzed to determine whether differences existed in these areas as well. For each of the 20 electric circuit problems on the pre/posttest, after solving the problems students were asked to rate their levels of confidence in their responses on a scale ranging from 1 (Blind guess) to 5 (I'm sure I'm right). Comparisons of the circuit problem-solving confidence scores were done using a repeated measures analysis of variance (ANOVA) with an alpha value of 0.05 to establish whether significant gain differences existed between the control and experimental groups, as a whole and by gender.

The sample problem below illustrates the non-quantitative, conceptual nature of the pre/post test problems as well as the manner in which students were asked to rate their levels of confidence in their solutions. A complete set of Pre/Post test questions is available upon request from the authors.

Sample Pre/Post-Test Question

In this circuit, all four bulbs are identical, and all four bulbs are lit, although they may or may not all be the same brightness.



Which of the following is true?

A. The current at point B is greater than the current at point C.

B. The current at point B is equal to the current at point C.

C. The current at point B is less than the current at point C.

D. There is not enough information to know the relative current at the two points

My level of confidence in my solution is:

A. Blind guess

B. Not very confident

C. Somewhat confident

D. Confident

E. I'm sure I'm right

Upon completion of their respective circuit electricity instructional units, all students also completed a 21-question survey designed to gauge their beliefs and attitudes about their experiences of learning about electricity. Previously established survey instruments that were examined (Osborne et al., 2003; Adams et al., 2006; Stelzer et al., 2010;) did not contain questions that we felt were of high relevance to both traditional and model-based electricity instruction, so we developed an exploratory survey that would allow us to generate hypotheses about connections between students' learning experiences, conceptual understanding, and confidence levels.

The survey questions consisted of statements about students' personal learning experiences and required them to indicate their level of agreement by selecting one of five possible descriptors. The student responses ranged from least positive (scored at 1) to most positive (scored at 5) and were grouped into categories of negative (1 & 2), neutral (3), and positive (4 & 5) responses and coded by treatment group and gender. Cross-tabulations of the percentages of student responses in each of these categories by treatment were generated and a Pearson Chi-Square analysis with a level of significance of 0.05 was administered to identify questions whose responses differed significantly between the control and experimental groups, as a whole and by gender.

Results

Pre/Posttest Confidence Ratings

The average pre and posttest circuit problem solving confidence scores for the Control and Experimental groups (overall and by gender) are shown in the data tables and graphs below. Since the lowest possible confidence rating on each of the 20 questions was 1/ 5 and the highest score was 5/5, for the Percentage values shown on Tables 3 and 4, a rating of 1/ 5 equates to 0%, 3/ 5 equates to 50%, and 5/ 5 equates to 100%.

Control Group (Traditional Curriculum and Instruction)

	Raw Score	**Percentage**
Overall Mean Pre-Test Confidence Score	2.79 / 5	44.8%
Overall Mean Post-Test Confidence Score	3.43 / 5	60.8%
Overall Mean Confidence Score Gain	0.60 / 5	16.0%
Males Mean Pre-Test Confidence Score	2.97 / 5	49.3%
Males Mean Post-Test Confidence Score	3.55 / 5	63.8%
Males Mean Confidence Score Gain	0.58 / 5	14.5%
Females Mean Pre-Test Confidence Score	2.60 / 5	40.0%
Females Mean Post-Test Confidence Score	3.30 / 5	57.5%
Females Mean Confidence Score Gain	0.70 / 5	17.5%

Table 3 - Pre/ Post Test Confidence Scores by Gender – Control Group

Experimental Group (Model-Based Curriculum and Instruction)

	Raw Score	**Percentage**
Mean Pre-Test Confidence Score	2.63 / 5	40.8%
Mean Post-Test Confidence Score	3.79 / 5	69.8%
Mean Confidence Score Gain	1.16 / 5	29.0%
Males Mean Pre-Test Confidence Score	2.86 / 5	46.5%
Males Mean Post-Test Confidence Score	3.94 / 5	73.5%
Males Mean Confidence Score Gain	1.08 / 5	27.0%
Females Mean Pre-Test Confidence Score	2.38 / 5	34.5%
Females Mean Post-Test Confidence Score	3.62 / 5	65.5%
Females Mean Confidence Score Gain	1.24 / 5	31.0%

Table 4 - Pre/ Post Test Confidence Scores by Gender – Experimental Group

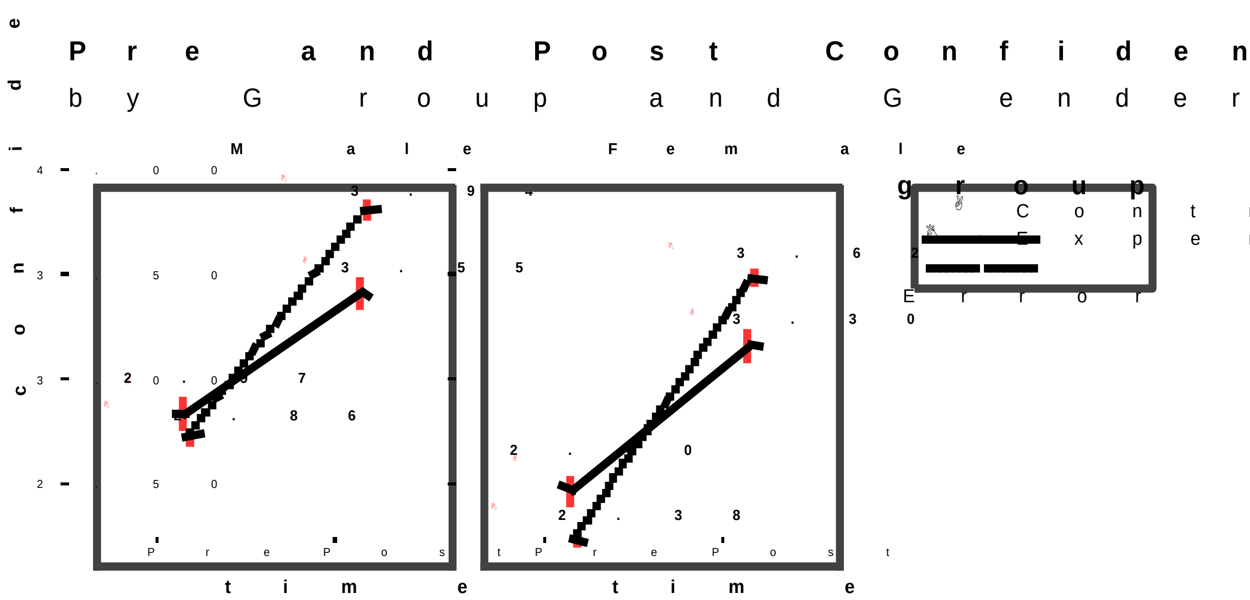


Fig. 2 – Pre/ Post Test Confidence Scores by Treatment Group and Gender

Statistical analysis determined that the students (overall and by gender) who received model-based instruction experienced significantly greater problem-solving confidence score gains than the students who received more traditional electric circuit instruction. The effect size of the experimental treatment (model-based instruction of electricity concepts) on students' (regardless of gender) confidence in their ability to solve circuit problems is 0.713; deemed to be a medium to large effect based on Cohen's (1992) scale.

Of particular interest was the substantial 31.0 % gain in the average problem solving confidence ratings of the female students in the model-based instruction group -- a significantly higher gain than the 17.5% gain reported by the female students in the traditionally instructed control group. Considering the substantial body of research documenting the low participation rates of girls and women in physics study and careers, and the inherent hypothesis that this may be related to low self-confidence in the subject content, one can't help but wonder if the kinds of curricular design and instructional methodology utilized in the model-based classrooms under study may have the potential to help move the gender participation numbers closer to equality.

Post-Instruction Science Learning Survey

In an effort to develop plausible hypotheses as to why the students in the model-based instructional group, and in particular the females as a sub-group, experienced such substantial gains in their electric circuit problem solving confidence levels, we looked to the results of the post-instruction Science Learning Survey. For 11 of the 21 post-instruction survey questions (#1, 2, 9,10,11,12,13,14,16,17,18) that students were asked, regardless of gender, the responses of those in the experimental group were significantly more positive than those in the control group. The results for these eleven survey questions are displayed in the tables below. The terms (positive) and (negative) have been added to aid the reader in understanding how the answers were interpreted by the authors.

1) As a result of studying the electricity unit, my confidence in my ability to explain concepts in electricity has increased (positive)/ decreased (negative):

Group	Negative	Neutral	Positive
Control Overall	6.5%	15.8%	77.7%
Control Males	7.9%	15.0%	77.2%
Control Females	5.3%	16.5%	78.2%
Experimental Overall	1.0%	3.0%	96.0%
Experimental Males	0.7%	2.7%	96.6%
Experimental Females	1.3%	3.3%	95.3%

Table 5

Result: Students (Male, Female, and Overall) in the Experimental group reported a significantly greater gain in their confidence in explaining electricity concepts than students in the Control group.

2) After studying the electricity unit, my overall confidence about my abilities in science has improved (positive)/ decreased (negative):

Group	Negative	Neutral	Positive
Control Overall	17.9%	27.6%	54.5%
Control Males	18.4%	26.4%	55.2%
Control Females	17.4%	28.8%	53.8%
Experimental Overall	2.3%	15.8%	81.9%
Experimental Males	1.4%	15.5%	83.1%
Experimental Females	3.3%	16.0%	80.7%

Table 6

Result: Students (Male, Female, and Overall) in the Experimental group reported a significantly greater gain in their overall confidence in their abilities in science than students in the Control group.

9) Compared to other courses or units in science, I found myself becoming surprised by the results of experiments and demonstrations more (positive)/ less (negative) often:

Group	Negative	Neutral	Positive
Control Overall	17.9%	23.7%	58.4%
Control Males	19.5%	28.9%	51.6%
Control Females	16.4%	18.7%	64.9%
Experimental Overall	8.4%	18.8%	72.8%
Experimental Males	10.8%	23.0%	66.2%
Experimental Females	6.0%	14.7%	79.3%

Table 7

Result: Students (Male, Female and Overall) in the Experimental group reported a significantly higher frequency (compared to other units) of surprise in the results of experiments and demonstrations than students in the Control group.

10) When the results of my experiments surprised me by turning out differently than I thought they would, I was interested (positive)/ discouraged (negative):

Group	Negative	Neutral	Positive
Control Overall	9.9%	25.2%	64.9%
Control Males	10.2%	28.9%	60.9%
Control Females	9.7%	21.6%	68.7%
Experimental Overall	4.7%	16.9%	78.4%
Experimental Males	4.8%	20.4%	74.8%
Experimental Females	4.7%	13.4%	81.9%

Table 8

Result: Students (Males, Female and Overall) in the Experimental group reported a significantly greater interest in finding out why experiments turned out differently than expected than students in the Control group.

11) While learning about electricity in this unit, I found that I revised or updated my ideas about electricity often (positive)/ rarely (negative):

Group	Negative	Neutral	Positive
Control Overall	11.5%	35.5%	53.1%
Control Males	13.3%	32.0%	54.7%
Control Females	9.7%	38.8%	51.5%
Experimental Overall	3.7%	22.5%	73.8%
Experimental Males	4.7%	25.0%	70.3%
Experimental Females	2.7%	20.0%	77.3%

Table 9

Result: Students (Males, Female and Overall) in the Experimental group reported a significantly higher frequency of revising or updating their ideas about electricity than students in the Control group.

12) In reflecting on how I learned the concepts of electricity in this unit, I found that I criticized my own ideas often (positive)/ rarely (negative):

Group	Negative	Neutral	Positive
Control Overall	21.1%	36.0%	42.9%
Control Males	23.4%	31.3%	45.3%
Control Females	18.8%	40.6%	40.6%
Experimental Overall	11.8%	26.6%	61.6%
Experimental Males	14.3%	26.6%	59.1%
Experimental Females	9.3%	26.7%	64.0%

Table 10

Result: Students (Male, Female and Overall) in the Experimental group reported a significantly higher frequency of criticizing their own ideas than students in the Control group.

13) As a result of the way I learned about electricity in this unit, in the future I am likely to make up pictures in my head to explain science ideas to myself more (positive)/ less (negative) often:

Group	Negative	Neutral	Positive
Control Overall	9.3%	23.6%	67.2%
Control Males	10.4%	26.4%	63.2%
Control Females	8.2%	20.9%	70.9%
Experimental Overall	6.7%	8.4%	84.9%
Experimental Males	8.8%	10.1%	81.1%
Experimental Females	4.7%	6.7%	88.7%

Table 11

Result: Students (Males, Female and Overall) in the Experimental group reported a significantly greater likelihood that, as a result of the way they learned about electricity, in the future they would create mental images to help explain scientific ideas to themselves than students in the Control group.

14) As a result of the way I learned about electricity in this unit, in the future I am likely to draw diagrams or pictures on paper to help solve problems more (positive)/ less (negative) often:

Group	Negative	Neutral	Positive
Control Overall	13.8%	24.1%	62.1%
Control Males	13.4%	23.6%	63.0%
Control Females	14.2%	24.6%	61.2%
Experimental Overall	4.0%	7.7%	88.2%
Experimental Males	5.4%	9.5%	85.0%
Experimental Females	2.7%	6.0%	91.3%

Table 12

Result: Students (Males, Female and Overall) in the Experimental group reported a significantly greater likelihood that, as a result of the way they learned about electricity, they would draw diagrams or pictures on paper to solve problems than students in the Control group.

16) During the electricity unit, I contributed my ideas in small group discussions often (positive) /rarely (negative):

Group	Negative	Neutral	Positive
Control Overall	17.2%	23.7%	59.2%
Control Males	20.3%	27.3%	52.3%
Control Females	14.2%	20.1%	65.7%
Experimental Overall	6.4%	33.7%	59.9%
Experimental Males	6.8%	31.3%	61.9%
Experimental Females	6.0%	36.0%	58.0%

Table 13

Result: Students (Male, Female and Overall) in the Experimental group reported a significantly greater frequency of contributing their ideas to small group discussions than students in the Control group.

17) During the electricity unit, other students explained their ideas to me often (positive)/ rarely (negative):

Group	Negative	Neutral	Positive
Control Overall	27.5%	34.0%	38.5%
Control Males	29.7%	34.4%	35.9%
Control Females	25.4%	33.6%	41.0%
Experimental Overall	10.1%	23.5%	66.4%
Experimental Males	12.2%	19.6%	68.2%
Experimental Females	8.0%	27.3%	64.7%

Table 14

Result: Students (Male, Female and Overall) in the Experimental group reported a significantly greater frequency of having other students explain their ideas to them than students in the Control group.

18) During the unit, while talking with others in small group discussions I felt that I was learning about electricity often (positive)/ rarely (negative):

Group	Negative	Neutral	Positive
Control Overall	15.3%	36.3%	48.5%
Control Males	14.8%	38.3%	46.9%
Control Females	15.7%	34.3%	50.0%
Experimental Overall	8.7%	24.5%	66.8%
Experimental Males	9.5%	27.0%	63.5%
Experimental Females	8.0%	22.0%	70.0%

Table 15

Result: Students (Male, Female and Overall) in the Experimental group reported a significantly greater frequency of learning about electricity through small group discussions than students in the Control group.
Questions about your Interest Level:

Based on the nature of these questions, these responses indicate that, as a result of their learning experience, students who studied electricity through the model-based curriculum viewed themselves as: a) more confident in their electricity understanding and overall science abilities, b) more participative in sharing their ideas with and learning from others in small group discussions, c) more determined to find out why experiments didn't always turn out as expected,

d) more likely to draw diagrams when solving problems, and e) more likely to criticize and revise or modify their explanations than students who studied electricity through more traditional means.

For another 7 of the 21 survey questions (#4, 5, 6, 8, 15, 19, 21) it was seen that the responses of female students who learned about electricity through the model-based curriculum were significantly more positive than those of females who studied electricity in a non-model-based manner. Differences in these particular aspects of student learning experiences and attitudes were not observed between the male students in the control and experimental groups. The results for these seven survey questions are displayed in the tables below.

4) Compared to other courses or units of study, in this unit I have come up with my own ideas or explanations more (positive)/ less (negative) often:

Group	Negative	Neutral	Positive
Control Overall	15.7%	39.5%	44.8%
Control Males	15.6%	35.2%	49.2%
Control Females	15.8%	43.6%	40.6%
Experimental Overall	7.7%	33.0%	59.3%
Experimental Males	7.5%	36.1%	56.5%
Experimental Females	8.0%	30.0%	62.0%

Table 16

Result: Students (Female and Overall, but not Males) in the Experimental group reported a significantly higher level of idea or explanation generation than students in the Control group.

5) While studying and working through problems in this unit, I thought about images of charge movement often (positive)/ rarely (negative):

Group	Negative	Neutral	Positive
Control Overall	24.0%	34.7%	41.2%
Control Males	21.9%	32.8%	45.3%
Control Females	26.1%	36.6%	37.3%
Experimental Overall	15.1%	30.5%	54.4%
Experimental Males	16.9%	31.8%	51.4%
Experimental Females	13.3%	29.3%	57.3%

Table 17

Result: Students (Female and Overall, but not Males) in the Experimental group reported a significantly higher frequency of thinking about charge movement imagery during their studies than students in the Control group.

6) Compared to other courses or units, while studying electricity, I formed pictures in my head to understand new ideas more (positive)/ less (negative) often:

Group	Negative	Neutral	Positive
Control Overall	11.1%	49.4%	39.5%
Control Males	12.6%	47.2%	40.2%
Control Females	9.7%	51.5%	38.8%
Experimental Overall	7.8%	35.1%	57.1%
Experimental Males	9.6%	39.7%	50.7%
Experimental Females	6.0%	30.7%	63.3%

Table 18

Result: Students (Female and Overall, but not Males) in the Experimental group reported a significantly higher frequency (compared to other courses or units) of forming mental pictures to understand new ideas than students in the Control group.

8) While studying the unit on electricity, I found myself becoming surprised by the results of experiments and demonstrations with high (positive)/ low (negative) frequency:

Group	Negative	Neutral	Positive
Control Overall	37.0%	29.4%	33.6%
Control Males	40.6%	29.7%	29.7%
Control Females	33.6%	29.1%	37.3%
Experimental Overall	37.9%	40.6%	21.5%
Experimental Males	41.9%	38.5%	19.6%
Experimental Females	34.0%	42.7%	23.3%

Table 19

Result: Students (Female and Overall, but not Males) in the Experimental group reported a significantly lower frequency of surprise in the results of experiments and demonstrations than students in the Control group.

15) During the electricity unit, I explained my ideas in whole class discussion often (positive) /rarely (negative):

Group	Negative	Neutral	Positive
Control Overall	29.1%	33.0%	37.9%
Control Males	27.3%	32.8%	39.8%
Control Females	30.8%	33.1%	36.1%
Experimental Overall	19.2%	36.4%	44.4%
Experimental Males	19.0%	37.4%	43.5%
Experimental Females	19.3%	35.3%	45.3%

Table 20

Result: Students (Female and Overall, but not Males) in the Experimental group reported a significantly greater frequency of explaining their ideas during whole class discussions than students in the Control group.

19) After studying in the electricity unit, my curiosity about science has increased (positive)/ decreased (negative):

Group	Negative	Neutral	Positive
Control Overall	14.5%	38.9%	46.6%
Control Males	11.7%	37.5%	50.8%
Control Females	17.2%	40.3%	42.5%
Experimental Overall	3.7%	35.4%	60.9%
Experimental Males	5.4%	36.1%	58.5%
Experimental Females	2.0%	34.7%	63.3%

Table 21

Result: A significantly larger portion of students (Female and Overall, but not Male) in the Experimental group reported increased curiosity about science after studying electricity than students in the Control group.

21) Because of studying the electricity unit, my interest in learning science has increased (positive)/ decreased (negative):

Group	Negative	Neutral	Positive
Control Overall	6.9%	44.3%	48.9%
Control Males	6.3%	43.0%	50.8%
Control Females	7.5%	45.5%	47.0%
Experimental Overall	4.0%	37.2%	58.7%
Experimental Males	4.1%	38.5%	57.4%
Experimental Females	4.0%	36.0%	60.0%

Table 22

Result: A significantly larger portion of the Students (Female and Overall, but not Male) in the Experimental group reported an increase in their interest in learning science than students in the Control group.

Based on the responses to these seven survey questions, it was observed that females in the experimental group viewed themselves: a) generating their own ideas or explanations, b) forming mental images of charge movement, c) explaining their explanatory models during whole class discussions, and d) having a curiosity and interest in learning about science more so than their traditionally instructed female counterparts.

It is particularly worthy of note that, in total, there were 18 of the 21 survey questions for which the female students in the experimental model-based instruction group reported significantly more positive science learning attitudes than the female students in the traditionally instructed control group.

For only one survey question (#7) were the responses of male students in the experimental (model-based) group observed to be significantly more positive than male students from the control (traditional instruction) group. This difference was not observed between the female students in the control and experimental groups. The results of this question are displayed in the table below.

7) While studying the electricity unit, I formed pictures in my head to understand new ideas with this high (positive)/ low (negative) frequency:

Group	Negative	Neutral	Positive
Control Overall	42.0%	20.2%	37.8%
Control Males	46.1%	22.7%	31.3%
Control Females	38.1%	17.9%	44.0%
Experimental Overall	37.7%	16.5%	45.8%
Experimental Males	37.4%	15.0%	47.6%
Experimental Females	38.0%	18.0%	44.0%

Table 23

Result: Male students in the Experimental group reported a significantly higher frequency of forming mental pictures to understand new ideas than male students in the Control group.

Of the 21 survey questions, there were only two items (#3 & 20) where no significant differences were found (overall or by gender) between the control and experimental groups. The results of these two survey questions are displayed below.

3) Having completed the unit on electricity, my level of anxiety or worry about doing science experiments has increased (negative)/ decreased (positive):

Group	Negative	Neutral	Positive
Control Overall	16.4%	43.1%	40.5%
Control Males	18.8%	43.0%	38.3%
Control Females	14.2%	43.3%	42.5%
Experimental Overall	22.9%	39.7%	37.4%
Experimental Males	28.6%	36.1%	35.4%
Experimental Females	17.3%	43.3%	39.3%

Table 24

Result: There is no overall Sig. Diff. between Experimental & Control Results

20) While studying the unit on electricity I found myself thinking about the ideas outside of class often (positive)/ rarely (negative):

Group	Negative	Neutral	Positive
Control Overall	30.9%	40.5%	28.6%
Control Males	25.8%	43.8%	30.5%
Control Females	35.8%	37.3%	26.9%
Experimental Overall	25.3%	37.4%	37.4%
Experimental Males	24.5%	36.1%	39.5%
Experimental Females	26.0%	38.7%	35.3%

Table 25

Result: There is no overall Sig. Diff. between Experimental & Control Results

There were no post-instruction survey questions in which the traditionally-instructed control group recorded significantly more positive responses than the model-based group.

Discussion

In this study we set out to investigate whether model-based teaching can have an influence on the interest, attitudes, and confidence levels of high school physics students compared to their traditionally instructed counterparts, and particularly whether there were any differences by gender. In response to our first research question:

"What is the influence of model-based teaching on high school physics students' (particularly females') levels of confidence in their conceptual science understanding?"

Statistical analysis of over 550 students' self-reported pre/post instruction problem solving confidence levels indicated that students (regardless of gender) who learned about electricity through model-based instruction experienced significantly greater gains in levels of confidence in their scientific reasoning (29%) than those who did not (16%). When analyzed separately, this was found to be true for female students as well, with girls in the model-based physics classes reporting gains of 31% in their scientific reasoning confidence levels compared to gains of 17.5% reported by the girls in the traditionally-instructed classes.

In response to our second research question:

“What is the influence of model-based teaching on high school physics students’ (particularly females’) interest in and attitudes about science?”

We also conducted an exploratory survey whose results indicated that the students in the model-based classes, particularly the females, gave responses to a science learning survey that were significantly more positive than students in the control group. In fact, for 18 of the 21 science learning survey questions, the girls in the model-based classrooms responded in significantly more positive fashion than their counterparts from the traditionally instructed control group. Their responses indicate that, as a result of the model-based learning experience, they viewed themselves as: a) more confident in their ability to explain concepts in electricity; b) more confident in their overall science abilities; c) more likely to form mental images and draw diagrams when solving problems in the future; and d) more curious about and interested in science in general than female students who studied electricity through more traditional means. With respect to their activities during the course, they were: a) more participative in sharing their ideas with and learning from others in both small group discussions and whole class discussions, b) more likely to generate their own ideas or explanations, c) more determined to find out why experiments didn’t always turn out as expected, and d) more likely to criticize and revise or modify their explanations.

The model-based approach to teaching with the CASTLE curriculum in the experimental group emphasized: the use of imagery; observation of discrepant events; development of explanatory models; sharing, critique and revision of models; and discussion of models in small and large groups. Thus there is reason to believe that these characteristics of the experimental classrooms contributed to the differences found on the survey summarized above, (as shown on the left side of Figure 3). Also, research by Blickenstaff (2005) suggests that science classrooms where students are actively engaged in the construction of understanding as opposed to the mere regurgitation of information, may be of particular appeal to female students. Corey et al. (1993) found that females participated at higher than usual levels in large-group discussions in science classes led by teachers who worked to establish ordinary, “outside the classroom” conversational norms and who provided instruction of a constructivist and cognitively-based nature, Their hypothesis is that when teachers foster a comfortable and non- judgmental environment in which to talk with others about their own ideas, female students may feel more at ease in sharing their scientific opinions.

The model-based teachers in the present study widely utilized whole-class discussions to foster the students' processes of continually updating and refining their models for electricity phenomenon. During these class conversations, students were encouraged by the teachers to critically evaluate each other's and their own explanations in search of those that were most strongly supported by the evidence on hand. We hypothesize that model-based science instruction, especially in classrooms where collaborative whole-class discussion is valued and where students have opportunities to consider the plausibility, rather than the mere correctness of explanations may provide particular types of learning opportunities that can lead to increases in female students' interest in, attitudes about, and confidence in their abilities in science. The model-based CASTLE curriculum examined in this study is designed to have students working on circuit experiments in pairs, supported by the use of color-coded diagrams and various analogies, followed by opportunities for whole-class sharing of the explanatory models developed.

The diagram in Figure 3 illustrates our hypotheses about how the model-based learning experience of the experimental group in this study may have positively influenced the female students' comprehension and confidence in their science abilities and how this might ultimately contribute to their decisions to pursue additional study and possibly careers in STEM-related fields. In order to home in on the differential effects of the experimental course specific to females, Figure 3 focuses on those survey results where only the females in the experimental group obtained more positive ratings than their counterparts in the control group.

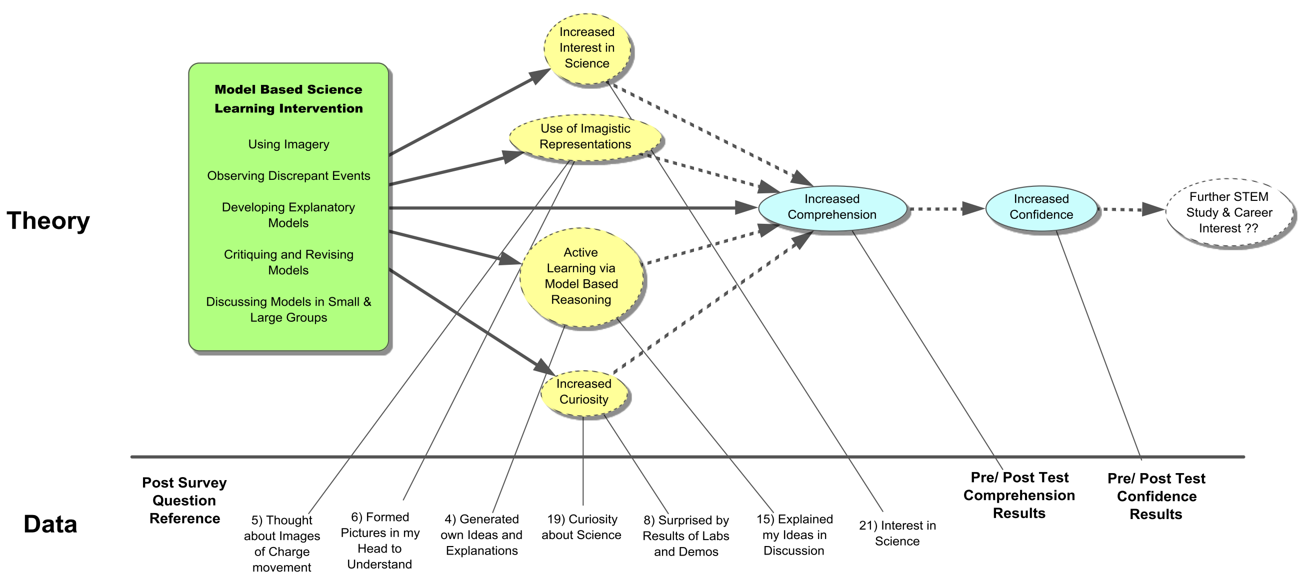


Fig. 3 – Hypotheses on How Model-Based Learning may Affect Comprehension, Confidence, and Potentially, Further STEM Study & Career Interest.

On the left hand side of the diagram are five of the primary activities of the Model-Based Science Learning Intervention (CASTLE Curriculum) experienced by the students in the Experimental Group. Based on the results of the pre/post-instruction conceptual problem solving test data, there is evidence that this type of Model-Based Science Learning Intervention leads Increased Comprehension; thus the arrow connecting them is solid; representing the hypothesis that the increase in comprehension was due to the intervention. The Science Learning Intervention box and the Increased Comprehension oval are enclosed in solid outlines meaning that they are supported by curricular design and test data respectively.

The results of the exploratory post-instruction survey indicate that female students in the Model-Based Science Learning Intervention group experienced significantly greater levels of Interest in Science, use of Imagistic Representations, Active Learning via Model-Based Reasoning, and Curiosity than the females in the traditionally instructed control group. The arrows from the Model-Based Science Learning Intervention box to the ovals of these characteristics are solid since our hypothesis is that the intervention led to these outcomes, however, we have shown the ovals as outlined with dotted lines since the survey questions were exploratory in nature. In the Data section at the bottom of the diagram, we show abbreviated versions of the seven post-instruction survey questions whose positive female responses (compared to controls) provide some initial support for our hypotheses about increases in these four areas.

Our additional hypothesis is that the female MBL students' Interest in Science, use of Imagistic Representations, Active Learning via Model-Based Reasoning, and Curiosity may also contribute to Increased Comprehension, however we have represented these connections with dotted arrows since we don't have experimental test or survey data to confirm this hypothesis. However, research by Singh et al. (2002) and Nieswandt (2007) have shown that high levels of interest and curiosity in science can have significantly positive effects on high school students' conceptual understanding. Additionally, research by Nersessian, (2002) and Clement (2008) relate the use of imagery to skillful scientific explanation processes in experts, and Schwartz & Heiser (2006), and Gilbert (2005) relate the use of imagery, visualization and model-based reasoning to students' deep conceptual understanding of a variety of science topics. Thus, we view our hypotheses that female high school students' interest in and curiosity about science as well as their use of imagery and model-based reasoning could have positive impacts on their conceptual understanding of electric circuits as being quite plausible.

The arrow connecting the Increased Comprehension oval to the adjacent Increased Confidence oval is dotted since, although we have observed simultaneous significant increases in female MBL students' conceptual understanding and their confidence in their conceptual understanding as measured by their responses to the pre/post instruction test, we cannot say for certain whether one led to the other. While it is plausible to expect that students who gain increased conceptual understanding of a topic could also experience increased confidence in their abilities, without experimental data to support that hypothesis in this study, the connection remains a plausible hypothesis. However, Chang & Cheng (2008) found that senior high school students' science achievement was significantly correlated with their self-confidence and interest in science for 11th-grade students from 30 classes attending four high schools throughout Taiwan.

Our final hypothesis is one where we have no supporting data in this study and therefore it is the most speculative one-- that female high school students' Increases in their Confidence in science may lead to Further Study and pursuit of Careers in STEM related fields. Since we did not measure career interest in this study, the arrow indicating this connection, although plausible, is purely speculative and is shown as dotted and the final oval is white and enclosed with a dotted line. However, Seymour and Hewitt (1997) found that students whose confidence is lowered may trigger the onset of a cycle that increases their chances of failing and consideration of switching out of science. And Linn (1993) has attributed part of women's precipitous decline in participation in science courses to gender differences in confidence, as opposed to differences in cognition. Subsequently, in future studies of this type, it would be interesting to follow-up with the female students to ascertain whether there was any relationship between reported increases in levels of confidence in understanding of science concepts and further science study or career paths.

Limitations

These hypothesized connections are the most plausible ones to us; certainly there could be others, along with two way feedback loops. As an example, it could be argued that characteristics such as Interest in Science and engagement in Active Learning experiences may contribute to Increased levels of Confidence and that such an increase could reciprocally support further increases in Interest., Figure 3 is certainly not 'proven' by our initial data; however, our purpose has been to propose the simplest hypothesis as an initial theory consistent with our data.

The methodology behind this paper assumes that there is an important role for exploratory studies that generate theoretical hypotheses that are tentative, but that have some initial grounding in data, as a way to promote progress in the field. The pre-post comprehension and confidence studies reported here are exploratory in the sense that the sample could not be fully randomly selected and the sample size was not large enough to use classes as the unit of analysis. Thus we do not try to use them to project findings onto a larger population in a formal way. Nevertheless they provided very interesting data on the samples *within* the study, with important gain differences that we would like to explain. The survey data was also exploratory. We do not present it at this stage as an evaluative standardized measure, but as a tool to aid in generating hypotheses for theory in an area where theory is sparse--hypotheses that might explain our gain and confidence differences within the sample.

We do not present the theory in Figure 3 as fully evaluated, but as a provocative hypothesis with some initial grounding that can provoke larger evaluation studies. In Figure 3 we have tried to develop a diagrammatic representation that allows us to show which aspects of the theory have initial grounding in supporting data and which aspects are more speculative. Because it takes large amounts of time and resources to assemble studies with very large sample sizes, we see an important role for smaller exploratory studies in generating such provocative hypotheses that can steer future research in an efficient way.

Conclusion

Within the limits of this exploratory study, there were indications that learning about electric circuits through model-based instruction positively influenced the conceptual understanding, confidence levels, and science learning attitudes of both males and female high school physics students. However, there were also indications that the teachers using model-based electricity instruction fostered some disproportionately positive learning outcomes for the female students. It was determined that the pre/post instruction problem solving confidence levels of girls who learned about electricity through model-based instruction experienced significantly greater gains in levels of confidence in their scientific reasoning (31%) than those who did not (17.5%).

The results of a post-instruction survey indicated that the girls in the model-based classes reported themselves as significantly more: confident in their science abilities, likely to generate their own explanations, likely to share their ideas, determined to find out why experiments didn't always turn out as expected, likely to form mental images and draw diagrams when solving problems, likely to criticize and revise their explanations, and curious about and interested in science than female students who studied electricity through more traditional means.

It is our hypothesis that the instructional strategies utilized by the teachers in the model-based physics classes supported the positive learning outcomes experienced by the female students. The teachers' use of whole-class discussions to engage students' in the collaborative co-construction of explanatory models seems to have contributed to increases in female students' interest in, attitudes about, and confidence in their abilities in science. It appears that the use of discrepant events, analogies, diagrams, and mental imagery as tools to promote student reasoning, especially when done in an environment where students are encouraged to critically but cooperatively evaluate and revise their explanatory models, may be a teaching approach that female high school physics students respond positively to.

Considering the well documented gender-gaps in science learning and the pursuit of post-secondary study and STEM-related careers that have challenged researchers, policy makers, curriculum developers, and educators for some time, we are encouraged by even preliminary evidence on instructional methods that may offer solutions. If model-based science instruction rich in whole class discussions can foster increased conceptual understanding as well as improved levels of confidence in and attitudes toward science of female students, then additional studies in this area seem like a prudent pursuit.

References

Adams, W. K., Perkins, K. K., Podolefsky, N. S., Dubson, M., Finkelstein, N. D., & Wieman, C. E. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey. *Physical review special topics-physics education research*, *2*(1), 010101.

Alexakos, K. & Antoine, W. (2003) The gender gap in science education: strategies to encourage female participation in science. *The Science Teacher*, v. 70, March. pp 30-33.

Beede, D.; Julian, T.; Langdon, D.; McKittrick, G.; Khan, B.; and Doms, M. (2009). *Women in STEM: A Gender Gap to Innovation*, U.S. Department of Commerce Economics and Statistics Administrations. www.esa.doc.gov.

Blickenstaff, J.C. (2005). Women and science careers: Leaky pipeline or gender filter? *Gender and Education*, v17, n4, p369-386. Taylor & Francis.

Brotman, J. S. and Moore, F. M. (2008), Girls and science: A review of four themes in the science education literature. Journal of Research in Science Teaching, 45: 971–1002.

Burkam, D., Lee, V., and Smerdon, B. (1997). Gender and Science Learning Early in High School: Subject Matter and Laboratory Experiences. *American Educational Research Journal*. June 20, 1997 34: 297-331.

Chang, C. Y., & Cheng, W. Y. (2008). Science achievement and students' self-confidence and interest in science: A Taiwanese representative sample study. International Journal of Science Education, 30, 1183–1200.

Clement, J., (2008). *Creative model construction in scientists and students: The role of imagery, analogy, and mental simulation*. Softcover edition, 2009. Dordrecht: Springer.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*, pp. 155-159.

Corey, V., van Zee, E., Minstrell, J., Simpson, D., & Simpson, V. (1993). When girls talk: An examination of high school physics classes. *Paper presented at the annual meeting of the National Association for Research in Science Teaching*. Atlanta, GA.

Dasgupta, N. & Stout, J. (2014). Girls and women in science, technology, engineering, and mathematics: STEMing the tide and broadening participation in STEM careers. *Policy Insights from the Behavioral and Brain Sciences*. 1 (1), pp. 21-29. Sage.

Gilbert, J. K. (2005). Visualization: A metacognitive skill in science and science education. In *Visualization in science education* (pp. 9-27). Springer Netherlands.

Gilbert, S.W. (2011). Models based science teaching: Understanding and using mental models. Arlington, VA: NSTA Press.

Halpern, D., Aronson, J., Reimer, N., Simpkins, S., Star, J. and Wentzel, K. (2007). *Encouraging girls in math and science.* NCER 2007-2003. Washington, DC: National Center for Education Research, Institute of Education Science, U.S. Department of Education.

Hill, C., Corbett, C., & St Rose, A. (2010). *Why so few? Women in science, technology, engineering, and mathematics*. American Association of University Women. 1111 Sixteenth Street NW, Washington, DC 20036.

Ingham, A.M., & Gilbert, J.K. (1991). The use of analogue models by students of chemistry at higher education level. *International Journal of Science Education*, 13, pp. 193-202.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MA: Harvard University Press.

Lavy, V. & Sand, E. (2015). On the origins of gender human capital gaps: Short and long term consequences of teachers' stereotypical biases. *National Bureau of Economic Research Working Paper* No. 20909

Lehrer, R., & Schauble, L. (2006). *Cultivating Model-Based Reasoning in Science Education*. Cambridge University Press.

Linn, M.C. (1993). Gender, mathematics, and science: Trends and recommendations. In *Restructuring learning: 1990 Summer Institute papers and recommendations by the Council of Chief State School Officers*: Wash. DC: CCSSO, pp. 47-67.

Nersessian, N. J. (2002). The cognitive basis of model-based reasoning in science. *The cognitive basis of science*, 133-153.

Nieswandt, M. (2007). Student affect and conceptual understanding in learning chemistry. *Journal of Research in Science Teaching*, *44*(7), 908-937.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049-1079.

Schwartz, D. L., & Heiser, J. (2006). Spatial representations and imagery in learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences*, (pp. 283-298). New York, NY, US: Cambridge University Press, xix, 627 pp.

Schwarz, C., Reiser, B., Davis, E., Kenyon, L., Acher, A., Fortus, D., Schwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632-654.

Seymour, E., & Hewitt, N.M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Boulder, Co: Westview Press.

Singh, K., Granville, M., & Dika, S. (2002). Mathematics and science achievement: Effects of motivation, interest, and academic engagement. *The Journal of Educational Research*, *95*(6), 323-332.

Sinnes, A., & Loken, M. (2014). Gendered education in a gendered world: Looking beyond cosmetic solutions to the gender gap in science. *Cultural Studies of Science Education.* 9 (2), pp.343-364. Springer.

Steinberg, M.S. (2004). *The CASTLE project student manual*. Pasco Scientific.

Stelzer, T,; Brookes, D. T.; Gladding, G.; & Mestre, J. P. (2010). Impact of multimedia learning modules on an introductory course on electricity and magnetism. *American Journal of Physics.* 78 (7), pp 755-759.

Valian, V. (2007). Women at the top in science - and elsewhere. In S. J. Ceci and W. M. Williams (Eds). *Why aren't more women in science?: Top researchers debate the evidence*, (pp. 27-37). Washington, DC, US: American Psychological Association.

Vosniadou, S. (2002). Mental models in conceptual development. In L. Magnani & N. Nersessian (Eds.), *Model-based reasoning: Science, technology, values* (pp. 353–368). New York, NY: Kluwer/Plenum.

Wang, X. (2013). Why students choose STEM majors: Motivation, high school learning, and postsecondary context of support. *American Educational Research Journal,* Oct. 2013, 50 (5), pp. 1081-1121.

Williams, E. G. (2011). *Fostering high school physics students' construction of explanatory mental models for electricity: identifying and describing whole-class discussion-based teaching strategies.* (Unpublished doctoral dissertation). University of Massachusetts, Amherst.

Williams, G., & Clement, J. (2015). Identifying multiple levels of discussion-based teaching strategies for constructing scientific models. *International Journal of Science Education*, *37*(1), 82-107.

Windschitl, M., Thompson, J. and Braaten, M. (2008), Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education.*, *92*, 941–967.

Zeldin, A. L., Britner, S. L. and Pajares, F. (2008), A comparative study of the self-efficacy beliefs of successful men and women in mathematics, science, and technology careers. *Journal of Research in Science Teaching.*, 45: 1036–1058.