Moving Science Education Out of the Classroom: The Impact of Collaboration and Conceptual Change Activities on Learning

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ABSTRACT

In order to support the Chief of Naval Operations' vision of a "Revolution in Training", the Navy is committed to shifting much of its training out of traditional classrooms and into more distributed environments via computer-based training (CBT) and distance learning (DL) courses. However, designing effective instruction and learning activities that can be conducted without a co-located instructor is challenging, especially in complex, technical domains. This paper will present and discuss the results of two parallel experiments investigating the impact of specialized instructional activities on science learning when an instructor is not available to answer questions, counter misconceptions or provide additional information. Both experiments examine two types of specialized instruction recommended in the research literature – working collaboratively with other students and completing conceptual change activities. One experiment assesses the effectiveness of these techniques in the domain of basic direct current (DC) circuits and the other experiment focuses on classical mechanics. A total of one hundred sixty participants (80 per experiment) completed a pre-test, worked through a CBT lesson, conducted a series of hands-on activities, and then took a post-test. Participants completed the experiment either individually or collaboratively with another student, with half of the individuals and half of the collaborative pairs also completing conceptual change activities. Scores from the pre- and post-tests were used to assess learning outcomes. Results from the circuits domain suggest that, among participants who were not exposed to conceptual change activities, working collaboratively led to significantly better learning than working individually. However, completing conceptual change activities did not appear to impact learning outcomes. The data collected for mechanics, a conceptually more difficult topic, indicate that learning outcomes were not differentially affected by either conceptual change activities or working collaboratively. Future research questions and implications for Navy training programs will be discussed.

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INTRODUCTION

In order to support the Chief of Naval Operations' vision of a "Revolution in Training", the Navy is committed to shifting much of its training out of traditional classrooms and into more distributed environments via computer-based training (CBT) and distance learning (DL) courses. However, designing instruction and learning activities that can be conducted effectively without a co-located instructor is challenging, especially in complex, technical domains. This paper will present and discuss the results of two experiments investigating the impact of specialized instructional activities on science learning when an instructor is not available to answer questions, counter misconceptions or provide additional information.

The remainder of the Introduction will describe existing research into instructional strategies that appear to be effective in science education and technical training when applied in a classroom environment. The majority of the paper will describe two experiments that were conducted to investigate the effectiveness of these instructional strategies in a computer-based, instructorless environment. Finally, in the Discussion, we will consider possible explanations for our experimental results and address the implications of this research for the design of Navy technical training systems.

Science Learning in the Classroom

There has been a lot of research investigating how students of all ages learn scientific and technical subject matter in a classroom environment. The single most consistent and robust finding in the research literature is that people of all ages and at all levels of education, even those with advanced technical degrees, have conceptual understandings of the physical world that are considered incorrect by the scientific community. For example, many children believe that the world is flat (Nussbaum, 1985), adolescents typically believe that the amount of water an object will displace depends, in part, on the weight of the object (Burbules & Linn, 1988), and most adults believe that any movement of an object implies that a force is acting on that object in the direction of the movement (Clement, 1982).

The second most consistent and robust finding that has arisen from this research is that these misconceptions are very resistant to change (Champagne, Klopfer & Anderson, 1980; Eylon & Linn, 1988; Linn, 1986; McDermott, 1984). Many studies of physics show that even college students with high grades in physics courses often maintain the same incorrect naïve theories of physics as adolescents with little or no physics education (Champagne, Klopfer & Anderson, 1980; diSessa, 1982). Similarly, Berg and Brouwer (1991) reported that even high school physics teachers harbored some of the most common misconceptions about gravitational force and motion.

In other words, these subjects are difficult to learn, even when studied in a traditional classroom setting with an instructor present. As might be expected, the fact that traditional instructional methods are often ineffective at overcoming people's misconceptions has produced a surge of interest in proposing and investigating alternative instructional techniques.

Many of the alternative instructional techniques that have been proposed in the literature are based on the conceptual change model (CCM) put forward by Posner and his colleagues (1982). These researchers suggested that there are four conditions typically associated with conceptual change. These conditions can be summarized as (1) experiencing dissatisfaction with an existing conception, (2) having a basic understanding of an alternative conception, (3) recognizing the potential of the alternative conception to resolve problems inherent with the existing conception and (4) recognizing the additional power, versatility and fruitfulness of the alternative conception. More recently, Smith, Blakeslee and Anderson (1993) posited that all four of these conditions must be met in order for a person to be willing to update or replace an existing conception with a new one.

Various instructional strategies based on the CCM have been described in detail previously (e.g., Tao & Gunstone, 1999 a & b; Chambers & Andre, 1997, 1995; Smith et al., 1993; Wang & Andre, 1991). These studies all use minor variations of the same basic instructional approach. Students are first encouraged to verbalize and formalize their intuitive theories and the implications of those theories. Students then participate in activities designed to test those conceptions. These activities may be designed by either the teacher or the students themselves. In cases where the students' theories are incorrect an anomaly will become apparent during these activities, and the correct conceptualization is brought to the students' attention. This instructional technique is often referred to as the application of the "predict-verify-evaluate" (or PVE) cycle.

An alternative cluster of instructional strategies believed to help overcome scientific misconceptions involves the use of collaborative learning activities (e.g., Dillenbourg, 1999). It has been suggested that two cognitive mechanisms account for the success of collaborative learning. First, collaboration requires that each person explain and justify his or her conceptualization(s). Second, social conflict between opposing conceptualizations may also help refine and/or modify inaccurate conceptualizations.

Field studies of the effectiveness of these two types of instructional strategies, the PVE cycle and the use of collaborative learning groups, have been conducted in a classroom context with an instructor present. The current research was designed to extend these studies and investigate the effectiveness of these instructional techniques in a distributed learning environment, without an instructor present.

The main contrast of interest will be the comparison between the effectiveness of traditional instruction and instruction that incorporates the PVE cycle in a scientific domain. The hypothesis is that the PVE cycle will be significantly more effective than traditional instruction. The second contrast of interest will be the comparison between performance in the individual condition and the collaborative condition. The hypothesis is that, students in the collaborative condition will learn more than students in the individual condition.

To increase the generalizability of the results, two studies were conducted, using different scientific domains. The first study focused on topics in basic DC electricity and circuits, and the second study focused on classical mechanics. These domains were selected for two reasons. First, they both have direct relevance and importance for Navy training. Second, it has been hypothesized that they differ in important qualitative ways, including the probable origin of common misconceptions and the nature of their primary elements. Biswas and colleagues (1997), for example, propose that most misconceptions in electricity and circuits are formed in the classroom itself, sometimes through the inappropriate use of analogies. These researchers also point out that this domain is primarily composed of invisible elements. Many researchers, on the other hand, (e.g., Clement, 1982) believe that misconceptions in classical mechanics arise from our experiences interacting with visible, tactile objects in the physical world, long before we ever reach a classroom.

STUDY 1: BASIC DC CIRCUITS DOMAIN

Method

Participants

A total of 80 students, 26 males and 54 females, from the University of Central Florida completed the experiment. Their average age was 20.69 years (SD = 2.96). Students received extra credit points, payment, or some combination of the two in exchange for their participation.

Design

The two independent variables, type of instruction (traditional versus PVE-cycle based) and social context (individual versus collaborative) were manipulated as between-subjects variables. Participants were randomly assigned to one of four conditions: individual w/traditional instruction, individual w/PVE cycle-based instruction, collaborative w/traditional instruction, and collaborative w/PVE cycle-based instruction. In the individual conditions, the participant worked alone throughout the entire experiment. In the collaborative conditions, a pair of participants worked together on the lesson and activities, but took the pre- and post-tests separately.

In all cases, the participants worked through a computer-based lesson on the topic and then completed a series of hands-on activities. The type of instruction varied only during these activities. In the traditional condition, students were asked to follow a series of directions and record the results. In the PVE cycle condition, students were first asked to predict what they thought would happen in each activity. Then, upon completion of that activity, they were asked to compare the results to their predictions and reason about any discrepancies.

Materials

A self-paced computer-based training (CBT) lesson was created using Toolbook© that covered introductory DC circuits topics, such as current, voltage, resistance, power, complete circuits, and parallel and series configurations. Each page of the lesson included text on the right and supporting images on the left. Forward and back buttons were provided for navigation through the lesson, and a progress bar at the top of the screen indicated the relative position of the current page within the context of the complete lesson. Several multiple-choice questions were embedded in the lesson. The CBT was designed to provide immediate (canned) feedback in response to any answer selected from the available options, and to prevent a student from moving forward in the lesson until the correct answer was selected.

Pre- and post- tests were developed to assess the participants' knowledge of the material. These tests were also presented via Toolbook©. Each test consisted of thirteen multiple-choice questions. After a student selected his/her answer for each question, a text box appeared on the screen and the student was asked to type in an explanation for his/her choice. No feedback was provided to the student about the accuracy of his/her choices. Whenever possible, the distractors used in the tests were chosen based on common circuit misconceptions found in the research literature.

Four hands-on activities were designed to accompany the CBT lesson on electricity and circuits. Each activity involved building one or more simple circuits, using batteries, light bulbs, switches and wires (with attached alligator clips) and making observations of bulb brightness and/or measuring voltage and current with a voltmeter and compass respectively. These activities were explicitly focused on misconceptions that have been found to be prevalent in the research literature, such as the misconception that voltage is only present in a complete circuit and the misconception that current weakens as it moves through a circuit.

A worksheet was designed for each activity that provided the directions for completing the activity and space for recording the results and/or observations made during the activity. In addition, an explanation handout was created for each activity, which summarized the observations that should have been made and explained the underlying principles that the activity had been designed to illustrate.

Finally, a prediction worksheet was designed for each activity. These worksheets asked participants to predict what would happen during an activity before actually conducting it, and they were only given to participants in the PVE cycle condition. The prediction worksheets had specific questions, such as "Will the bulb be on or off when the switch is open?"

Procedure

Participants were either run individually or in collaborative pairs. We will describe the procedure from the perspective of an individual participant, and then address any modifications made for collaborative pairs.

First, the experimenter read a pre-briefing script to the participant, which outlined the schedule of the experiment, and explained the extra credit and payment policies. After signing the informed consent paperwork, the participant completed a series of questionnaires, including a demographic questionnaire, a personality inventory, a measure of locus of control, and a goal orientation measure.

This paperwork was followed by a brief computer video that described how to use the computer interface for the lesson and tests, after which the participant completed the pre-test. Following the pre-test, the participant was offered an optional break before beginning the computer-based training lesson. Most participants were able to complete the CBT in under an hour.

After another optional break, the participant completed the four hands-on activities. In the traditional instruction condition, for each activity, the participant followed a series of explicit written directions, recorded several observations and then read the explanation handout.

In the conceptual change condition, there were two modifications to the activity phase of the experiment. First, the participant was asked to complete the prediction worksheet before conducting the activity. Then, after completing the activity, the participant was asked to note whether or not the results he/she found agreed with his/her prediction(s), and to explain any discrepancies.

Another break was offered before the participant completed the post-test, which was similar to the pre-test. Finally, after the student finished the test, he/she was given a subjective reaction questionnaire that asked about his/her experiences with the lesson and activities. Specifically, the participant was asked to indicate his/her level of agreement (or disagreement) with such statements as: "I thought the computer-based lesson was boring," and "I thought the hands-on activities were well designed and easy to follow." Before leaving, the participant was thanked and debriefed. The experiment (including breaks) lasted approximately 3 hours.

If two participants were assigned to complete the experiment in a collaborative pair, the same basic procedure was followed. Participants were asked to complete the pre- and post-tests individually, however they were instructed to "work together" during the CBT and the hands-on activities. In particular, pairs assigned to the PVE cycle condition were asked to try to come to agreement on their predictions for the outcomes of the activities. Finally, in addition to the CBT reaction questionnaire, those in the collaborative conditions filled out a collaboration reaction questionnaire addressing their interaction with their partner, by indicating their level of agreement or disagreement with such statements as "I went out of my way to ensure that our partnership would be a success," or "My partner contributed significantly to our task-related discussions."

Results

A 2 (instructional condition) x 2 (social condition) between-subjects analysis of covariance was conducted. The dependent measure was the post-test score. SAT scores were used as the covariate because this was the only measure significantly correlated with post-test scores, r=0.423, p=.002. (Unfortunately, as some students did not report their SAT scores, this reduced our degrees of freedom). There were no significant main effects of either independent variable, but there was a significant interaction, $F(1,48)=7.062$, $p=0.011$, illustrated in Figure 1.

Follow-up tests revealed that, among participants in the traditional condition, those who worked collaboratively (M=9.75, SD=0.54) performed significantly better on the post-test than those who worked individually (M=7.99, SD=0.53). However, for participants in the PVE cycle condition, there were no statistically significant differences between those who worked individually (M=9.33, SD=0.52) and those who worked collaboratively (M=8.29, SD=0.53).

Discussion

The two instructional techniques under investigation in this study were the conceptual change technique and the use of collaborative learning. We were particularly interested in determining whether or not these instructional techniques could be implemented effectively in a distributed learning environment, without an instructor present. Hence, the techniques were implemented via a computer-based lesson and the use of worksheets. Participants were responsible for their own level of effort and attention to detail when reviewing the lesson and conducting the activities.

Our results were mixed. Neither technique alone showed a significant learning advantage. However, there was a significant interaction. When faced with

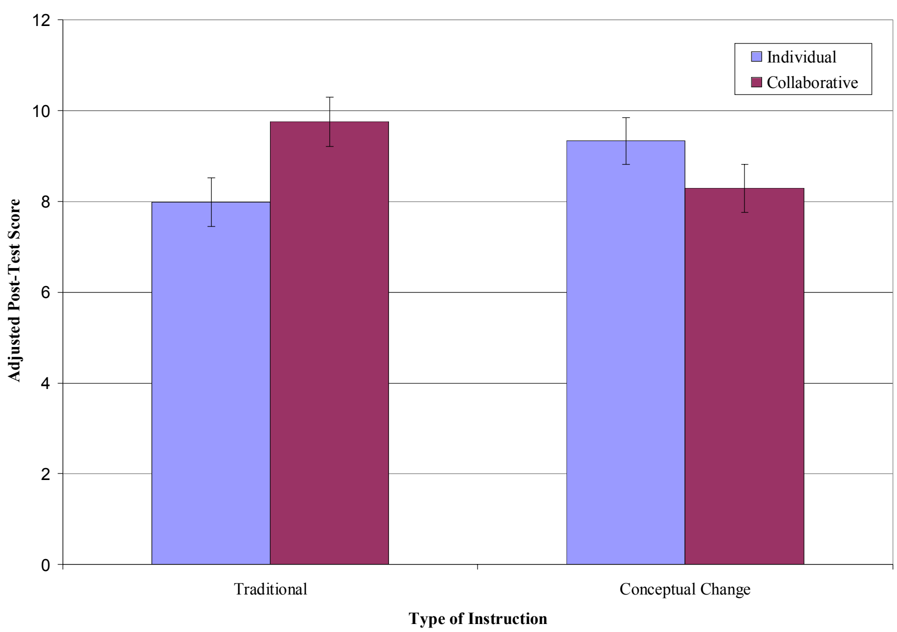

Figure 1. Significant Interaction in Circuits Domain

traditional instruction, participants working collaboratively learned significantly more than participants working individually. This advantage did not hold when participants were following the PVE cycle.

It is interesting to note that, in this study, pre-test scores were not correlated with post-test scores. We expect that this is because, among our sample of participants, few students had any real exposure to the topic of electricity and circuits. The significant correlation between SAT scores and post-test scores suggests that, as is often the case, SAT scores are representing some general measure of ability to learn in an educational setting.

As stated earlier, to increase the generalizability of our research, we conducted a highly similar study in a second domain, that of classical mechanics. Classical mechanics is probably the most studied area of scientific misconceptions in the research literature, and appears to be one of the most difficult scientific topics to learn.

STUDY 2: CLASSICAL MECHANICS DOMAIN

Method

Participants
A total of 80 students, 29 males and 51 females, from the University of Central Florida completed the experiment. Their average age was 20.73 years (SD = 3.72). Students received the same incentives for participation in the experiment as those in Study 1: extra credit points, payment, or a combination of the two.

Design
The experimental design used for this study was identical to the experimental design in Study 1.

Materials
Toolbook© was used to create a CBT lesson that covered Newton's three laws of motion, and the format was identical to that of the first study.

Pre- and post-tests were developed to assess the participants' knowledge of the material using Toolbook ©. The twelve-item tests followed the same format used in Study 1.

Two activities were designed to address Newton's laws. The first activity involved observing a puck move across an air hockey table under different conditions, including when the table was turned on (thus approximating a frictionless surface) and when it was turned off. A hand-held hair dryer was provided to supply the force to move the puck.

The second activity involved comparing the speeds of wind-powered sail cars with different designs. The car designs varied in the presence and location of two components, a sail and a fan. One car had an attached sail, and was powered by a stationary fan. A second car was powered by an attached fan, and had no sail. The third car had both an attached sail and an attached fan blowing into that sail. As in Study 1, these activities addressed common misconceptions found in the literature.

Procedure
The procedure followed for this study was identical to the procedure in Study 1.

Results

In this study, partial correlation analyses showed that two variables, pre-test score and the number of relevant courses that each participant had already taken, were the only two variables that each accounted for unique and significant amounts of variance in the dependent variable, post-test score. Thus, a 2 (instructional condition) x 2 (social condition) between-subjects analysis of covariance was conducted, with those two variables serving as the covariates.

Table 1. Descriptive Statistics.

	Individual	Collaborative	Total
Traditional	6.37 (0.48)	6.72 (0.48)	6.55 (0.34)
Conceptual Change	5.54 (0.49)	5.82 (0.48)	5.68 (0.34)
Total	5.96 (0.34)	6.27 (0.34)	6.11 (0.24)

Descriptive statistics are presented in Table 1. There were no statistically significant main effects or interactions.

Discussion

Our second study, using the same instructional techniques in a different, and possibly more difficult domain, did not replicate the results from our first study. More specifically, neither of the specialized instructional strategies appeared to confer a significant learning advantage to our participants. Also in contrast to the results from the first study, in this domain, performance on the post-test was determined primarily by knowledge of the topic (as demonstrated on the pre-test) and the number of relevant courses that a student had previously taken.

GENERAL DISCUSSION

These studies were designed to investigate the effectiveness of two proposed instructional strategies, the PVE cycle and collaboration, to teach two scientific domains, basic DC circuits and classical mechanics, in a computer-based, instructorless environment. The hypotheses were that the application of each method would be more effective than the control condition of having neither specialized technique (i.e., working alone through traditional instruction). Unfortunately, these hypotheses were not supported. When the topic was classical mechanics, neither technique conferred any instructional benefit on the students. When the topic was basic DC circuits, working collaboratively was significantly more effective than working individually, but only within the context of the traditional instructional environment.

Previous research has found more promising results from these same instructional techniques, when applied in a classroom environment with the guidance of an instructor. There are several reasons why the techniques, especially the PVE cycle, may not have worked as well without an instructor. An examination of the prediction worksheets, for example, shows that some participants may not have taken the worksheets seriously. They used the answer "I don't know" or "I just guessed" for many of the questions. It is difficult to know how to interpret this type of statement. It may reflect a genuine confusion after deep thought or it may reflect a lack of cognitive effort. The presence of an instructor could have mitigated either problem. The instructor could have provided hints for the confused student and encouragement for the unmotivated student.

While these results are disappointing, they do illustrate the potential difficulty associated with transitioning instruction from a classroom environment to a distributed environment without an instructor present. Of course, it would be rash to draw strong conclusions from a series of two studies; however this research does suggest that it would also be foolhardy to assume that, just because a technique works in a classroom, a few minor revisions will enable it to work effectively in a computer-based, distributed learning environment. Additional research is needed to determine how each technique should be modified in order to preserve its effectiveness in this new type of learning environment. This research will help the Navy, and all of the Department of Defense, to effectively leverage advanced computer and communication technology to support innovative instructional programs.

REFERENCES

Berg, T. & Brouwer, W. (1991). Teacher awareness of student alternative conceptions about rotational motion and gravity. *Journal of Research in Science Teaching*, 28, 3-18.

Biswas, G., Schwartz, D., Bhuva, B., Bransford, J., Brophy, S., Balac, T. & Katzlberger, T. (1997). Analysis of student understanding of basic electricity concepts. Interim Technical Report #TR-CS-97-01.

Burbules, N. C. & Linn, M. C. (1988). Response to contradiction: Scientific reasoning during adolescence. *Journal of Educational Psychology*, 80, 67-75.

Chambers, S & Andre, T. (1995). Are conceptual change approaches to learning science effective for everyone? Gender, prior subject matter interest, and learning about electricity. *Contemporary Educational Psychology*, 20, 377-391.

Chambers, S. & Andre, T. (1997). Gender, prior knowledge, interest, and experience in electricity and conceptual change text manipulations in learning about direct current. *Journal of Research in Science Teaching*, 34(2), 107-123.

Champagne, A. B., Klopfer, L. E. & Anderson, J. H. (1980). Factors influencing the learning of classical mechanics. *American Journal of Physics*, 48, 1074-1079.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics*, 50, 66-71.

Dillenbourg, P. (1999). *Collaborative learning: Cognitive and computational approaches.* Pergamon Press.

diSessa, A. A. (1982). Unlearning Aristotelian physics: A study of knowledge-based learning. *Cognitive Science*, 6, 37-75.

Eylon, B.-S. & Linn, M. C. (1988). Learning and instruction: An examination of four research perspectives in science education. *Review of Educational Research*, 58, 251-301.

Linn, M. C. (1986). Science. In R. F. Dillon & R. J. Sternberg (Eds.) *Cognition and Instruction*. Orlando, FL: Academic Press. Pp. 155-204.

McDermott, L. C. (1984). Research on conceptual understanding in mechanics. *Physics Today*, 37, 24-32. Posner, G. J., Strike, K. A., Hewson, P. W. & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66(2), 211-227.

Nussbaum, J. (1985). The earth as a cosmic body. In R. Driver, E. Guesene & A. Tiberghien (Eds.) *Children's ideas in science*. Philadelphia, PA: Open University Press. Pp. 170-192.

Posner, G. J., Strike, K. A., Hewson, P. W. & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66(2), 211-227.

Smith, E., Blakeslee, T., Anderson, C. (1993). Teaching strategies associated with conceptual change learning in science. *Journal of Research in Science Teaching*, 30(2), 111-126.

Tao, P. & Gunstone, R. (1999a). The process of conceptual change in force and motion during computer-supported physics instruction. *Journal of Research in Science Teaching*, 7, 859-882.

Tao, P. & Gunstone, R. (1999b). Conceptual change in science though collaborative learning at the computer. *International Journal of Science Education*, 21, 39-57.

Wang, T. & Andre, T. (1991). Conceptual change text versus traditional text and application questions versus no questions in learning about electricity. *Contemporary Educational Psychology*, 16, 103-116.

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