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Using Computer Simulations to Enhance Conceptual Change: The Roles of Constructivist Instruction and Student Epistemological Beliefs

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Abstract: Learners enter the classroom with informal ideas (alternative conceptions) about scientific phenomena; these ideas affect how the corresponding scientific explanations are learned. In addition, students' epistemological beliefs concerning learning influence achievement. This study investigated the effects of a constructivist versus objectivist learning environment on college students' conceptual change, using a computer simulation of the human cardiovascular system as an instructional tool. This study also investigated the interaction between constructivist versus objectivist learning situations and the students' epistemological beliefs. The constructivist approach resulted in significantly greater conceptual change than the objectivist approach for 2 of 6 commonly held alternative conceptions; the other 4 of 6 areas showed no significant differences for treatment group. More important, however, the treatment interacted significantly with epistemological beliefs. Individuals with more advanced epistemological beliefs learned more with a constructivist treatment; individuals with less developmentally advanced beliefs learned more with an objectivist treatment. © 1998 John Wiley & Sons, Inc. J Res Sci Teach **35:** 145–160, 1998.

This study investigated the effects of constructivist versus objectivist computer simulation environments on students' conceptual change within the setting of a college human physiology class. This study also examined the potential interaction between student epistemological belief and type of simulation environment, with regard to the development of conceptual understanding. We will discuss the general nature of alternative conceptions with a special focus on the human cardiovascular system. A brief discussion of conditions necessary for conceptual change, including emerging findings on epistemological beliefs and instructional strategies for effecting conceptual change, follows. Finally, we present a conceptual change and constructivist approach to the use of computer simulations.

A note follows about the use of the term *constructivism.* The view that students construct their knowledge from individual and/or interpersonal experiences and from reasoning about these experiences is called "constructivism." Cobb (1994) described two distinct but complementary constructivist perspectives concerning knowledge construction. The *cognitive* constructivist view emphasizes the unique way knowledge is configured and evolves within the individual learner. The *sociocultural* constructivist view emphasizes the development of shared

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knowledge through social interaction. This study uses the cognitive constructivist paradigm as its basis for investigation.

Alternative Conceptions about the Human Cardiovascular System

Scientific explanations of phenomena, with their characteristic rationality and generalizability, are often at odds with the informal explanations given by young learners. This discrepancy gives rise to the term *alternative conception* for the learner's explanation (alternative to the scientific conception). Alternative conceptions have the general characteristics of being poorly articulated, internally inconsistent, and highly dependent on context. Despite these qualities, informal ideas often have tremendous explanatory power in the mind of the student (Driver & Easley, 1978; Hewson & Hewson, 1983; Pines, 1985; Posner, Strike, Hewson, & Gertzog, 1982). In some cases, this explanatory power makes such informal ideas highly resistant to change.

Mintzes, Trowbridge, Arnaudin, and Wandersee (1991) questioned students in fifth, eighth, and 10th grade, as well as college freshmen and sophomores about the cardiovascular system. When asked to select from several illustrations which heart was most like their own, three- and four-chambered hearts were chosen in equal numbers by the middle school and high school students, while college students selected the four-chambered heart in a 2:1 ratio over the three-chambered heart. Few students among those who chose the four-chambered heart as a model could explain the function of the chambers. This finding supports the assumption that anatomical knowledge has limited connection with a broader functional conceptualization of how the circulatory system works.

At every grade level, most students (65–80%) understood that the heart pumps blood, but as many as a third at each level suggested that the heart also cleans, makes, filters, and stores blood. Except for college biology majors, fewer than a third of those questioned understood that the right side of the heart pumps deoxygenated blood, and many students failed to acknowledge in any respect that the heart acts as a double pump. When asked to select an illustration that describes the path of blood in the body, the students' most frequent response was an incorrect pattern in which blood flowed from the heart to an extremity then back to the heart, not including any flow to the lungs.

Conceptual Change

Conditions for Conceptual Change

Educational conditions that promote conceptual change have been described as follows (Hewson, 1981; Hewson & Hewson, 1983; Hewson & Thorley, 1989; Posner et al., 1982):

1. The student must experience *dissatisfaction* with an existing conception. Without a sufficient level of dissatisfaction, students tend to assimilate conflicting information into a widening web of misconceptions rather than go through the process of conceptual change (Anderson & Smith, 1987; Perkins & Simmons, 1988).
2. The new conception must be *intelligible.* If this condition is not met, the learner has no option but to internalize the conception through rote memorization, which means there are no propositional linkages formed, and reconciliation with existing schema does not occur.
3. The new conception must be *plausible.* The new conception must also be congruent with personal standards of knowledge. Students, however, may be socialized to believe

that the teacher is always right or that authors are infallible; thus, ideas directly transmitted from these sources may carry a predetermined level of plausibility.

4. The new conception must be *fruitful.* The candidate conception should have the power to solve problems or predict phenomena more decisively than the conception it will replace.

In a general sense, conceptual change strategies focus on externalizing (exposing) the learner's knowledge structure, then modifying it (Lawson & Weser, 1990; Lawson & Worsnop, 1992), as well as emphasizing the need for self-monitoring and controlling the events of learning.

Strike and Posner's original theory has been criticized for failing to consider the forces of motivational beliefs of the learner such as goals, purposes, and intentions. Children often resolve their misconceptions with the goal of receiving a good grade (this goal is not always congruent with gaining a scientific set of conceptions), preserving self-esteem in an intellectually overwhelming situation, or bringing closure to a learning situation at any cost (Pintrich, Marx, & Boyle, 1993).

Epistemological Beliefs and Conceptual Change

Some authors have elaborated on the possibility that motivational beliefs (goals, values, self-efficacy, and control beliefs) play a major role in conceptual change (Dweck, 1986; Entwistle, Entwistle, & Tait, 1993; Pintrich et al., 1993; West & Pines, 1983). Students have many social goals such as making friends, besting others, or impressing the teacher. These goals, not directly associated with learning, result in surface processing and less intellectual engagement. This surface processing is reinforced by traditional forms of education which emphasize the acquisition of incremental, decontextualized knowledge (Entwistle et al., 1993).

Epistemic motivation has been defined as one's beliefs toward knowledge and the process of building knowledge (Boyle, Magnusson, & Young, 1993). Kruglanski (1989, 1990) suggested that a learner's motivation toward knowledge as an object (epistemic motivation) influences knowledge acquisition. In research with postsecondary students' beliefs about the nature of knowledge and learning, Schommer (1993) described students' epistemological dispositions that have implications for how students view learning and how they choose to deal with new knowledge. She identified four dimensions of belief. The four continua are belief in:

1. simple knowledge → complex knowledge,
2. quick knowledge → knowledge being gained over time,
3. certain knowledge → knowledge as context-dependent, and,
4. deterministic innate ability → ability to learn how to learn.

Dweck (1986) suggested that children who believe intelligence is a fixed trait tend to focus their efforts toward gaining favorable judgments of that trait (performance goals) and shy away from challenging academic situations. Children who believe intelligence can be cultivated orient themselves toward developing that quality (learning goals) and seek challenging intellectual situations as well as deeper understandings.

Constructivist Uses of Technology

The increasing availability of computer-related technologies in classrooms (Becker, 1991) has prompted the investigation of their influence on processes of conceptual development and

conceptual change. Simulations are particularly adept at representing complex processes such as photosynthesis or the functioning of the human cardiovascular system. The ability of simulations to portray phenomena and allow users to interact with the dynamics of a model system creates an arguably unique way of helping learners conceptualize (Windschitl, 1996).

Unfortunately, because of traditional objectivist approaches to science instruction, the use of computer simulations in classrooms is often reduced to step-by-step cookbook approaches, prescribed by teachers for students to follow. The traditional use of simulations may not be as effective as constructivist approaches to simulation use which afford learners the opportunity to freely create, test, and evaluate their own hypotheses in a more richly contextualized environment. A constructivist approach to the use of computer simulations encompasses the elements of conceptual change strategies as described by current theory (Hewson, 1981; Hewson & Hewson, 1983; Hewson & Thorley, 1989; Posner et al., 1982). A well-designed simulation allows learners to choose their mode of informational representation on the computer screen; it allows them to develop hypotheses about phenomena that accommodate their way of solving problems.

Constructivist learning environments may frustrate students who have shallow motivations for academic work (completing tasks for the purpose of receiving a grade or besting others) because there is no correct answer, specific task requirements are not furnished for them, and there is difficulty quantitatively comparing understanding among students (Miller & Hamilton, 1992). Students who have more sophisticated motivations to understand the material profit from the constructivist approach, but may also be frustrated by the relatively unstructured nature of constructivist learning environments.

Using Simulations as Vehicles for Conceptual Change

Gorsky and Finegold (1992) asserted that if naive conceptions are grounded in personal experience, then reexperience of the phenomena in an educational environment may be effective in precipitating conceptual change. Other than laboratory experiences for the students, this implies the use of simulations. Zietsman and Hewson (1986) used a computer simulation to diagnose and remediate alternative conceptions about velocity. Their results indicate that computer simulations can be credible representations of reality, and that remediation produced significant conceptual change in students holding alternative conceptions. Other studies have found little or no effect using simulations to promote conceptual change. In a study on electrical circuits, Carlsen and Andre (1992) found that using text designed to produce conceptual change resulted in better performance on tests, but that using a computer simulation in addition to the text produced no greater change than the text alone.

Using Strike and Posner's model of conceptual change, the issues of *dissatisfaction* with a current conception, and the *intelligibility, plausibility,* and *fruitfulness* of the scientific conception can all be addressed in a learning environment supported by the constructivist use of simulations. Dissatisfaction arises when, within the simulation, the learner is faced with results that conflict with what was predicted. Asking students to make and explain these predictions can activate prior knowledge and force them to mindfully articulate explanations. Prediction and testing encourages "internal discourse" to take place in the mind of the student (Perkins & Simmons, 1988); only by stimulating hypothesis testing on the part of the learner can computer-based instruction offer the possibility of conceptual conflict (Osborne & Squires, 1987). Objectivist uses of simulations often become overly prescribed exercises that reflect the simplistic confirmatory nature of many science lab activities. This may effectively promote complacency toward a critical examination of simulated phenomena and fail to activate prior knowledge.

Intelligibility, a second criterion for conceptual change, may be established by use of simulations prior to didactic instruction (Gorsky & Finegold, 1992). When used to provide an introductory framework to formal classroom instruction, simulations have facilitated learning gains in the areas of knowledge (Thomas & Hooper, 1991) and application of knowledge (Brant, Hooper, & Sugrue, 1991). Confirmatory (objectivist) simulation exercises do not necessarily engage the learner beyond following instructions, and the process of sense making (a strong epistemological preference in many students) is not part of the cognitive activity. Using a strong theme or storyline with extended simulation exercises capitalizes on the constructivist idea of contextually bound knowledge. It adds coherence and level of intelligibility beyond the level of "information" (Cognition & Technology Group at Vanderbilt, 1990).

The plausibility of a new conception is dependent on intelligibility. In a simulation, candidate hypotheses are quickly tested, and the fruitfulness of the hypotheses (in explaining or predicting results) give retrospective plausibility to the candidate hypotheses. If a learner sets up conditions within a simulation that result in a confirmation of predictions, and the learner can understand what they have done to the system (not always a given), there is a chance that the learner can refine his conceptual understanding of a phenomenon.

Research Questions and Hypotheses

Constructivist uses of simulations appear to produce conditions cited by literature that facilitate conceptual change. In this study, one treatment group (the *exploratory* group) was placed in a constructivist instructional setting. This group used a computer-based cardiovascular simulation exercise in a context-bound framework and was allowed to create and test hypotheses regarding cardiovascular phenomena. The other treatment group (the *confirmatory* group) completed the same simulation exercise, but in a prescribed fashion to simply confirm information as directed by a written guide.

As noted above, student epistemological beliefs may have an influence on the depth of information processing and potential for conceptual change. Furthermore, the constructivist use of simulations may favor subjects with a higher degree of epistemological sophistication, differentially encouraging them toward deeper information processing and conceptual change. These considerations support the following two hypotheses:

1. When prior computer experience and pretest scores are statistically controlled, the exploratory simulation group will demonstrate a significantly greater degree of conceptual change as compared with the confirmatory simulation group.
2. The degree of epistemological sophistication will more positively covary with posttest scores in the exploratory simulation group than in the confirmatory simulation group. Thus, it is hypothesized that degree of epistemological sophistication and simulation condition will interact.

Methodology

Sample

The sample was composed of approximately 250 students who were nonbiology majors at a large midwestern university; the subjects were enrolled in a human anatomy and physiology survey course in the spring semester of 1995. The sample was composed of freshmen and sophomores who typically had taken no other life science courses at the university.

Design

There were two instructional conditions:

1. In the confirmatory simulation condition, students used the cardiovascular simulation in prescribed steps, following written instructions that led to the resolution of a set of 12 questions. This condition was designed to represent more stereotypical objectivist instruction.
2. In the exploratory simulation condition, the same cardiovascular simulation was used in a constructivist setting. Students used a thematic instructional guide to hypothesize about and test possible answers to the same 12 questions used by the confirmatory group.

The nature of the differences between the two groups is illustrated in the description of the materials below.

Materials

The anatomy/physiology course introduced students to the anatomy of the human body as well as the physiology of the cardiovascular, nervous, digestive, muscular, and skeletal systems.

All procedures and materials were tested earlier in a pilot study. Two groups of 25 students enrolled in a physical education class at the same university were used as participants for the pilot study. As a result of the pilot, pre- and posttest questions were refined. In addition, the theme of a hypothetical student's experiences was incorporated into the exploratory group's guide text.

Computer Simulation. A computer simulation that modeled the functioning of the human cardiovascular system was used for this study. The simulation presented the user with two windows, one of which contained buttons that could select displays of dynamic information in multiple forms such as line graphs, bar graphs, pie charts, or digital counters. This information was reflective of the pictorial representations in the second window. The second window contained an electrocardiograph-type display, a transparent frontal view of the human circulatory system, a transparent frontal view of the heart, and a small animated figure that could be made to rest, walk, or run. The user could also select a fitness level for the simulated figure.

Written Simulation Guides. Alternative conceptions were identified from a pilot study and from a related study of the human cardiovascular system (Mintzes et al., 1991). These alternative conception topics were incorporated into the written simulation guide. The guide for the confirmatory group provided carefully prescribed written steps to follow. These steps guided the user through the simulation without latitude in making decisions about creating or testing hypotheses within the simulation. This guide turned the exercise into a cookbook procedure. For example, one segment of the guide asked: "At rest, are there any significant differences between a fit and unfit individual concerning heart rate and/or stroke volume?" The students were then directed to: "Stay on the STROKE VOLUME window. Change the figure to a "couch potato" and standing still; now click the GO icon; wait until the readings stabilize then record the stroke volume and heart rate." Students were further directed to: "Change the figure to an athlete and standing still, now click the GO icon, wait until the readings stabilize then record the stroke volume and heart rate."

In contrast, the written guide for the exploratory group was based on a set of cases concerning a hypothetical individual. The segment described above for the confirmatory group is described this way for the exploratory group: "Lynn is disappointed in the results of the treadmill test and plans to begin exercising regularly. Lynn asks the doctor if a person who becomes an athlete will see a change in heart rate or stroke volume when at rest. At rest, are there any significant differences between a fit and unfit individual concerning heart rate and/or stroke volume?" Students were then asked to state a prediction and explain it. Without further guidance, students tested their prediction with the simulation. Students then described how they tested the case, including specific numbers generated with the simulation. Finally, the students were asked to state a conclusion. The contrast in the two guides is explained further in the Procedures section.

Epistemological Survey. The students' epistemological beliefs were assessed by a previously developed instrument (Schommer, 1993). The instrument consists of 63 items in 12 logical subsets. The items are statements that reflect beliefs about the nature of knowledge and learning. The overall mean of the subset means was used as the independent variable. Examples of some of the logical subsets are (from the naive viewpoint): belief in learning information the first time you are exposed to it, belief that the ability to learn is innate, and belief in single answers to problems. Each item was rated on a 5-point *agree–disagree* Likert-type scale. Some typical items were: "Students have a lot of control over how much they can get out of a textbook," and "The best thing about science courses is that most problems have only one right answer."

Multiple Choice Pretest of Cardiovascular Concepts. The pretest was a 24-item multiple choice instrument with questions designed by a human physiology instructor, the author, and two instructors in health and human performance. The questions focused on common misconceptions from relevant literature and misconceptions noted from the experience of the instructors. Six areas of conceptualization were identified: the effects of physical activity on blood flow, pattern of blood flow through the circulatory system, blood flow to the brain, movement of oxygen through lungs and heart, structure of the heart, and blood flow within the heart. The pretest also solicited information on gender, frequency of computer use, and perceived proficiency with computers.

Concept Comparison Posttest. One posttest measure was a concept pairing test in which students were asked to rate the closeness of the relationship between pairs of items (22 pairs in total). Studies have shown that this method can validly assess an individual's conceptual and structural knowledge (Diekoff, 1983; Stanners, Brown, Price, & Holmes, 1983). The terms for this instrument were suggested by experts in the area of the human cardiovascular system. These terms (or phrases) were paired with each other, with some pairs intended to be perceived as having a high degree of association such as "heart rate" and "activity," and other pairs intended to be perceived as having a lower degree of association such as "capillary" and "cardiac output." Another set of seven experts rated the closeness of each of the pairs of terms on a 1–5 scale. After calculating the *z*-scores across and within expert raters, 10 pairs of terms with the highest variance across expert raters were deleted from the original criterion group. The average expert rating of each remaining pair were used as the criterion against which student scores were compared. Some examples of concept pairs were: ventricle–stroke volume, carbon dioxide–arteries, artery–high blood pressure, and heart–lungs.

Multiple Choice Posttest. A second posttest instrument was a multiple choice test parallel to the pretest, using approximately the same number of questions. Examples of topical areas for posttest questions were: structure of the cardiovascular system, structure of the heart, effects of activity, and fitness effects. An example of a posttest question was:

> Going from rest to activity, what happens to the blood flow to the intestinal region?
> a. It remains the same as during rest.
> b. It decreases.
> c. It increases slightly.
> d. It increases substantially.
> e. The intestinal region does not require blood flow.

Procedure

Students participated in their assigned class sections; there were 14 sections of approximately 15 students each. Each of the 14 sections was randomly assigned to the confirmatory (objectivist) or exploratory (constructivist) conditions.

The study took place in regular laboratory sessions of the class. In Week 1, all subjects were given a 3-min overview of the cardiovascular simulation during their laboratory class. This was done to acquaint subjects with the functions of the simulation so that they would be able to spend more time using the simulation rather than learning how to use it during the next two lab periods. Subjects also completed the epistemological survey and the multiple choice pretest.

In Week 2, students met during regular class times in a nearby computer lab. The subjects were introduced to the simulation and given an instructional guide which included identical introductory information for both groups, but different case descriptions for each group. With the subjects seated individually at computer stations, they were shown what the dynamic graphical outputs represented and how to select various views. They were also shown how to change the effort and fitness levels of the simulated character. Beyond this stage, the two subject groups were given a slightly different orientation to the simulation.

The confirmatory group was asked to follow verbal directions to set certain variables within the simulation and generate the screen conditions to show a particular type of output for interpretation. This was to be done in a step-by-step prescribed fashion. The confirmatory group was then given a set of specific instructions to follow in manipulating the software. These instructions led them to deal with concepts that had been identified as sources of misconceptions for students at this level. The students had few options for exploration; they were prompted to select appropriate parameters for adjustment and to select particular graphical outputs for display to be presented with evidence that refuted commonly held misconceptions about aspects of the cardiovascular system. Over the next two laboratory class periods, the students attempted to resolve 12 cases that were designed to generate refutational evidence about several commonly held misconceptions.

The exploratory groups were prompted during the orientation period to consider how to construct simple hypotheses about the cardiovascular system's operation. They were shown how to test a sample hypothesis using the simulation. They were then asked to test another sample hypothesis on their own, after which the class as a whole discussed the results. They were then given a general set of guidelines to follow in exploring their conceptions of the cardiovascular system. Students were asked to resolve the same 12 cases that the confirmatory group investigated, but without being given further specific direction. These 12 cases were components of a larger theme dealing with a hypothetical college student whose ongoing health situations fur-

nished the exploratory group with the same basic cases as the confirmatory group. Individuals in the exploratory group were required to explicitly state a prediction about certain phenomena within cases, formulate their own hypotheses about how to test their prediction with the simulation, and then find ways to test them.

For the exploratory group, interaction with the researcher or teaching assistants was limited to solving software difficulties or suggesting how to formulate hypotheses without reference to specific cases they were working on. These interactions were minimal.

In Week 3, both groups continued their experience with the simulation, and at the end of the laboratory period they were given the posttest. The total amount of time spent with the simulation was about 7 hours.

A recitation class was held weekly in association with the laboratory. Six of the 14 recitation sections were taught by the head lab coordinator, and the other 8 were taught by a novice instructor. Recitation instructor was used as a covariate in later statistical analyses.

Results

Internal Consistencies

The pretest internal consistency estimate was .52 (using Cronbach's alpha); this low estimate was likely due to random guessing by the subjects and to the diversity of topical areas addressed by the test. The internal consistency of the epistemological survey (using the means of each of the 12 subscales as items) was .69. The alpha values for the posttest multiple choice and posttest concept comparison instruments were .77 and .64, respectively. While these internal consistencies are somewhat low, they were judged sufficient for experimental purposes. Such lower internal consistencies increase error variance and make a Type I error less likely. Thus, if significant effects are found, they are less likely to be due to chance.

Pretest

The mean score for all subjects on the pretest was 15.72, or approximately 63% [24 was the maximum possible, standard deviation (SD) = 3.12]; a t test revealed no significant differences between the treatment group ($p < .81$). The subjects did have some accurate knowledge of the circulatory system. Students also reported that they had used computers relatively infrequently. On a question about frequency of computer use, the choices ranged from "usually once a day" (value = 1) to "never" (value = 5); the mean was 3.42 (SD = 1.10). In response to the question, "As a student, how would you rate your general proficiency in using a computer?" most students rated themselves as "average" (132 of 221 students, mean = 2.94, SD = .74, 1 = "very high," 5 = "very low"). A composite of these two responses was formed by calculating their mean; this was used as a covariate term *computer proficiency* in later analyses (α = .62).

Identifying Misconceptions

The pretest was used to identify areas of misconception as well as act as a covariate for later analyses. When asked to select a diagram (adapted from Arnaudin & Mintzes, 1986) that depicted the pathway of blood in the body, 8% of respondents indicated that blood traveled to an extremity such as the toe and remained there (heart–toe). About 15% of respondents selected a

path going from the toe to the lungs, then to the heart (heart–toe–lung–heart); about 30% of respondents selected a path going to the lungs, then to the toe, then the heart (heart–lung–toe–heart). The correct choice (heart–toe–heart–lung) was selected by 46% of the students.

In response to the question, "Going from rest to activity, what happens to the blood flow in the intestinal region?" 59% of students correctly selected "It decreases"; 35% of students indicated that it increased.

In response to the question, "Going from rest to activity, what happens to the blood flow to the brain?" about 46% of students indicated that it would increase substantially. The correct response ("It remains about the same as during rest") was chosen by about 47% of students.

Another question adapted from Arnaudin and Mintzes (1986) asked, "Where does oxygen go after it enters your lungs?" About 5% of students indicated that "air tubes from the lungs carry oxygen throughout the body"; about 6% indicated that "air tubes carry oxygen from the lungs through the heart"; and 22% indicated that "blood in vessels carries oxygen directly to the body." The correct response, that "blood in vessels carries oxygen from the lungs through the heart," was selected by 65% of the respondents.

Students were asked to select a correct diagram of the human heart. Only 52% correctly identified the four-chambered diagram. Other responses were one-chambered (1%), two-chambered (12%), three-chambered (9%), and five-chambered (26%). In a separate question asking directly about the number of chambers in the human heart (no diagrams), 89% of students indicated that the heart has four chambers.

In response to the question, "In the atria of the heart, would you find blood that is relatively high in oxygen or low in oxygen?" 38% of students chose the correct response (it depends on which atrium); the greatest response was "high in oxygen" (39%).

Treatment Group Comparisons

The first hypothesis predicted that the exploratory group would experience a greater degree of conceptual change than the confirmatory group when controlling for computer experience, pretest scores, gender, and recitation instructor. Areas of alternative conception were identified on the pretest by selecting questions that were answered incorrectly by a large number of students (at least 70 of 221). A further selection from this pool retained only those items that subjects were likely to have had *prior conceptions* about (through previous academic experience, media exposure, peer influence, or personal experience). There were some items that dealt with advanced concepts or terminology particular to a college physiology class that many subjects failed to answer correctly, but these were not used to identify alternative conceptions.

This selection yielded six questions that focused on conceptions/misconceptions central to the structure and function of the cardiovascular system; some differences in posttest responses were found between the treatment groups (means presented in Table 1).

Using only those students who held misconceptions about the internal structure of the human heart (as indicated by their answers on the pretest), a one-way analysis of covariance with multiple covariates was computed using the score on a parallel posttest question as the dependent variable. With treatment group as the independent variable, and pretest, computer proficiency, gender, and recitation instructor as covariates, the exploratory group performed significantly better than the confirmatory group, $F(1, 105) = 3.99$, $MS_e = .23$, $p < .05$.

Using those students who held misconceptions of where oxygen goes after it enters the lungs (as indicated by their answers on the pretest), a one-way analysis of covariance with multiple covariates was computed using treatment group as the independent variable. The score on a parallel posttest question was the dependent variable. Using pretest, computer proficiency, gen-

Table 1
Means and standard deviations for each treatment: Posttest Questions 15, 8, 2, 3, 5, and 27

	Confirmatory			Exploratory		
Question	*n*	*M*	*SD*	*n*	*M*	*SD*
15	55	.53	.50	51	.71*	.46
8	37	.51	.51	40	.67*	.48
2	42	.45	.50	48	.27	.44
3	54	.48	.50	65	.54	.50
5	58	.60	.49	60	.57	.50
27	63	.49	.50	74	.57	.50

Note. Questions are as follows: 15 = structure of heart; 8 = oxygen path aftter entering lungs; 2 = blood flow to intestinal region; 3 = path of blood in circulatory system; 5 = blood flow to brain; 27 = oxygen content of blood in atria.
*$p < .05$.

der, and recitation instructor as covariates, the exploratory group performed significantly better than the confirmatory group, $F(1, 76) = 4.03$, $MS_e = .23$, $p < .05$.

No significant group differences were found (using the one-way analysis of covariance described above) for those students who held misconceptions about the question, "Going from rest to activity, what happens to the blood flow in the intestinal region?" $F(1, 89) = 2.31$, $MS_e = .22$, $p < .13$.

No significant group differences were found for those students who held misconceptions about the path of blood in the circulatory system, $F(1, 118) = .66$, $MS_e = .25$, $p < .42$, about the flow of blood to the brain during activity, $F(1, 117) = .10$, $MS_e = .25$, $p < .76$, or about the oxygen content of blood in the atria of the heart, $F(1, 136) = 1.14$, $MS_e = .22$, $p < .29$.

There were no significant differences between the treatment groups concerning the concept comparison posttest measures, $F(1, 216) = .20$, $MS_e = .23$, $p < .65$. There was a significant correlation between the concept comparison measure and the multiple choice posttest, $r = -.32$, $p < .01$, lower scores for the concept comparison measure reflect greater understanding.

Regression on Posttests

The second hypothesis predicted that the degree of epistemological sophistication would more positively covary with posttest scores in the exploratory group than in the confirmatory group. Regressions on the posttest multiple choice score were calculated to determine the relative influences of variables and to identify whether treatment interacted with epistemological belief. Predictor variables were entered in the following order: pretest score, recitation instructor, treatment group, epistemological belief, and Group × Epistemological belief (Table 2). In the final regression stage, pretest score was the strongest predictor, $\beta = .64$, $p < .01$. Treatment group was found to be significant, $\beta = 1.15$, $p < .03$, as well as epistemological belief, $\beta = .32$, $p < .05$. The interaction of Group × Epistemological belief was significant, with $\beta = -1.20$ ($p < .03$).

Figure 1 displays the Epistemological belief × Treatment interaction, with pretest score and recitation section set to their means. Figure 1 illustrates that in the exploratory group, more sophisticated levels of epistemological belief led to higher posttest performance. In the confirmatory group, epistemological belief related negatively to performance.

Table 2
Summary of hierarchial regression analysis for variables predicting posttest multiple choice score

Predictor	B	β	*t*	*p*
Step 1 (R^2 = .427)				
Pretest score	.97	.65	12.40	.01**
Step 2 (R^2 = .433, ΔR^2 = .006)				
Pretest score	.96	.65	12.33	.01**
Recitation instructor	−.69	−.08	−1.52	.13
Step 3 (R^2 = .434, ΔR^2 = .001)				
Pretest score	.96	.65	12.25	.01**
Recitation instructor	−.69	−.08	−1.51	.13
Group	−.05	−.01	−.11	.91
Step 4 (R^2 = .434, ΔR^2 = .000)				
Pretest score	.95	.64	11.49	.01**
Recitation instructor	−.71	−.08	−1.54	.13
Group	−.06	−.01	−.14	.89
Epistemological belief	−.29	.02	−.31	.75
Step 5 (R^2 = .447, ΔR^2 = .130)				
Pretest score	.95	.64	11.54	.01**
Recitation instructor	−.86	−.10	−1.90	.07
Group	9.88	1.15	2.18	.03*
Epistemological belief	5.38	.32	1.97	.05*
Group × Epsitemological belief	−3.88	−1.20	−2.20	.03*
Constant	−5.37		−.74	.46

* $p < .05$ **$p < .01$.

Discussion

The primary purpose of this study was to compare exploratory and confirmatory uses of an educational simulation. It was hypothesized that the level of epistemological sophistication and treatment would interact. In the exploratory condition we expected epistemologically unsophisticated subjects to do less well than more sophisticated subjects. In the confirmatory condition, we expected either a neutral or negative relationship epistemologically. Precisely this result was found. As expected, individuals with more sophisticated epistemological beliefs performed better when allowed to explore, but individuals with less sophisticated beliefs did poorly when asked to explore. In the confirmatory condition the reverse was true; individuals with less sophisticated beliefs did well when given explicit directions on how to use the simulation; individuals with more sophisticated beliefs performed poorly under confirmatory instructional conditions. Why should this interaction occur? Epistemologically less mature students believe that knowledge is simple and certain. An instructional approach that provides overly prescribed instructions as to how to proceed and leads students to specific conclusions would be consistent with these students' approach to knowledge. The confirmatory approach followed that instructional model. Epistemologically less mature students should find less compatible an approach that emphasized self-exploration and self-construction of knowledge. The reverse relationships should be true for epistemologically more mature students; thus, the confirmatory approach may induce more positive motivation for learning in epistemologically less mature students and more negative motivation for learning in epistemologically more mature students. Alternatively, the exploratory approach may induce more positive motivation for learning in epistemologically more mature students and induce negative motivation for learning in epistemologically less ma-

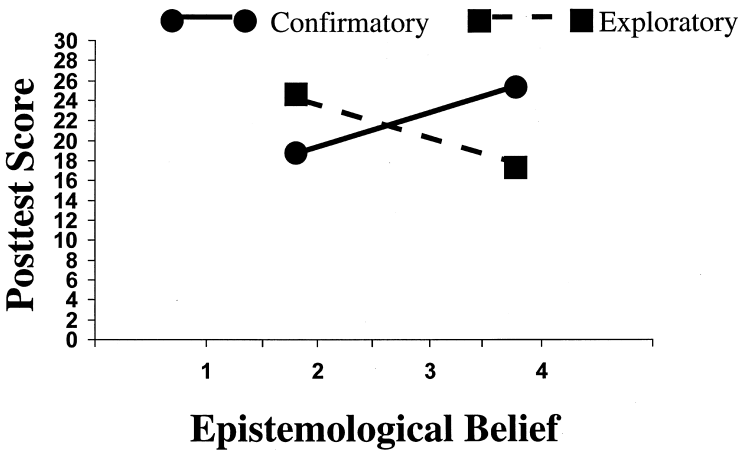

Figure 1. Two-dimensional projection of regression of posttest score on epistemological belief, with pretest score and section set to their means (higher epistemological values reflect *less* sophistication).

ture students. The observed interaction between epistemological level and treatment could result from differences in student motivation induced by the treatment. While this explanation is plausible, it may not be entirely satisfactory. Overall, there is a significant main effect of exploratory treatment, and an examination of Figure 1 indicates that the differences between the conditions seem to be greatest for students with higher-level epistemological sophistication. The differences between students with lower levels of epistemological sophistication are less extreme. This pattern of results suggests that the interaction is primarily due to the more epistemologically sophisticated students. These students seem to be particularly stimulated by an exploratory treatment and inhibited by a confirmatory treatment. It may be that epistemologically sophisticated students are frustrated when instruction is overcontrolling, as in the confirmatory condition, and perform poorly under such conditions. Unfortunately, we cannot directly assess this hypothesis in the present study. Future research should assess students' emotional reactions to the instruction as well as their learning gains.

We hypothesized that the exploratory experience would produce greater conceptual change than the confirmatory experience. In the analysis of the six questions used to identify alternative conceptions, two showed significant differences for treatment group favoring the exploratory learners (Questions 8 and 15). Four of the six means were higher for the exploratory group (Questions 3, 8, 15, and 27). The confirmatory group outperformed the exploratory group on two of the six questions (Questions 2 and 5; nonsignificant differences). Thus, some evidence was found that exploratory computer simulation exercises can in some cases be significantly more effective than confirmatory exercises in changing alternative conceptions. In contrast to a student receiving a confirmatory lesson, a student in an exploratory condition may build her or his own idiosyncratic (but productive) line of reasoning from hypothesizing and testing the hypotheses. This exploratory process highlights not only the conclusion but the path of reasoning used to arrive at the conclusion. Such exploration may directly challenge student ideas and lead students to develop better conceptions.

The misconceptions held by the subjects were consistent with those described in related studies (Arnaudin & Mintzes, 1986; Mintzes et al., 1991). In general, only about half the sub-

jects exhibited correct conceptions about topics central to the understanding of the cardiovascular system. Responses to questions in the pre- and posttest which focused on issues central to the cardiovascular system may have been influenced by personal experiences and early academic experiences related to those topics. Topics such as the structure of the heart and pathways of blood through the circulatory system are more likely to be subjects of alternative conception than esoteric topics such as cardiac output and stroke volume (students are more likely to have a lack of knowledge in these latter areas rather than a preexisting belief).

There was an interesting discrepancy between the number of students who chose the correct diagram of the heart (52%) versus the number of subjects who chose the correct textual response "four chambers" in a separate question (89%). Some students may lack the visual literacy to interpret basic diagrams in instructional materials and assessments, not necessarily having an alternative conception; another explanation is that students may have memorized a verbal response of "four-chambered heart" without truly understanding its meaning.

The natural class setting for this or any experiment helps support the ecological validity of the results. Many studies in computer-based learning have taken place in contrived settings. Results obtained in such settings are harder to generalize to classroom settings in which crosstalk between computer stations and other interpersonal phenomena are common. Although there was some crosstalk during the exercises in this study, informal observations indicated that it was sparse, random across groups, and often socially rather than academically oriented.

The high overall achievement of both treatment groups may have been due, in part, to the setting of time and place. There were two presentations covering the cardiovascular system held in the lecture class that was associated with the laboratory. Almost all subjects were enrolled in this lecture. In addition, the students returned to their labs after the first session with the simulation and did a hands-on activity directly related to the cardiovascular system (an actual sheep heart dissection).

Because constructivist instructional approaches may differ in several ways from objectivist approaches, it is difficult to conclusively attribute differences in student performance to particular aspects of one condition versus the other. The exploratory group had a context-bound, thematic instructional guide, and was asked to write predictions, test hypotheses, and explain phenomena (the confirmatory group was asked only to write conclusions after each case). Manipulating constructivist settings to isolate and control certain variables for experimentation may, however, result in an analysis of the effects of parts that obscures effects of the whole.

There are several assumptions associated with evaluating the effectiveness of simulations, particularly in a constructivist mode. We assumed that without explicit instruction, learners could comprehend the tasks required of them within the simulation and that they were capable of creating testable hypotheses. It was further assumed that learners could make sense of the graphical/pictorial information on the screen and use that information to support or refute their hypotheses. Testing the validity of these assumptions may be the basis for future studies.

Conclusions

This study provided some evidence that an exploratory (constructivist) simulation experience could be more effective in altering learners' misconceptions than a confirmatory simulation experience. Some evidence was obtained consistent with the view that providing learners with overly detailed procedural instructions to solve problems in a simulated environment could be deleterious to conceptual change. In addition, the results of this study suggest that the epistemological beliefs of learners interact with the type of learning environment in determining achievement. Students with greater epistemological sophistication did better in the exploratory

simulation environment, while students with less sophisticated beliefs about knowledge and learning achieved best in the more prescribed, confirmatory simulation environment.

In addition to the specific findings described above, this study also supported the idea that computer-based simulations offer a suitable cognitive environment within which to test learners' self-resolution of alternative conceptions, achievement, and general response to constructivist instruction.

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