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Abstract

This paper briefly reviews evidence on gender inequities in science education. It argues that making science instruction more effective is one way in which greater equity can be achieved. A line of research conducted in my laboratory dealing with conceptual change (CC) approaches to science instruction is discussed. CC instruction explicitly activates students' pre-existing conceptions, leads students to be dissatisfied with less than adequate conceptions, and helps students construct more effective conceptions. Across several studies, CC instruction was found to be more effective than didactic instruction. CC features added to science text and science lessons facilitate learning for both males and females. Finally, I argue that in adopting new mathematics and science curriculum standards, it is important to recognize the need to promote CC and that "minds-on' as well as "hands-on" approaches are essential to effective learning.

Once upon a time, a quantitatively oriented cognitive educational psychologist set off on a journey to investigate and contribute something to research in science education. On that journey, he probably became a little less "objectivist," more appreciative of alternative research approaches, more aware of problems in teaching science, and of reasons for the under-representation of women and minorities in some domains of science. This paper is, in part, a story of that journey.

I have three purposes in this paper: (a) to highlight the problems of under-representation in some domains in science, (b) to discuss some of my research on the conceptual change (CC) model in science education, and (c) to highlight the need to include CC approaches in the emerging constructively oriented, activity- and manipulative-focused science curricula.

Let me begin by highlighting some data on under-representation in science. Because my research only involves gender, I will focus on gender under-representation, but I recognize that ethnic under-representation deserves equal emphasis.

A common stereotype is that women show less interest in science and that women perform less well in science. Like most common stereotypes, this one has a grain of truth but is less than entirely accurate. Matthews (1990) reported that women comprise about 45% of the bachelor's degrees in the life sciences and mathematics. Thus, gender differences are not large in these areas. However, women only receive about 35% of the bachelor's degrees in computer science, 30% in physical science, and 15% of in engineering. Clearly, a more serious under-representation occurs in the latter areas. Astin and Astin (1992) reported that about 50% of first year students and graduates in biology are women, but only about 35% of first year students and graduates in physical science and 20% of first year students and graduates in engineering are women. Vetter (1988) reported that approximately 12% of employed physical scientists are women, 22% of individuals employed in mathematical fields are women, and 25% of individuals employed in computer programming or scientist positions are women. The reason is not because there are no women applicants. Vetter (1988) reported that a higher proportion of women than men are seeking employment in these fields.

The math/science "pipeline" data also support gender under-representation. Berryman (1983) used the pipeline metaphor to represent the flow of students into careers that require substantial education in mathematics and science. Leakage from the pipeline was large. Of the 20% of all students who report some interest in science/mathematics careers early in high school, only 5% complete bachelor's degrees in these fields and only 0.2% complete doctoral degrees (Task Force on Women, Minorities, and the Handicapped in Science and Technology, 1988). Hilton and Lee (1988) reported gender related pipeline data from the "High School and Beyond" studies. About 20-25% of the males are in the pipeline in grade 12; this drops to about 5% of males graduating college in the sciences and 2-3% in graduate school. For females the comparable numbers are 7%, 2-3%, and 1-2%. Clearly, females represent a smaller proportion of the pipeline than do males. In one of the most sophisticated of the pipeline studies, Brookhart (1994) examined individuals who left, entered and persisted in the math/science/engineering pipelines. By the first year of college, only about two thirds as many females (10%) as males (15%) remained in the pipeline. Clearly, women are underrepresented in physical science occupations because fewer traverse the pipeline.

Why is it important that women elect not to pursue physical science or engineering fields? Here are three important reasons:

1. Physical sciences fields are correlated with higher paying positions in our society; thus, under-representation of women contributes to gender inequities in salaries paid to men and women.
2. It is likely that at least part of the under-representation of women represents structural biases that inhibit women from selecting physical science fields.
3. Science loses women's perspectives women's perspectives that may yield advances on some problems.

Why are there fewer women in science? Much research supports the notion that women receive less encouragement in the physical sciences and that the climate and approaches to knowledge in the physical sciences may be less consistent with the average woman's characteristics than the average man's. Several sources report that both male and female teachers interact differently with boys and girls when teaching science and math. They call on boys more than girls. Compared to boys, girls are more likely to receive lower level questions and feedback that implies lower ability and provides excuses for mediocre performance (See Kahle & Meece (1995) for a comprehensive summary of research on gender differences in science education.) Keller (1982), Rosser (1986, 1990), and Rosser and Kelly (1994) argued that structural biases inhibit women from pursuing science and engineering. These biases included glass ceiling labor practices that prohibit women from reaching decision making levels, diminishing of "women's" scientific problems (e.g., menstrual cramps, breast cancer), use of males to represent the species, and sexual" harassment.

Rosser (1990) argues that the epistemological approach of science is inconsistent with women's approaches to knowledge. As a result, the intellectual atmosphere of science is chilly to women. She argues for differences between typical women's and typical men's approaches to science (Figure 1).

I disagree partially with Rosser. The gender differences in ways of doing science are far less absolute than she implies and variance within genders is far greater than between genders (see pipeline argument below). However, she does make a case that typical differences exist and that many women, particularly in higher education, stop taking science because of incompatibilities in ways of knowing. Overall, the research literature is sufficiently strong to support the conclusion that differences in educational treatment, coinciding with differences in social expectations, contribute substantially to the under-representation of women in physical science.

As an aside, I will comment on one interpretation of the pipeline data. Rosser (1990) and others (e.g., Anderson, 1992; Bowen, 1990), have argued that the science education pipeline supports the hypothesis of differences in men's and women's ways of knowing. While there may be average gender differences in ways of knowing, differences between the genders are small relative to individual differences within the genders. Moreover, the pipeline data make clear that the overwhelming majority of both female and male students never enter or leave the science/math pipeline. How can the fact that over 90% of both males and females elect non-science/math careers be evidence of gender incompatibilities in ways of knowing? Perhaps the 90% plus of males who avoid science also prefer women's ways of knowing. If so, what justification is there for gender labeling such ways of knowing? I think Tobias' (1990) view, that both women and men in the "second tier" prefer alternative classroom approaches to those typically used in the physical sciences and engineering, is probably closer to the truth. But I don't want to belabor this point; a more important question to me is how to help all students understand science better and how to remove artificial barriers that may prohibit female students from considering or pursuing careers with mathematical or scientific underpinnings.

Women	Men
♦ Expansion of the types of observations used in science	♦ Fewer types of observations used in science
♦ Increasing the length of the observational period	♦ Shorter observational periods
♦ Acceptance of personal experience as part of scientific data	♦ Rejections of personal experience as part of scientific data
♦ Deeming women's problems worthy of research	♦ Focusing on problems related to men
♦ Including gender as part of scientific hypotheses	♦ Using men to represent the species, excluding gender as part of scientific hypotheses
♦ Adopting a more holistic approach to scientific problems	♦ Adopting a more narrow, less contextual approach to scientific problems
♦ Combining qualitative and quantitative methods	♦ Focusing on quantitative methods
♦ Greater use of cross-disciplinary research	♦ Less emphasis on cross-disciplinary research
♦ Including females as research participants	♦ Excluding females as research participants
♦ Awareness of race, class, sexual orientation, and religious biases	♦ Ignoring possible race, class, sexual orientation,and religious biases
♦ Theories that are relational, interdependent and multi-casual, instead of hierarchical and reductionist	♦ More reductionist, less situated theories
♦ Less competitive models of interaction between scientists	♦ More competitive models of interaction between scientists
♦ Greater emphases on research methods that emphasize participants/researcher interaction	♦ Emphasis on research methods that minimize research/participant interaction

Figure 1. Differences between typical women's and men's approaches to science.

What should we do about gender inequities? Many reforms urged by feminist writers on science should work effectively for both female and male students. This section will focus on one reform related to my research. That reform is to teach science more effectively. Science often is taught in a way that makes it difficult for students to understand. Obviously, many dedicated elementary and secondary science teachers lead exciting and intellectually challenging lessons. However, I think that many students drop out of the science pipeline because they don't find science either exciting or understandable as it is taught.

Science classes often consist of students memorizing formulae to compute answers to word problems. Because there is little emphasis on providing students with a conceptual understanding of the underlying theory or on addressing students' preexisting ideas, students often don't understand the formulae. So students adopt an approach that one of my undergraduate assistants called "plug and chug." She described her performance in science classes as grabbing numbers from the problems, plugging them into some memorized formula, and chugging out an answer.

Such classes don't help students focus on developing conceptuerts reason first from conceptual, qualitative models before applying quantitative reasoning. One way to help students understand science more effectively may be to help them develop better qualitative models. In the science education literature, the approach called conceptual change (CC) has focused on helping students change their conceptual qualitative models. During the last several years, I have been conducting research on CC and science learning and education (see Wandersee, Mintzes, & Novak (1995) for a review of the CC literature).

Within the science education area, conceptual change is jargon for an approach that has its roots in Piaget's concept of disequilibrium and philosophical studies of Zeitgeist change or paradigm shift. The fundamental notion is that the learner can have pre-existing conceptualizations or knowledge structures that may be inconsistent with the knowledge structures the cultures of the subject matter domain have constructed. These pre-existing knowledge structures may interfere with the learner constructing new knowledge consistent with the culture that defines the subject matter. Put more simply, the learner may have beliefs that are inconsistent with the knowledge beliefs of subject matter experts. In this case, CC theory postulates that learners do not meekly abandon beliefs. Instead, they may reinterpret the presented message in a way consistent with their beliefs. Alternatively, learners may engage in a kind of double think and hold to prior beliefs, but memorize sufficient of the subject matter knowledge to pass school-based, inauthentic tests.

For example, many students believe that heavier things fall faster than lighter things. According to CC theory, students do not simply accept the physics statement that objects fall at the same rate. Rather, students memorize a formula, $s= 1/2\ gt^2$, which allows them to calculate how far an object falls in a given amount of time or how fast it is falling after so many seconds. They answer quantitative test questions correctly, but still believe that heavier things fall faster than lighter things.

CC theory holds that it is necessary to produce what Piaget called disequilibrium to encourage the student to construct a revised conceptualization. Posner and associates, in what is probably the best known version of CC theory, argue that education needs to induce dissatisfaction in the learner (Posner, Strike, Hewson, & Gertzog, 1982). Once the learner is dissatisfied, the instruction presents a new conceptualization that the learner will find intelligible, plausible, and fruitful. An intelligible, plausible, and fruitful description will lead the dissatisfied learner to construct a revised conceptualization.

CC theory argues that traditional instruction does not directly try to address students' misconceptions, but should. Activating prior knowledge and explicitly addressing and challenging alternative conceptions is necessary for the student to construct a revised, understanding.

My students and I began to investigate how to use CC in facilitating learning from text. The work was influenced by the early work of Roth (1984). Most work on CC had involved small groups and in-class instructional activities. Working with Charles Anderson, Roth adapted the Posner et al. (1982) CC approach to text. She included CC features in existing texts on how plants produce food. Compared to students using the original text, students using the CC texts were more likely to adopt CC thinking and construct understandings of plant and food consistent with botanist culture.

Reasoning that text in some form will always be an important component of instruction, we began to investigate how CC features added to text might help students construct more complete understandings of series and parallel circuits in electricity. In an early study, Wang and I (1991) modified an existing middle school physical science text to contain CC features. Our modifications were straightforward. Fredette & Clement (1981), Osborne (1983), and Shipstone (1984) had identified common misconceptions students had about series circuits. For example, a developmentally early misconception is called the sink conception. Students believe a single wire connection between a battery and a bulb will light the bulb because electricity flows like water from the battery to the bulb. To activate and challenge the students' misconceptions, we created a prototypical situation such as a picture of a battery and bulb connected by a single wire connection, and asked students to predict if the bulb would light. This is shown in the Figure 2.

Next, we directly addressed the misconception in the text by asserting, "Some students believe that a single wire connection between a battery and bulb will cause the bulb to light. These students are wrong." Then, as indicated in Figure 3, we presented evidence that the bulb would not light. We repeated this basic approach for each of the identified misconceptions. (Subsequently, we found that Alvermann and her colleagues had developed a similar approach that they called refutational text; e.g., Hynd & Alvermann, 1986.)

To control ability variance, we assessed students' verbal ability and obtained a measure of their experience with electricity. Because of my past research interests, we also included or did not include adjunct questions in text that students had to answer. The adjunct questions focused on calculations. So our independent variables were: two types of text (traditional versus conceptual change), presence or absence of adjunct questions, and gender.

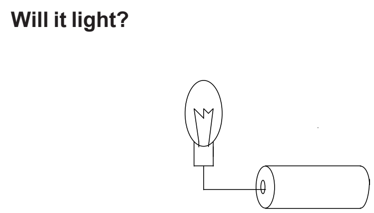

Figure 2. Question designed to elicit pre-existing conception from Wang and Andre (1991).

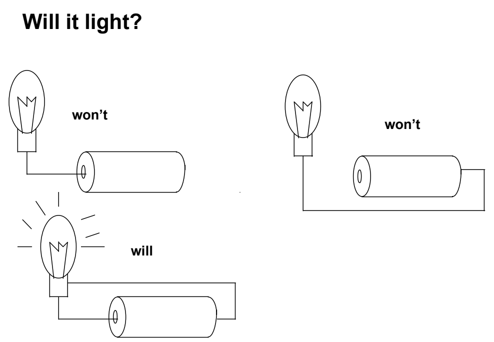

Figure 3. Example of dissatisfaction inducing text diagram.

What did we find? CC features produced a significant positive effect on conceptual understanding, but this main effect was modified by a Text Type X Question Type X Gender interaction. For men given adjunct questions and for women not given adjunct questions, the effect of CC text was positive. For women given adjunct questions and men not given adjunct questions, CC was neutral. We speculated that these effects were due to differences in motivation. Women have lower reported interest in physical science (Kahle & Meece, 1995). The adjunct question conditions imposed heavy task demands on students. Students with a lower level of interest may not have been sufficiently motivated to work very hard to meet those demands, but students with a higher level of interest may have been sufficiently motivated to meet the demands of processing adjunct questions and CC features. I wasn't satisfied with this explanation, but it led us to explore the relationship between interest and CC text.

In Chambers and Andre (1997), we replicated the Wang and Andre (1991) study but added a measure of interest in electricity along with the experience and verbal ability measures. The independent variables were gender and text type. We also modified the text and the posttest slightly.

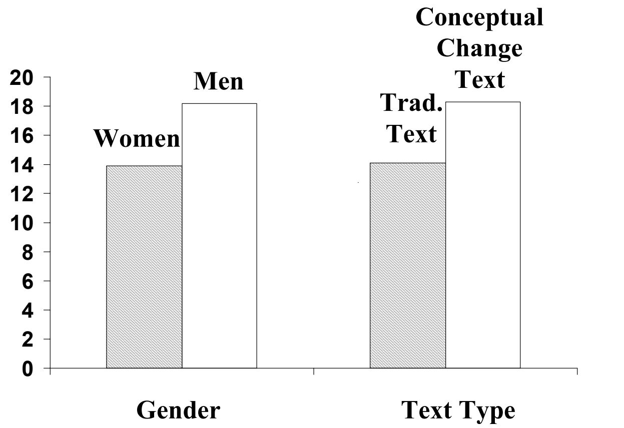

Figure 4. Gender and Text type main effects in analysis without covariates from Chambers & Andre, 1997.

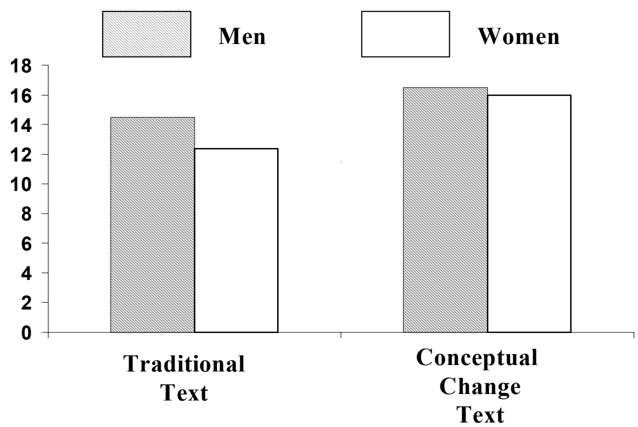

Figure 5. Adjusted means for men and women given traditional and conceptual change text in analysis with covariates (Chambers & Andre, 1997).

What did we find? We first analyzed the data without controlling for interest or experience. There were significant main effects of gender and text type. Figure 4 displays the means. Men apparently did better than women and CC text led to better performance than the traditional text. Next, we analyzed the data using a covariance analysis that controlled for verbal ability, experience, interest, and pretest knowledge. Only the main effect of text type remained significant (see Figure 5). CC text led to better performance than did traditional text for all students. In other words, when we did not control for interest and experience, men did better than women. When we controlled for pre-existing differences, women scored about the same as men.

We replicated these findings in a second study (Chambers & Andre, 1996). The same basic variables were included. Again, we first analyzed the data without controlling for pre-existing differences. This analysis yielded significant main effects for gender and for text type, again men apparently outperformed women and CC text led to superior performance.

When we controlled for preexisting differences, again only the effect of text type was significant. Again, gender differences in science learning seem to be due to differences in experience and interest.

In Chambers et al. (1994), we also found that controlling for the effects of verbal ability, prior experience, and interest eliminated a main effect for gender. In this study, we had five instructional conditions. The first was a traditional text on electricity. In the second condition, students received the traditional text augmented with more examples and diagrams. In the third condition, students received the CC text. In the fourth condition students received a CC text. However, instead of being told that circuits would or would not work, students were told to turn to a computer simulation that allowed them to build electrical circuits and to determine for themselves if the circuit would or would not work. Finally, in a fifth condition, students received CC text, but, after making predictions, were told to turn to actual light bulbs, batteries, and wires to test circuits.

On a delayed posttest, when interest and experience were not used as covariates, gender produced a significant effect. But when interest and experience were covaried, only the effect of CC condition was significant for females, but not males. Females receiving CC text did better. Figure 6 displays the means. The means for the men were quite high, and we might have failed to find an effect because of ceiling effects.

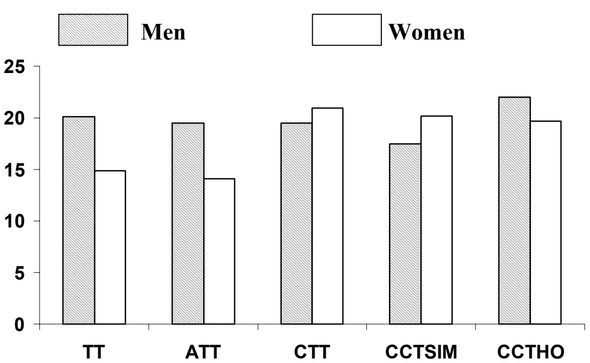

Figure 6. Adjusted means as a function of gender and condition from Chambers et al. (1994) TT-Traditional, Text, ATT-Augmented Traditional Text, CCT-Conceptual Change Text, CCTSIM-CCT with simulation, CCTHO-CCT with hands-on experience

One other of my studies supports these findings. Carlsen and Andre (1992) used CC texts in conjunction with computer simulations to help students learn about electricity. When prior experience was controlled, there were no gender differences and CC texts led to better performanc and women show similarities in how they learn science. In each of these studies, gender differences were found if pre-existing differences in knowledge, interest in, and experience with the subject matter were not considered in the analyses. When such differences were statistically eliminated, there were no gender differences in how men and women learned from CC text.

These results are consistent with the results of a study by Burbeles and Linn (1988). Burbeles and Linn found that boys and girls both profited from experiences that contradicted their prior expectations, but that, probably because of pre-existing experiential differences, girls required more contradicting experiences than did boys to reach the same level of understanding. Finally, a recent metaanalysis of CC approaches reported by Guzzetti, Snyder, Glass, and Garnat (1993) found significant and moderately strong effects of CC approaches. I think we can conclude that CC approaches do help both male and female students develop better conceptual understandings of physical science topics.

Recently NCTM and NSTA published new standards for science and mathematics teaching. These new standards argue that students should be involved in learning mathematics and science as a thinking activity. Learning to "mathematicize" or to "science", that is to use mathematical thinking to recognize patterns and solve meaningful problems or to use scientific procedures to investigate authentic problems, lie at the core of the new standards. Viewing the student as an active participant in the construction of his/her knowledge is central to the new standards.

I heartily encourage this approach and think that at least 50% of instructional time in science should be devoted to authentic investigative projects in which students do science. There are many lessons and curricula being developed which use this approach.

But I am concerned that we may miss the CC nugget in the gold rush to activity-oriented mathematics and science. Based upon their research with teachers, Anderson and Smith (1988) describe problematic activity-oriented and discovery-oriented teachers of science. Let me quote their descriptions.

The *activity-driven teachers* are "uncomfortable teaching science. These teachers focus primarily on the activities to be carried out in the classroom: textbook reading, demonstrations, experiments, answering questions, and the like. These teachers are unsure how specific activities contribute to student learning" (p. 100).

Discovery-oriented teachers "using activity-based programs try to avoid telling their students answers, encouraging them instead to develop their own ideas from the results of experiments. They ask their students to interpret their observations in open-ended ways, assuming that the performance of the experiments will eventually lead students to develop the appropriate scientific conceptions. In the absence of direct information and feedback from the teachers, however, students generally use their own misconceptions as the basis for interpretation of activities" (p. 100).

I am concerned that without an adequate understanding of conceptual change, the necessity to allow students opportunity and time to accommodate will not be given. Let me share a case reported by Champagne, Klopfer, and Gunstone (1985). Seventh graders were taught a unit on falling bodies using a conceptual change approach and much hands-on experience. But even after several weeks, some students continued to argue for their original preconceptions and propose other alternative experiments that might show that heavier bodies would fall faster than lighter bodies. It was not a simple matter for the students to give up or change their preconceptions. Champagne et al.'s results demonstrated that these students would not have given up their preconceptions by simply exploring falling bodies. The students needed to have the teacher or the instruction point out the contradiction between their belief system and the results of their experiments. The students needed to be encouraged to create alternative qualitative models that encompassed their new observations. Teachers needed to be somewhat directive in facilitating students' thinking towards construction of an appropriate new model.

Conceptual change approaches can work in real schools. In 1993, with some colleagues, I conducted a workshop dealing with CC in the areas of motion and electricity for middle school teachers. After studying CC, teachers planned CC lessons for their students based upon the workshop materials (electricity and motion simulations and hands-on kits). In the following academic year, the teachers taught the lessons to their pupils. Their students displayed a more advanced conceptual understanding of motion and electricity compared to middle-school students taught with traditional lessons.

The CC approach is only one of many that can work to help students construct more adequate conceptual understandings in physical science. What features should lessons designed to promote conceptual understanding have? Such lessons should contain motivating and intellectually challenging activities that lead students to compare their preconceptions with the content being taught and direct student thinking towards constructing a revised conceptual model similar to the ideas of the culture of scientists. Such lessons emphasize developing the conceptual model before developing strength in quantitative analysis. Overall, the focus is on ensuring the instructional activities are minds-on as well as hands-on (I want to thank whoever first coined the wonderful minds-on phrase.) Certainly, authentic investigation activities are a critical component in reforming science education. But education should not adopt the obvious hands-on features of inquiry activity without incorporating the less obvious minds-on features. Effective instruction needs to incorporate CC features to achieve the full benefit of the proposed new standards. Instruction that incorporates these features can help to improve science education for all students and can thereby contribute to reducing gender and minority inequities in participation in science.

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