USING INTERACTIVE SIMULATIONS TO ENHANCE STUDENTS' EXPLANATIONS REGARDING PHYSICAL PHENOMENA

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ABSTRACT
The objective of this research was to investigate the effects of Interactive Computer-Based Simulations (ICBSs) on student's ability to give "scientifically accepted" explanations regarding physical phenomena in Mechanics, Waves/Optics, and Thermal Physics. Four subtopics were presented within each of the three main topics. There was one Interactive Computer-Based Simulation (ICBS) with relevant physics content for each subtopic. Theoretically, each of the ICBSs should serve as a cognitive framework to enhance students' explanations regarding physical phenomena in Mechanics, Waves/Optics, and Thermal Physics. To test this theoretical prediction a self-controlled design was used, where each of the subjects served as his/her own control. A random block design was used where each of the subjects was assigned alternatingly to the experimental and control conditions. The control condition was an assignment to do additional problems in the same content area as the ICBS and required approximately the same amount of time. The ICBSs were integrated into a sixteen-week semester physics content class for prospective physics teachers who served as students in the study. The course used a conceptually oriented approach. After using the ICBS, or for the control condition after doing the additional problem sets, semi structured interviews were obtained. These interview data were used to assess the students' ability to give scientifically acceptable explanations of discrepancies between their predictions and observations following the use of the ICBS. Results indicated that the use of ICBSs in comparison to the control conditions improved students' ability to give "scientifically acceptable" explanations regarding physical phenomena in Mechanics, Waves/Optics, and Thermal Physics.

KEYWORDS
Computer simulations, inquiry-based experiments, physics education

INTRODUCTION

Research studies have well documented that students enter physics courses with ideas about the physical world, interpretations for science terminology, and reasonable explanations for how and why things function, long before they come to study physics in schools. (Dykstra et al., 1992) These ideas and interpretations, based on everyday experiences and language, often interfere with learning of scientific models/paradigms introduced during physics classes, and affect the ability of the students to assimilate the scientifically correct ideas (Duschl and Gitomer, 1991).

Posner *et al.* (1982) point out that students' ideas about how the world operates are strongly held because their conceptual knowledge has been constructed over many years of experience in the everyday world. Thus, a meaningful learning experience requires physics instruction that embraces students' worldviews in a way that promotes assimilation of the scientifically accurate conceptions (Kalman *et al.*, 1999; Roth and Lucas, 1997). Piaget (1985) suggested that, to foster conceptual change students have to be confronted with "discrepant events" that contradict their conceptions and invoke a "disequilibration or cognitive conflict" that positions students in a state of reflection and resolution.

The discrepant events could be provided through the use of ICBSs. According to Tao and Gunstone (1997), the use of ICBSs is an ideal tool for an instruction that promotes conceptual change. Their argument validated by a large number of studies in mechanics (Gorsky and M. Finegold, 1992), kinematics (Hewson, 1985), electric circuits (Lea et al., 1996), optics (Goldberg, 1997), waves (Grayson, 1996), and across the curricula (Van Heuvelen, 1999).

Researchers attribute success of simulations to the empowerment of students, the unique instructional capabilities, the support for new instructional approaches, the development of skills, the development and use of concepts, the development of cognitive skills, and the development of attitudes (Chou, 1998). In addition to these, Steinberg (2000) argues that, simulations are a very effective learning activity that can provide the environment, and within it the concrete experiences necessary, for the development of insight about abstract physics concepts.

Physics educators believe that simulations hold a promise of improving physics education (i.e., Van Heuvelen, 1999; Goldberg, 1997; Grayson, 1996; Lea et al., 1996; Gorsky and M. Finegold, 1992; Hewson, 1985). However, before implementing simulations into physics instruction there is a need for evaluation of (a) the effectiveness of this type of learning environment, (b) the details of their programmatic development, and (c) the way in which they are implemented (Steinberg, 2000). One aspect of the current study was to investigate the effects of Interactive Computer-Based Simulations (ICBSs) on student's ability to give "scientifically accepted" explanations regarding physical phenomena in Mechanics, Waves/Optics, and Thermal Physics (the accuracy of this reasoning skill was assessed by using textbook information as the criterion).

METHODOLOGY

There were three instructional topics (Mechanics, Waves/Optics and Thermal Physics), each with four more specific subtopics [see Zacharia and Anderson (in press) for a sample of study's curriculum]. Each presentation of a subtopic had the same organizational plan. There was an introductory experience differing for the experimental and control condition. In the introductory experience, all participants had a reading assignment from the text and problem sets intended to orient them to the physical phenomenon that was presented through the Interactive Computer-Based Simulation (ICBS). However, the students in the experimental treatment assigned to the simulation condition in addition used the ICBS. Whereas, the students in the control treatment, non-simulation condition, were given additional problems to ensure comparability of opportunity to learn. The additional problems were comparable to the level of difficulty of the corresponding ICBS for that subtopic and required the same amount of time spent by the students using the ICBS. Moreover, they included the same concepts and context as the corresponding ICBS.

The ICBSs were selected from simulations available on the World Wide Web, based on previous research studies (i.e., Van Heuvelen, 1999; Goldberg, 1997; Grayson and McDermott, 1997) and were integrated into a sixteen-week semester physics content class, in a graduate school of education in New York City. In general, the course curriculum and physics textbook emphasized conceptual physics, instead of a more calculus-based approach.

One of the aspects of the ICBSs was that the students had to decide which variables to vary and which to keep constant before running an ICBS and to make the necessary observations. They also had the option to repeat an ICBS as many times as they wanted in case they had any doubts about the outcome. The ICBSs were simple to run, but in case the students had any difficulties, assistance was offered.

Since only 13 individuals were enrolled in the course, a self-control design was used. Participants were randomly assigned to either an experimental treatment (simulation condition, designated as S condition) or a control treatment (additional textbook problems and no simulation condition, designated as N condition) in an alternating pattern throughout the instructional sequence of the 12 subtopics. Each participant used an ICBS only two times per physics topic and for a different subtopic each time (there were 78 cases where students used an ICBS and 78 where they did not, yielding a total of 156 cases). In other words, each student completed half of her/his subtopics in the N condition and half in the S condition. Students were randomly assigned to one or the other condition for each subtopic. No two students had the same sequence of conditions throughout the twelve subtopics.

Students in the experimental condition engaged in three steps during the introductory experience. First, they were presented with a picture taken from the ICBS relevant to the subtopic and asked to make a prediction about the consequences if certain changes in the variables represented in the picture taken from the ICBS were made, and then explain their reasoning behind their prediction (Prediction Phase). Second, they studied the computer simulation (ICBS). Finally, they had to reconcile any discrepancy between their prediction and their observation in the ICBS (Explanation Phase).

Students in the control condition also were presented with three steps, but only the first step was the same as in the experimental condition. The students were presented with the same picture and conditions as in the experimental condition including making a prediction (Prediction Phase). They were not given immediate feedback, but the solutions to the additional problems (as explained below) provided by the instructor served as delayed feedback. In the second step, they studied additional problems that were particularly relevant to the content of the ICBS used in the experimental condition. The problems were comparable to the level of difficulty of the ICBS and the length was chosen to be equivalent to the time-on-task of the ICBS. Third, the students were given the solutions to the additional problems and asked to reconcile differences between their answers and the solutions provided (Explanation Phase). This was intended as a parallel task to the third step in the experimental condition.

Two semi-structured interviews were obtained for the purposes of investigating students' explanations regarding physical phenomena in the ICBSs (physical phenomena in Mechanics, Waves/Optics, and Thermal Physics). The interviews were conducted as each student was using an ICBS (experimental condition) or studying the additional problems (control condition). The first interview (before the ICBS) required students in both the experimental and control conditions to make a prediction (Prediction Phase) about the consequences if certain changes in the ICBS variables were made. Furthermore, in the first interview, the students were asked to explain their prediction. After conducting the ICBS (experimental condition) or studying the additional problems (control condition), the second interview took place. During this interview, the students were asked to reconcile any discrepancy between their prediction and their observation (Explanation Phase) of phenomena in the ICBS.

Overall, 156 interviews within the prediction phase and 156 interviews within the explanation phase were obtained (78 interviews for each condition). The duration of the introductory experience (use of ICBS or additional Problems) combined with the two semi-structured interviews was about thirty-five minutes.

Since the study involved quantitative analysis of interview statements, to ensure objective assessment the interviews were scored anonymously. Internal reliability data were collected, as well. The reliability measures ranged from 0.95 to 1.0 across all of the items assessed.

RESULTS AND DISCUSSION

Much research has been done to investigate exactly what kind of ideas, scientifically accepted or not, are developed by students using *simulations* in physics classes. These findings are particularly important, because designing a physics curriculum requires an understanding of the particular state of the student's knowledge. However, very little research has been done on how simulations can be integrated in a physics curriculum. DeBoer has argued that the processes of research and curriculum development are inextricably intertwined. Thus, curriculum development raises issues that call for research, both with respect to student conceptual understanding and the efficacy of instructional methods and materials. Correspondingly, the results of research have implications for curriculum development, both in terms of what to teach and how to teach it.

The present study aimed to clarify the effects that interactive computer-based simulations – exploratory learning environment tools that allow students to participate in the scientific process – have on students' ability to give "scientifically accepted" explanations regarding physical phenomena. The comparisons between the experimental and the control conditions showed that ICBSs are beneficial in promoting scientifically accurate conceptions. They improved students' ability to give "scientifically accepted" explanations regarding physical phenomena in the subject matter domain of Mechanics, Waves/Optics, and Thermal Physics. The study was done in the natural setting of a classroom and included the ICBSs within a normal course of study in physics, thus adding additional validity to the conclusions that use of ICBSs can enhance physics learning when properly integrated within a substantial physics curriculum emphasizing conceptual understandings.

CONCLUSION AND IMPLICATIONS

Steinberg (2000) has stated that, "if we ignore the critical role of computers in science and engineering, we would be doing a disservice to students." Simulations seem capable of playing an important role in cognitive development and concept learning, and therefore, physics curriculum and instruction should definitely include them. However, the process of integrating simulations into physics curricula requires an evaluation of their effectiveness. Neglecting this research may result in missing the desired positive effects of the simulations on students' knowledge.

This study is particularly important because very little research has been conducted on the effects of ICBSs on students' reasoning skills (predictions and/or explanations) regarding physical phenomena in physics. In addition, studies in this domain are particularly important because they could, ultimately, answer potential questions on whether computer-based physics courses could be offered through the World Wide Web for long distance learning and how these courses could be more effective.

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