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Using computer simulations to enhance conceptual change: the roles of constructivist instruction and student epistemological beliefs

Mark A. Windschitl
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Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs

by

Mark A. Windschitl

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY

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GENERAL INTRODUCTION

Conceptual change

Students' informal ideas about natural phenomena often influence their ability to learn science. These conceptions have been described in areas such as the human cardiovascular system (Arnaudin & Mintzes, 1986), electric circuits (Dupin & Johsua, 1987), the reflection of light (Mohapatra, 1988), and simple mechanics (Viennot & Rozier, 1994). Such informal ideas, also known as 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; Posner, Strike, Hewson, & Gertzog, 1982; Pines, 1985).

Oftentimes, learners are unresponsive to traditional instructional methods that attempt to stimulate conceptual change. Theories have developed concerning specific characteristics of instruction that can effect conceptual change in learners. One question investigated in this dissertation is: "How can the implementation of instructional philosophies such as constructivism affect the degree of conceptual change in college science students?" Another question is: "Can motivational factors such as epistemological belief affect how learners develop conceptualizations or revise alternative conceptions?"

These questions were explored in two separate papers within this dissertation. This dissertation was written in an alternative format, and is composed of two papers which are intended for submittal to scholarly journals. The first paper is a review of literature on the topics of conceptual change and the ways that
constructivist uses of technology can impact the degree of conceptual change in learners. The second paper describes an experimental study that investigates the effects of a constructivist instructional approach versus an objectivist instructional approach in facilitating conceptual change for students learning science. A computer simulation is the central instructional tool for this experiment. The effects of epistemological beliefs of learners were also investigated as to their effect on conceptual development and conceptual change.

Dissertation organization

This dissertation is written in a format that allows the two parts contained within to be submitted as papers to scholarly journals. The format does not follow the traditional dissertation "chapter" format but includes the same content. All references cited in the general introduction and in both papers are cited after the general conclusion section following the second paper. All tables cited in the second paper are found at the end of the second paper. Materials included in the appendices will not be submitted to journals with the papers.
INTRODUCTION

Helping students construct an understanding and acceptance of scientific explanations about the way the world works has been a challenge for American education (Champagne, 1992; Anderson & Smith, 1987). Learners hold a variety of alternative conceptions about natural phenomena that may actively interfere with the development of scientific conceptualizations (Hewson & Hewson, 1983; Villani, 1992; Dykstra, Boyle & Monarch, 1992). One specific area of research has been in the development of instructional methodologies that stimulate scientific conceptualization on the part of the student, causing the student to restructure or reject their alternative conceptions. One product of this research, conceptual change theory, describes how learners come to understand phenomena around them and how instructional interventions can reinforce or change these interpretations (West & Pines, 1985). The area of conceptual change is one of several instructional approaches within the framework of constructivism, the theoretical position that learners construct their own knowledge (Honebein, Duffy, & Fishman, 1993).
Related areas of research in helping students understand science better are: identifying how alternative conceptions begin (Panofsky, John-Steiner & Blackwell, 1990; Driver & Easley, 1978), identifying commonly held alternative conceptions (Fisher, et. al, 1986; Arnaudin & Mintzes, 1985), and developing assessment techniques that can effectively measure student understanding of scientific conceptualizations (Gutierrez & Ogborn, 1992; Stanners, Brown, Price & Holmes, 1983).

In the search for ways to influence the conceptual development of learners, computer technologies have emerged as a possible vehicle for helping students learn and for effecting conceptual change (Gorsky & Finnegold, 1992; Zietsman & Hewson, 1986). The use of computer-related technologies in instruction has grown substantially in the past 10 years (Becker, 1991). With the development of more sophisticated software and hardware, interest has been generated in the new ways technology can be used in instruction, particularly in the area of simulating scientific processes that are prone to misunderstanding by learners. While these some of these dynamic technologies are designed for educational use, they are often "administered" to students without reference to any theory-based instructional design. There is a need for investigation into how computer simulations can be used in a constructivist manner to effect conceptual change.

This paper focuses on the constructivist positions that underlie conceptual change theory and the nature of alternative conceptions held by science students. The cognitive aspects of conceptual development will be discussed as the basis for understanding how students develop alternative conceptions about the world of science and how instructional strategies can be developed to promote conceptual change. This paper then addresses how instructional strategies can
incorporate the power of computer simulations in developing conceptualizations and effecting conceptual change.

BACKGROUND

Alternative conceptions in science education

Overview

Substantial research has been done in the past 20 years concerning informal ideas about natural phenomena that students bring with them into the classroom. Students' informal ideas have been described in areas such as the human cardiovascular system (Arnaudin & Mintzes, 1986), electric circuits (Dupin & Johsua, 1987), the reflection of light (Mohapatra, 1988), and simple mechanics (Viennot & Rozier, 1994). These informal ideas have the general characteristics of being poorly articulated, internally inconsistent, highly dependent on context, and in some cases, highly resistant to change. Despite these qualities, informal ideas often have strong explanatory power in the mind of the student (Driver & Easley, 1978; Hewson & Hewson, 1983; Posner, Strike, Hewson, & Gertzog, 1982; Pines, 1985).

These informal ideas stand in contrast to the formal scientific conceptions that are taught as part of the curriculum and characterize the various disciplines. The term "scientific" refers to the characteristics of being internally consistent, well supported by empirical evidence, and generalizable to related contexts. A primary epistemological feature of scientific conceptions is that they reflect the authority of the scientific community— they are tentatively recognized as "correct" (West & Pines, 1985, p. 3).
Conceptual change presupposes a constructivist philosophy of both learning and instruction. Piaget was instrumental in developing the 20th century discourse on constructivism, and as cognitive psychology has evolved, the theory of constructivism has been elaborated and refined. A clear description of the philosophy begins with a contrasting ideological position, that of objectivism (Allen, 1992; Duffy & Jonassen, 1992).

Objectivism

In spite of the differences between the behavioral (learner-passive) model of learning and the variations of cognitive (learner-active) models of learning, both of these theories are essentially objectivist in nature. Objectivism holds that the goal of understanding is to know the entities, attributes, and relations that exist in the world. Scientific authorities have described and organized these entities, attributes, and relations that are acknowledged to exist (Lakoff, 1987, p. 159). The goal for the learner is to retain the "correct" propositional structures (Duffy & Jonassen, 1992) as described by content experts (scientific authorities) and curriculum designers. Set theoretic models (scientifically acceptable explanations of phenomena) in the various curricular areas are mapped onto the learners existing knowledge structure with the eventual goal being the mastery of the accepted knowledge.

Objectivism acknowledges personal experience as contributing information to memory structures and leads to the inevitable conclusion that no two individuals will have identical learning experiences. The impact of prior experience, however, is viewed as leading to partial and biased understandings (Duffy & Jonassen, 1992).
Two further assumptions of objectivism are that knowledge exists independent of the knower, and that the objectivist instructor can create assessments focusing on mastery learning as evidence that everyone has acquired the same knowledge. Tests are created to measure the learner's accuracy of match between what they understand and the conventional academic understanding, with instructional methodology seen as irrelevant to the design of the assessments (Bednar, Cunningham, Duffy & Perry, 1992). The depth and breadth of understanding for students are cause for some variations in assessment scores, but the students' understandings must fall within accepted frameworks of theory to be evaluated as "correct."

Objectivist approaches to instruction may be either learner-active or learner-passive. Learner activity is prescribed to aid in rehearsal of information and attention to stimuli (Duffy & Jonassen, 1992).

Carr et al. (1994, p. 147) describe objectivist implications for science instruction. They envision the instructor's position as transmissive of precise and unambiguous concepts from the expert to the novice. Within this context science is viewed as:

- being composed of knowledge that is unproblematic,
- having truths that are discovered by observing and experimenting,
- providing right answers, and,
- differentiating between correct and incorrect interpretations of the world in response to objective data.

Objectivist epistemology is associated with both behavioral and cognitive learning theory. In both theories stimuli are presented to the learner and regardless of how the learner is viewed to use those stimuli, the learning
outcome is judged on its consistency with an accepted academic knowledge base. Objectivist cognitive psychology is explicit about the acquisition of information that exists independently of the mind, and that through application of scientific methodologies and logical reasoning, the learner can come to a valid and unbiased understanding of the world (Bednar, Cunningham, Duffy, & Perry, 1992).

Absent from objectivist learning theories is the involvement of personal meaning as connected with learning. Personal meaning is not seen as connected with experience, and even experience is seen as an insignificant factor in how learners conceptualize the world (Solomon, 1987). Two types of meaning have been described by Ausubel (1968). Logical meaning refers to the "meaning that is inherent in certain kinds of symbolic material by virtue of its very nature" (pp. 44-45). This material is relatable on a non arbitrary and substantive basis to a learner's correspondingly relevant ideas. Psychological meaning is an idiosyncratic cognitive experience in which there is a non arbitrary and substantive relation of logically meaningful propositions to a particular learner's cognitive structure. This creates the possibility of transforming logical into psychological meaning during the learning process. Psychological meaning is related to the phenomenological position that "only in the stream of lived personal consciousness are the experiences to be found on which we draw for reflection and interpretation" (Solomon, 1987, p. 66).

To address the complexity of meaning in intellectual growth involves synthesizing ideas from fields such as social psychology and linguistics. This avenue leads to constructivism.
The epistemological basis for constructivism

Constructivism as a learning theory is not diametrically opposed to the objectivist position in every aspect. Both theories hold that there is a real world that individuals experience, and that this experience can influence learning, albeit in different ways (Duffy & Jonassen, 1992).

A central point of departure from objectivism is the constructivist view that meaning does not exist in the world as an entity separate from the learner, but that meaning is imposed upon the world by the learner (Duffy & Jonassen, 1992). Meaning is directly influenced by personal experiences that are associated with ideas. These personal experiences may be interactions between the learner and the external world, or they may be products of reflection; in either case, the experience associated with the ideation serves as a complex indexing mechanism for meaning (Solomon, 1987). Piaget (1964) emphasized that knowledge is not a copy of reality, and his positions on knowledge production reinforce the endogenous nature of knowledge. Piaget held that to know an object is to act on it, to transform it, and to understand the nature of the transformation.

Even the affective dimension serves to help fashion conceptions of the world; Claxton and Palmer (1991) noted that how we feel about what we are learning influences the structure of our conceptualizations, even in the abstract and "objective" domain of science. These ideas lead to the assumption that there are multiple and idiosyncratic ways to structure reality, all highly dependent on experiences; there is not a single "correct" view of the world. The various meanings that different individuals can have for concepts and propositions, however, are usually sufficiently similar to permit interpersonal communication and understanding (Ausubel, 1968). Shared meanings within a
culture are the bases upon which learners can compare the congruence of their understandings with those of others. Philosophical arguments beyond the scope of this paper may arise as to which conceptions may be considered "correct" or "incorrect". Constructivist theory does describe standards for judging the quality of products and processes that evidence learning, but there is a de-emphasis on the absolute notions of "correctness" and "incorrectness".

These basic premises suggest that, historically, there has been a complexity underlying learning that has not been addressed by objectivist pedagogy. Additionally, the model of learning supported by constructivism is composed of highly integrated personal experiences that resist the somewhat fragmented view of knowledge proposed by objectivist philosophies (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

A much more context-dependent view of learning has emerged and has been the topic of a recent body of research. Resnick (1987) and Driver, Asoko, Leach, Mortimer and Scott (1994) have noted the decontextualized nature of much of contemporary instruction, and suggest that the lack of transfer between in-school learning and out-of-school learning may be due to the way in which academic tasks are designed. These tasks tend to be contrived, non-thematic as a group, and unrelated to experiences that the students have had in the out-of-school environment. Constructivists have emphasized that classroom learning tasks should be authentic, that they should correspond to realistic processes that occur in society, and that the results of such tasks should be held as valuable in some cultural context. Constructivist instruction is characterized by continual restructuring, modification, and adaptation of knowledge claims (Duschl & Gitomer, 1991).
Driver et al. (1994) suggest that knowledge construction as an individual process is similar to discovery learning, but that learners must go beyond personal empirical inquiry. Learners must be given access to examples of conventional scientific thought processes because the objects of science are not the phenomena themselves, but the conventional interpretations of these events that are promoted by the scientific community.

It is arguable that a fundamental unit of scientific interpretation of the world is the conception. How the science community describes concepts is many times at odds with how individual learners build (construct) their own conceptualizations of objects and phenomena.

**Terminology of alternative conceptions**

A *conception* is, minimally, a meaningful proposition. A conception can also be an elaborate set of interrelated propositions that is central to other ideas in the intellect. "Conception" is used to mark plurality and complexity as opposed to "concept" (Strike & Posner, 1992); a conception has also been described as a way of seeing something, a qualitative relationship between an individual and some phenomenon (Johansson, Marton & Svensson, 1985). A *concept* may be viewed as a unit of meaning that captures regularities among objects, events, or other concepts. Concepts are human inventions that serve to distinguish entities from one another and relate entities to each other. Concepts may range from the directly experiential such as "tree" or "book", to those at higher levels of abstraction, representing relationships among higher order concepts such as "democracy" or "ecosystem" (Pines, 1985).
Not all conceptions are of equal importance. To understand that "the sky is blue" may not be the result of or lead to expanded ideation. To grasp the mechanism of photosynthesis however, requires some understanding of chemistry and botanical anatomy. This implies a level of understanding beyond the declarative product of rote memorization. Connecting meaning to the photosynthetic process empowers the learner to use the conception for other explanations related to plant functions such as respiration and growth. In this sense, concepts and conceptions structure perception, and may be considered "tools of thought" (Strike & Posner, 1992).

Learners try to establish some level of systematization as they form mental models (conceptualizations) of the real world that help organize and predict phenomena (Driver and Easley, 1978). These models are rarely elaborate or generalizable across contexts, but they serve to explain occurrences that the learner is exposed to in everyday life. Scientific explanations, with their characteristic rationality and generalizability are considered "correct" by content experts within the domain and are often at odds with the informal explanations of phenomena given by young learners. This discrepant condition gives rise to the term "alternative conception" for the learner's explanation (alternative to the scientific conception).

There are many additional terms used to describe these non-scientific conceptions, some are ostensibly synonymous while others imply different characteristics about the learners' beliefs. Driver and Easley (1978) prefer the term alternative frameworks, citing the negative nature of other terms such as naive conceptions (Champagne, Gunstone, & Klopfer, 1983), children's science (Gilbert, Osborne, & Fensham, 1982) and misconceptions. The term
misconception connotes a wrong idea; research studies using this term describe conditions of instruction that result in an incorrect assimilation of formal scientific models on the part of the learner. *Alternative frameworks* describes autonomous organizations for conceptualizing experiences of the physical world (Driver & Easley, 1978). Novak (Wandersee, Mintzes, & Novak, 1994) also offers the term *LIPHS*-- an acronym for *limited or inappropriate propositional hierarchies*. The term is based on Ausubelian learning theory and emphasizes the conceptual restructuring necessary for the learner to form scientifically viable models from an insufficient extant structure.

Alternative conceptual frameworks are not particular to the domain of science. Learners may have alternative conceptions about the workings of a democracy in social studies, the nature of conflict in literature, differential equations in calculus, or the composition of jazz in music. These disciplinary examples may not reference natural phenomena as consistently as science, but they do involve highly complex and abstract sets of relationships that demand a high degree of conceptualization. Science as a curricular area has found alternative conceptions particularly problematic, partly because the nature of science is explanatory of natural phenomena, and also because of the vast number of concepts associated with all branches of science, some of which relate to everyday student experiences (electrical circuits, weather phenomena), and some of which are totally abstract or unobservable (atomic structure, solar system dynamics).

Central to the constructivist view of learning is the experiential background of the learner and the multidimensional aspect of the extant intellectual artifacts related to these experiences. The influences of these components may help explain the development and nature of conceptions as well as suggest designs for
instruction aimed at conceptual change. Posner, Strike, Hewson, and Gertzog (1982) describe these intellectual artifacts and incorporate them into a "conceptual ecology" that influences the nature of conceptualizations. These artifacts are:

- *anomalies or incongruities*, the particular failures of an idea to explain certain phenomena,
- *analogies and metaphors*, allowing ideas to be understandable as they are mapped isomorphically onto concrete experiences,
- the *epistemological commitments* of the learner including explanatory ideals, metaphysical beliefs, general views about knowledge,
- *knowledge in related fields* including competing conceptions.
- *exemplars and images* which are prototypical examples, and
- *past experiences*.

Strike and Posner (1992) added:

- *motivations and goals*, including their institutional and social sources, and
- *current conceptions and misconceptions*.

The expansion of acknowledged influences upon conceptualization that go beyond information processing have strong implications for understanding learning and the design of conceptual change instruction.
Claims concerning alternative conceptions

A consistent group of claims about alternative conceptions has emerged from the literature; Wandersee, Mintzes, and Novak (1994) have summarized these. The first claim is that learners have a diverse set of alternative conceptions with regard to objects and phenomena. This claim is rarely disputed; the practical implication for instruction is to identify these alternative conceptions, probe their nature and their sources. There are potentially unlimited idiosyncratic versions of conceptions about phenomena.

The second claim is that alternative conceptions exist across age and ability. Alternative conceptions do seem to persist throughout all age levels, but the frequency of alternative conceptions vary considerably by domain of knowledge and quality of prior instruction. There are no consistent findings that suggest differences in numbers or types of alternative conceptions across ability groups (Wandersee, Mintzes, and Novak 1994; Placek, 1987).

The third claim, that alternative conceptions are resistant to extinction by conventional instructional methods, is highly dependent upon the nature of the alternative conception (Wandersee, Mintzes, and Novak 1994). The most resistant alternative conceptions are those in the physical sciences that oppose counterintuitive scientific conceptions. An example of this type of scientific conception is the notion of forces being exerted by stationary objects (Gorsky & Finegold, 1992). Some alternative conceptions are simply mistaken knowledge such as classification errors within the animal kingdom, which although playing a central role in other related conceptual structures, simply involve naming conventions.
Another claim with implications for classroom practice is that there are instructional strategies that can facilitate conceptual change. Conceptual change strategies are comprised of a diverse and eclectic set of approaches that share a basic assumption: students come into learning environments with prior understandings of how the world works and the role of the teacher is that of change agent (Wandersee, Mintzes, and Novak 1994). A more comprehensive description of conceptual change strategies is addressed in a later section.

Alternative conceptions in science

This section will provide an overview of alternative conceptions within the fields of physics, chemistry, and biology.

There is considerable variance in the nature of alternative conceptions held by science students that have been identified for study. Guzzetti, Snyder, Glass, & Gamas (1993) describe a list of alternative conceptions from "wild animals are always ferocious" (Gordon & Rennie, 1987) to belief in creationism (Lawson & Weser, 1990; Lawson & Worsnop, 1992). Guzzetti et al. add that there are differences between mistaken knowledge and alternative ideas that represent an entrenched belief; thus it is possible to know the theory of evolution without believing it.

Within the field of physics, simple mechanics have generated the most research with regard to alternative conceptions. Most students hold a commonsense belief about moving bodies that combines Aristotelian and impetus theories of motion (Wandersee, Mintzes, & Novak, 1994; Hewson & Thorley, 1989; Dykstra, Boyle, & Monarch, 1992; Gutierrez & Ogborn 1992). In general terms, the misconceptions center around the idea that motion implies
force. This erroneous idea is often elaborated by students when they claim that, under the influence of a constant force, objects move with a constant velocity (Brown & Clement, 1987). Other topical areas prone to alternative conceptions are electrical current and how it flows through circuits (Carlsen & Andre 1992; Hargrave 1993; Shipstone, 1988; Dupin & Johsua, 1987), and the laws of light reflection (Mohapatra, 1988).

Within the field of chemistry, Fensham (1994) describes several alternative conceptions that appear to be common across age and experience groups. The general categories of misconception are: that there is a continuous or non-particulate composition of substances, believing in additive rather than interactive models of how chemicals react with one another, and viewing chemical equilibrium as a non-dynamic state in which no chemical reactions occur. He claims that traditional teaching and assessment fail to challenge these misconceptions and students may persist in maintaining the misconceptions, still performing well in testing situations.

Most research in alternative conceptions in biology can be organized into five groups: concepts of life, animals/plants, the human body, continuity principles of reproduction, and genetics/evolution (Wandersee, Mintzes, & Novak, 1994). The emergence of the concept of life is an example of the developmental aspect of conceptions and misconceptions as described by Piaget (Mintzes, Trowbridge, Arnaudin, & Wandersee, 1991; Inhelder, 1969). From ages three to seven, life is ascribed to any object exhibiting activity such as a noisy toy or kitchen appliance. From ages seven to eight, movement becomes the essential quality for defining life (a car in motion or a thrown ball). In the third stage, approximated by the years 9 to 11, children ascribe life to things exhibiting
spontaneous movement (the wind, the sun or moon). At about 11 to 12 years of age, children restrict their identification of living things to plants and animals.

Carey (1985) examined the explanations of life processes given by 4, 6, and 10-year olds, and found that their reasoning followed an intuitive theory of human behavior. The youngest were asked for explanations of life processes such as breathing, eating, and sleeping. They consistently ascribed these activities to social and psychological needs. By age 10, students possess their own domain of "intuitive biology" which parallels the understandings held by naive adults. This supports the assumption that, if left unchallenged, alternative conceptions may persist throughout life.

Mintzes, Trowbridge, Arnaudin, and Wandersee (1991) surveyed 1,400 students in grades 5, 8, 11, and college sophomores about photosynthesis and nutrition in plants. About half the college sophomores claimed that a plant's food comes from soil. Fewer than 10% of the respondents described plants as making food from carbon dioxide. When questioned about the role of the leaf in plant biology, the majority of respondents at all grade levels suggested that the leaves make food (a correct response). The apparent conflict between the students' belief that soil furnishes food, and their responses that leaves make food, highlights the preservation of contradictory ideas by students. Other common misconceptions regarding plants are that: fertilizer is "food" for plants, chlorophyll is plant "blood", gases are not involved in making food, photosynthesis creates protein, and plants change water into sugar.

Classification of living things is another process that learners of every age show difficulty in understanding. An exercise in animal identification by Mintzes et al. (1991) revealed that the sample of students mentioned above could
correctly identify a cow and a seagull as animals, but with the exception of college biology majors, a quarter of the respondents failed to identify the fish and a third failed to identify the butterfly as animals. No respondents included a pine or mushroom as animals. Other related findings in this study showed that the view of "animal" is erroneously restricted by distinctions such as the presence of appendages, being terrestrial, having a backbone, or having fur.

The human cardiovascular system is an example of a subject which involves structures and processes that are not readily observable, but assumptions are made about it by young learners when they experience related subjective phenomena (feeling the heartbeat, noting patterns of breathing, seeing blood from cuts, feeling the warmth of the body). Cardiovascular concepts are particularly vulnerable to the three major influences on misconceptualization: physical interactions with the environment, interactions with peers or the media, and formal instruction.

Mintzes, Trowbridge, Arnaudin, and Wandersee (1991) questioned students in 5th, 8th, and 10th grade, as well as college freshmen/sophomores about the cardiovascular system. About two-thirds of the elementary students described blood as a red liquid. In the higher grade levels, the idea of cells suspended in this liquid emerged. Older students apparently assimilated the ideas of cells into their intuitive notions of blood as a red liquid; this particular explanation accounted for more than half the college-age responses. When asked to explain why blood is important to the body, most younger students and about half of the high school students gave naive reasons such as "keeps you alive" or "keeps you going." Older students showed a greater accuracy of scientific explanation as they identified the blood's role as transporting oxygen and nutrients. The
respondents were also queried about the anatomical construction of the heart. When asked to select from several illustrations which heart was most like their own, a three-chambered amphibian heart was selected by about 40% of elementary students. This model was selected by at least one quarter of all students regardless of grade level. Few students among those who chose the four chambered heart as a model could explain the significance or 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.

Conceptual change

Overview

There is no well articulated theory that describes the substantive changes in the process by which individuals' central, organizing conceptual frameworks are replaced by another set of beliefs which are incompatible with the first (Posner, Strike, Hewson, & Gertzog, 1982). It is commonly held that learning is the interaction between what a person is taught, and what he/she already possesses as conceptual structures. The nature of these interactions is complex even for simple learning. A conceptual change model of instruction is one of a group of four constructivist approaches listed by Duschl and Gitomer (1991), the others are: the learning cycle, the generative learning model, and the use of analogies and analogical bridges. The conceptual change model is based on the theoretical positions described below.

Many researchers in the area of conceptual change express a fundamental commitment that learning is a rational process (Posner, Strike, Hewson, &
Gertzog, 1982) and that people strive to make sense of the natural world (Hewson, 1981). Posner et al. have drawn parallels between the historical development of scientific thought and the personal intellectual change a learner experiences as conceptualizations are formed. Science has central commitments or paradigms that serve as a framework of "truth." This framework helps define problems, describe strategies for addressing these problems, and perhaps most importantly, suggest what will count as viable solutions (Kuhn, 1970). When science recognizes new evidence that fits within the boundaries of existing theory, that theory may be modified or added to. When science is faced with challenges to the basic assumptions upon which all research is based, deliberate inquiries must be made, and if the new idea demonstrates more explanatory and predictive power, it replaces the old paradigm. An example is the Copernican view of the universe and how the heliocentric theory explained celestial movement with greater accuracy than the Ptolemeic design. A more modern example is Einstein's theory of relativity which did not replace as much as subsume Newtonian physics.

Posner et al. asserts that analogous patterns exist in conceptual change in learning. If an individual is confronted with a new idea and the conceptualization of that idea is reconcilable with other existing ideas, then the individual is likely to assimilate (Piaget, 1964) the idea (an evolutionary change). Assimilation is the recognition that a physical or mental event fits into an existing conception and the consequent elaboration of that conception brought about by the new information (Dykstra, Boyle, & Monarch, 1992). This recognition also involves the purposeful ignoring of features not deemed salient to the assessment of the events. If the learner's current schematic structure fails
to allow her/him to grasp new phenomena at all, then *accommodation* (Piaget, 1964) may take place (a revolutionary change). Accommodation is a radical replacement of beliefs that are central to the way an individual systematizes and explains the world. The terms assimilation and accommodation were introduced by Piaget in his work with the conceptual development of children. Other terms cited in literature are Hewson's (1981) *conceptual capture* (analogous to assimilation) and *conceptual exchange* (analogous to accommodation).

Posner et al. clarify one aspect of accommodation that has been misrepresented in the past. Accommodation as a flash of insight or wholesale revision of beliefs is an oversimplification. A student will be more likely to adopt some aspects of a new conceptualization while retaining some features of the previously held belief. Each incremental adjustment to conceptualization may set the stage for the next, and there is the possibility of reversion in whole or part to original ways of thinking.

The conceptual change model of learning contrasts with the position of science learning as memorization of new information and skill-building. The conceptual change position is that learning science consists, in part, of a series of revisions in the conceptualizations learners use to organize acquired information and skills. In accordance with this view, science education should be designed to facilitate such changes. Several theorists have proposed conceptual change models that have direct applicability to instruction in science.
Conditions for conceptual change

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

1) There must be dissatisfaction with an existing conception. This can occur when a conception cannot be reconciled with new experiences (anomaly) or when the conception violates some epistemological criteria (this refers to inelegance, being unnecessarily complex, or diametrically opposing a metaphysical belief).

The remaining three conditions describe how the learner views the candidate conception (new conception) and how "satisfaction" with the new conception may be realized.

2) The new conception must be intelligible. The learner must be able to conceive of the new idea using existing structures even though the new idea may be at odds with existing patterns of explanation. This new conception must be internally coherent. 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 is moot. Many science concepts are unintelligible for one reason or another to the learner, and although some direct instruction is necessary to familiarize the student with the content (Anderson & Smith, 1987), objectivist-dominant instruction can promote the unconnected rote memorization of information.

3) The new conception must be plausible. This point touches upon the rationality of conceptual change theory. The learner must be able to envision a world in which this new model of phenomena can operate without
contradiction. This presupposes that the new model is intelligible, but intelligibility is not sufficient. The new conception must also fit in with personal standards of knowledge. Specious conditions of plausibility are generated when the classroom learning environment emphasizes authoritarian epistemology. Students may be socialized to believe that the "teacher is always right" or authors are infallible, thus ideas directly transmitted from those sources carry a predetermined level of plausibility. This imposed plausibility is not necessarily a rational influence, and is not the result of intellectual deliberation on the part of the learner.

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. The candidate conception should be applicable across a range of contexts, and, with some guidance, a learner should be able to demonstrate transfer to related situations in which the new conceptualization is appropriate. Conditions in the world which were not reconcilable with previous conceptions may now be interpreted with coherence by an accepted candidate conception.

A revised theory of conceptual change

The above conditions describe what may be necessary for a rational acceptance of a new theory (conceptualization) by learners. A revisionist theory of conceptual change is offered by Strike and Posner (1992) in which they suggested modifications are needed in their earlier conceptual change theory.

The first element of their self-critique questions the existence of well-formed preconceptions that are symbolically expressed, and the notion that such
preconceptions may be replaced in their entirety by correct scientific conceptions. Strike and Posner suggest that novice learners have iconic or enactive (Bruner, 1966) representations of how the world works. These are not explicit linguistic descriptions, but mental "images" of phenomena that may provide the intuitive basis for understanding the world. Consider the intuitive, anthropomorphic language associated with movement of inanimate objects. Young learners grow up with a vague belief that moving objects (a thrown ball for example) have a lot of energy; "they want to climb" and then "tire out" and fall. Miscellaneous popular jargon creates imagery that members of the culture use to form ideas about movement and energy that may not be scientifically correct. These are not well articulated beliefs, but they contribute to the way the learner prefers to see the world. Learners may also generate conceptions spontaneously in the instructional setting when asked to envision or explain phenomena they have not previously considered. Thus preconceptions are occasionally emergent artifacts of the classroom environment, not preformed in the intellect. This serves to further differentiate the scientists' paradigms from conceptual development in learners in the lack of clearly stated, symbolically expressed (i.e. in words, numbers, operations) conceptualization on the part of the individual learner. Strike and Posner also argue that these preconceptions, however well formed, have a developmental history, and that revealing that history may be more important than understanding the character of the misconception itself. Common metaphorical language is cited as a powerful influence on students' beliefs about phenomena, and singling out this aspect of the conceptual ecology may serve to expose misconceptions more than confronting learners with anomalies produced by their misconceptions.
Another point of revision for Strike and Posner is that conceptions were originally seen as cognitive objects that were affected by components of the conceptual ecology. Their view now is that conception and misconceptions serve as part of the ecology and that they influence, in turn, the metaphors, anomalies, knowledge, and other parts of the ecology.

Another clarification by Strike and Posner is that their original theory is overly rational. The original theory had been criticized (Pintrich, Marx, & Boyle, 1993) for failing to consider the forces of motivational beliefs of the learner such as goals, purposes and intentions. Language in the original theory described learners as logically weighing the consequences of accepting one explanation versus another. The assumption was that school children seek to resolve discrepancies between their conceptions and natural phenomena as a primary goal of intellectual activity. In reality, 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 a intellectually overwhelming situation, or bringing closure to a learning situation at any cost. Intellectual engagement as a game or academic hurdle (Villani, 1992) rather than the pursuit of understanding, fosters these types of non-scientific ways of resolving misconceptions.

Some authors have elaborated on the possibility that motivational beliefs (goals, values, self-efficacy, and control beliefs) play a major role in conceptual change (Pintrich, Marx, & Boyle, 1993; West & Pines, 1983; Dweck, 1986; Entwistle, Entwistle & Tait, 1993). A "cold" or overly rational model is contrasted to one which not only includes individuals' beliefs, but also the classroom context, and the nature of the interactions between the students and
the teacher. 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, Entwistle & Tait, 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. Dweck (1986) suggests 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.

Various styles of instruction play a subordinate role to the effects of opportunity and motivation on student learning (Perkins & Simmons, 1988). Scientists, as members of a learning community, internalize the goals of systematizing knowledge and refining theories, but this is not the orientation of most of the students in the classroom. Theories that base conceptual change on parallels between the two bodies of learners neglect (among other conditions) differences in motivation.

West and Pines (1983) argue that non-rational components are intrinsic to conceptual change. The non-rational aspects of intelligibility, plausibility, or
fruitfulness are not simply affective predispositions to conceptual change, but are part of what learning is. The feeling of power in identifying, explaining, and predicting is part of the learning process, as are the pleasurable aesthetics of balance and harmony in reason. Accepting the fruitfulness of a new conception implies value judgments about the new conception as well as goals as to how the new conception will help solve certain classes of problems (Boyle, Magnusson, & Young, 1993). These motivational characteristics are part of the process of conceptualization, but Strike and Posner (1983) caution that categorizing factors influencing conceptual change into rational and non-rational would add confusion to the research field. Basing acceptance of certain conceptualizations on aesthetic or moral grounds may seem irrational to the scientist, but perfectly well-founded to certain types of learners.

**Strategies for promoting conceptual change**

In a general sense, some conceptual change strategies focus on externalizing (exposing) the learner's knowledge structure, then modifying it. Other strategies emphasize the need for self-monitoring and controlling the events of learning. Anderson and Smith (1987) list three features of successful conceptual change instruction: presenting direct refutation to student misconceptions, immediate application of scientific conception to explanation of phenomena, and explicit emphasis with repetition.

Research from reading education has been critical of the list-like fashion in which information is presented in basal readers, as well as the excess of content material (Guzzetti et al., 1993). Based upon these criticisms, researchers have used alternative types of text or text-based strategies that provide a refutation of
commonly held misconceptions. The elements of surprise or incongruity are essential in initiating a conceptual change process; these are incorporated into explanations that prove the alternative conception untenable while at the same time giving supporting evidence for the scientific conception. In a metanalysis of conceptual change strategies in reading and science education, all variations of refutational text when used as a single intervention were more effective than any form of non-refutational expository text. Some of the variations of refutational text included expository versus narrative, and student choice-of-study strategy versus a no student choice-of-study strategy. The metanalysis also concluded that it was effective to use text in combination with other strategies that produce cognitive conflict (Guzzetti et al., 1993).

Concerning science education studies, the metanalysis by Guzzetti et al. identified three approaches that had the greatest effects on conceptual change: The Learning Cycle, bridging analogies, and conceptual conflict.

The Learning Cycle is an instructional approach, not an individual strategy. It has been used in studies on concept acquisition, and has recently been modified for use in the area of conceptual change (Lawson & Weser, 1990; Lawson & Worsnop, 1992). In the first phase, it allows students to learn through discovery-type experiences with little guidance from the instructor. The second phase calls for the organization of the information gathered in the first phase, refining patterns identified, and using discussion, text or other media to link student-discovered patterns with a scientific concept. The third phase of the cycle requires the student to extend their knowledge by abstracting their application from concrete examples, and generalizing a concept to other applications. A modification of the cycle includes the addition of a predictive phase in which
students are asked to predict outcomes as they engage in experimentation (Guzzetti et al., 1993).

Bridging analogies link a known example of a concept to an unknown example. After a diagnostic test to identify particular misconceptions, the instructor identifies student-held beliefs that have some approximate consistency with the scientific conception. These beliefs are used as anchoring points for helping students make sense of conceptions using their own intuitive experience. A skilled teacher can generate focused discussion on how the anchoring examples (a product of personal experience) and target examples (scientific conception) are similar or dissimilar (Guzzetti et al., 1993).

The conceptual conflict strategies are strongly associated with the constructivist approach to learning. They are premised on the idea that learning science is a complex process in which the learner's conceptions interact with new information. The model of conceptual change by Posner, Strike, Hewson, and Gertzog (1982) holds that learners must have dissatisfaction with their conception's ability to be reconciled with scientific conceptions or observations of natural phenomena. If this dissatisfaction exists or can be generated by examples of incongruity, the potential exists for some type of conceptual change. This approach is more theoretical in nature and overlaps the previous strategies in theoretical base and practical application. Hewson and Hewson (1983) identify four possible strategies within this theoretical framework:

- integrating students' existing conceptions with scientific conceptions,
- differentiating existing conceptions into separate but more clearly defined conceptions to show the students that their alternative ideas are not plausible in related situations (not generalizable),
• exchanging the entire alternative conception for the scientific conception after demonstrating the explanatory and predictive power of the scientific conception, and
• conceptual bridging (described as bridging analogies above).

The metanalysis of Guzzetti et al. summarizes the effective conceptual change methods as all producing some form of cognitive conflict. Teaching practices that challenge existing understandings, cause students to face contradictions and recognize counterexamples appear to facilitate conceptual change.

THE USE OF COMPUTER SIMULATIONS IN INSTRUCTION

Introduction

During the past decade, the number of microcomputers in U.S. schools has increased nearly 50-fold (Becker, 1991). The proliferation of computer-related technologies available for instruction has prompted investigation of their influence on learning and achievement, including the processes of conceptual development and conceptual change. There is general consensus that computer-based instruction can result in moderate achievement gains in students in a variety of classroom contexts (Kulik, Bangert, & Williams, 1983). There are, however, well founded arguments that resultant differences in learning from computer-based instruction may be attributed to uncontrolled effects of different instructional methods, content, or novelty (Clark, 1985). As the body of research in this area grows, it is becoming evident that the larger instructional setting in which computer-related technologies are employed should be considered as important as the specific types of computer programs used.
Among types of computer applications (word processing, databases, spreadsheets, hypermedia, communication software and others) simulations seem to offer strong potential as agents in contributing to conceptual change. The ability of simulations to portray phenomena and allow users to interact with the dynamics of a model system create an arguably unique way of helping learners conceptualize phenomena.

Overview

"Pictures, graphs, models, analogies, and metaphors have one thing in common. All can be used as tools to help understanding" (Snir, Smith, & Grosslight, 1988, p. 4). Educators use models as tools for helping students understand a process or thing. A model acts as a metaphor for the student to access something that is less well known by comparing it to something that is more familiar. Snir et al. (1988) describe two types of models that are used in instruction: the object-attribute model which resembles the object modeled in some aspect of its basic appearance (a physical model of the solar system for example), and relational models in which different elements of the model have the same systemic pattern of relationships as that which is being modeled (as in a mathematical model of photosynthesis mechanisms). Object attribute models, such as pictures and scale models do not attempt to map relationships between elements in the model other than isomorphisms such as color, shape, proximity to other elements. A model of an car engine is limited, therefore, to an anatomical inspection by students who need additional information to understand how it actually operates. Relational models, by contrast, can show qualitative and quantitative relationships between elements. These
relationships are usually theoretical entities that are expressions of patterns of regularity. From these types of models, inferences and deductions can be made about the model and the referent system. Children who set up an aquarium may observe relationships among the different species of fish, and between the fish and their environment. This can be viewed as a limited model by which they may infer about relationships in real aquatic systems. Although there is evidence that young students have difficulty grasping relational metaphors (Gentner, 1988), this ability seems to develop somewhere between 7-10 years of age. Relational models may also act as object-attribute models if components of the model resemble the parallel component in the referent system.

A simulation is a dynamic execution of the processes within a relational model system. Although a computer is not necessary to create a simulation, the technology creates powerful possibilities for the representation and manipulation of relational model systems. Thomas and Hooper (1991, p. 498) describe a simulation as: "... a computer program containing a manipulable model of a real or theoretical system. The program enables the students to change the model from a given state to a specified goal state by directing it through a number of intermediate states. Thus, the program accepts commands from the user, alters the state of the model, and when appropriate displays the new state."

There are computer simulations of solar systems, photosynthesis, the cardiovascular system and many more. One advantage of a computer-based simulation is the ability to make normally unobservable occurrences plainly visible for the student. These may be processes that:

• take place over a long period of time such as continental drift,
• take place too quickly to be grasped in real time such as engine cycles,
• are microscopic such as viral reproduction,
• are macroscopic such as astronomical motion, or
• have many complex sub-processes such as photosynthesis.

Additionally, real systems are often filled with non-relevant information, adding a distracting element to the cognitive load of understanding the concept. In a review of visual research, Dwyer (1978) notes that for young learners especially, the addition of too much detail in visuals hinders the ability to sort out relevant details. Computer-based simulations can eliminate (within limits) extraneous information. Simulations can also employ perceptual cues (also referred to as process highlighters) that draw the learner's attention to critical features and events that are functionally invisible. These may be visual cues such as flashing text or color coding, or they may be audio cues such as a "beep" or digitized speech. Perceptual cues are not particular to computer-based media, but they have been positively correlated with student understanding of computer-simulated environments (Chandler & Chaillé, 1993).

Computer simulations can also show multiple representations of the same phenomena simultaneously. The constructivist position that students should have access to multiple viewpoints and representations for information is partially satisfied by well-constructed simulations. One commercial cardiovascular simulation (Explorer's Cardiovascular System) has been designed to display several windows of pictorial and quantitative information simultaneously. The windows show an active human figure, a pumping model of the heart, full-body circulatory motion, and the user's choice of graphical readouts of blood pressure, stroke volume, heart rate, etc. These readouts can be
in the form of line graphs, pie charts, or digital counters. The processing speed of today's microcomputers enables these complex representations to be displayed to the learner, this condition being much advanced from the austere representations provided by previous generations of available classroom computers.

There is the potential for distraction when students have many choices within simulations (Carlsen & Andre, 1992), but the ability of the user to choose any combination of these representations allows them preference in observing and internalizing representations of relationships among phenomena.

Due to the nature of how information is entered, stored and represented in the digital medium, important limitations exist in computer modeling of reality. Model systems that have a logico/mathematical structure of organization are fragmented and programmed into the software in the discrete manner necessary to the medium. These equations are then stored as potentialities for later display. Physics simulations are easily created in this sense because of the inherent quantitative nature of the domain. This allows for the rapid/continuous display of certain types of information in reaction to user choices, because the computer is designed to handle just these types of calculations.

A more challenging test of simulation fidelity to real world phenomena is the area of complex qualitative relationships more common to the social sciences. A simulation may be employed in a teacher education class that allows users to act as teachers in a simulated classroom and select certain decision paths in response to phenomena in the classroom. The complexity of the qualitative interactions among children in classroom is artificially fragmented and quantified to make
the simulated environment amenable to programming (Bowers, 1988). These types of simulations contain a multitude of separate screens that "branch out" to one another depending on parameters in the environment. These screens must be predetermined by experts to allow the simulations to have any validity at all, but the result is ultimately reductionist in nature.

A concept related to simulation is that of microworld. Reiber (1991) describes a microworld as the "simplest model of a domain that is deemed accurate and appropriate by an expert" (p. 3), and "offers an initial point of entry which matches the user's cognitive state to allow fruitful interactions to take place" (p. 4). An example of a microworld might be that of a planet's surface in which a student can set the limited parameters of gravity and atmosphere, then observe how a game of baseball might take place on that planet (Dede, 1987). Simulations, according to this definition attempt to model reality more closely than microworlds and include many of the actual objects and relationships found in the referent system.

The distinctions between simulations and microworlds are not always clear, and the two concepts overlap considerably. Comparisons between microworlds and simulations as to the possible types of learning effects caused by each is lacking. The term computer simulation will be used then, in the broadest sense in this paper.

General instructional uses of simulations

As with many computer based learning tools, much of the early research on simulations focused on whether or not students could learn from them. Simulations were compared in their effectiveness to non-computer based media
or no instruction at all. This media comparison approach has been superseded by a more sophisticated set of questions dealing with the larger theoretical framework of instructional design. Research on how and when simulations are used with respect to other elements (didactic instruction, collaboration, lab experiences, assessment) in instruction is helping to clarify how simulations can be used for maximum effect in the classroom.

In a review of simulation research, Thomas and Hooper (1991) developed a useful taxonomy of uses for simulations and evaluated the effectiveness of simulations with respect to these uses. Their first category, *experiencing*, describes cases in which simulations precede formal instruction, and are used to set the stage for future learning. Experiencing is useful for providing motivation, providing concrete examples, providing an organizing structure, and exposing misconceptions. Brant, Hooper and Sugrue (1991) found that using a genetics simulation in this way (prior to formal instruction) resulted in significantly higher achievement than using the same simulation after formal instruction.

The second taxonomic category is *informing*. This use of simulations is simply for the delivery of information, and few learning benefits were found for students using simulations in this manner as compared with the use of computer tutorials, or direct instruction.

The third category, *reinforcing*, is described as the strengthening of learning objectives. The criteria for simulations classified as being used for reinforcing is that they direct the student to apply existing knowledge in the same context it was learned. As with informing, few learning benefits were found for students using simulations in this manner.
Integrating, the fourth category, is the use of simulations to assimilate isolated bits of information into functional units, and to promote the reorganization of learned material. Simulations used in this way were found to be beneficial in identifying and understanding problems.

Thomas and Hooper summarized their findings by saying that the effects of computer simulations are not revealed by tests of knowledge but by tests of transfer and application. Using simulations to give initial exposure to students about a concept (experiencing) and using simulations to integrate knowledge and stimulate problem solving behaviors (integrating) seem to be the two most promising classroom applications.

Constructivist uses of technology

As learners try to systematize their understanding of phenomenological relationships, they may profit from judicious didactic instruction (Klausmeier, 1961), but the complex picture of the conceptualization processes emerging from research indicates that learners create their own idiosyncratic webs of knowledge that are highly dependent on their backgrounds. Further, these individualistic backgrounds develop along lines of intellectual propensities particular to that learner. Learners are adept at different symbol systems such as language-based, logico-mathematical, or iconic (Gardner, 1993 & 1994); also, learners have different learning styles, and can have vastly different motivations for doing tasks (Pintrich et al., 1993; Schommer, 1993a & 1993b). A constructivist application of a well-designed simulation allows the learner to choose their mode of informational representation on the computer screen; it allows them to develop hypotheses about phenomena that are accommodative of their way of
solving problems. This is not to say that there is no place for the prescriptive in instruction. Unguided inquiry, especially using computer simulations can be an exercise in futility for the student (Rivers & Vockell, 1987).

General task descriptions within the simulation should be communicated to the learner and explicit understandings about what "counts" as a scientific explanation for phenomena should be discussed at some point in instruction (this is not the same as accepting a single answer). Constructivist learning environments do not require the learner to arrive at a predetermined answer, but rather allow the student form his/her own internal representations of phenomena.

Students who have shallow motivations for academic work (completing tasks for the purpose of receiving a grade or besting others) are often frustrated with constructivist learning environments because there is not a "correct" answer; specific task requirements are not furnished for them (Miller & Hamilton, 1992), and there is difficulty quantitatively comparing understanding among students. Students who have more sophisticated motivations to understand the material profit from the constructivist approach, but being brought up within the industrialized model of American education, they "grow accustomed to the chains that bind them" and are also frustrated by the relatively unstructured nature of constructivist learning environments.

Anomalies, part of the conceptual ecology, are important in simulation exercises. Incongruities that are recognized between an individual's explanations and the way phenomena actually occur in different environments are often vague and ill-defined in the mind of the learner. When learners realize, within the environment of the computer simulation, that they are
creating explanations "ad hoc" for most situations, or that incompleteness exists in explanations, their conceptual shortcomings are made explicit. The power to set conditions and test them repeatedly can produce successive iterations of inconsistency in predicted results that parallel the activities of confrontational class discussion and the argument of refutational text.

Although the prescriptive use of simulations can direct a student to set conditions within the simulation that exemplify a common misconception, it may not be the misconception of that particular learner, and may serve to confuse rather than guide.

Using simulations as vehicles for conceptual change

Simulations allow a student to observe a system of interrelationships, make changes in the system, hypothesize about the effects of these changes, then enact the system to see the results. In a computer model of photosynthesis there may be representations of plant parts, various gasses and light quality. If a learner observes how resources are used by the plant to make sugars and other products, curiosity may be aroused as to what would happen if some of these inputs were adjusted. Increasing the amount of a single variable quantity may not lead to expected results, and more problems are created than solved. This is not necessarily problematic in the constructivist view; part of the premise with well constructed learning environments is that there is not a single correct answer, and problem identification should be left to the student. The potential for simulations to help the student develop problem identification as well as problem solving skills is evident. There are many opportunities in some (but not all) simulations to identify and isolate variables, develop a structured
solution strategy, and monitor progress. One caveat here is that the learner's approach should have some structure whether it is self-imposed or teacher-imposed. Simulation software has become very dynamic, the possibility for disorientation is greater when the learner's approach is haphazard.

Another strength in the design of simulations is their potential to effect conceptual change. Zietsman and Hewson (1986) used a computer simulation to diagnose and remediate alternative conceptions about velocity. Their results showed that: 1) computer simulations are credible representations of reality, and 2) remediation using simulations produced significant conceptual change in those students holding alternative conceptions. There are studies that have found little or no effect using simulations to effect conceptual change. In an study on electrical circuits, Carlsen and Andre (1992) found that using text designed for conceptual change resulted a significant alteration of misconceptions, but that using a computer simulation in addition to the text produced no greater change than text alone.

Gorsky and Finegold (1992) assert that if naive conceptions are grounded in personal experience, then re-experience 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. 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 simulations. Dissatisfaction arises when, within the simulation's domain, the user is faced with results that conflict with what was predicted. An addition of carbon dioxide to a plant's immediate environment
does not always result in a greater production of sugars and oxygen. Simulations
that display phenomena with multiple representations (below the level of
distraction) give the user perceptual choices. These choices help make the
system's relationships more intelligible, and the intelligibility of the system as a
whole gives a clearer picture of phenomenological relations. Use of simulations
prior to didactic instruction may help establish the intelligibility of scientific
concepts (Gorsky & Finegold, 1992). When used to provide an introductory
framework prior 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). Plausibility of a new
conception is dependent on intelligibility. In a simulation, candidate hypotheses
are quickly tested, and the fruitfulness of the results give retrospective
plausibility to the candidate hypotheses. If a user sets up conditions within a
simulation that result in a confirmation of predictions and the student can
understand what they have done to the system (not always a given), there is a
chance that the student can refine their conceptual understanding of a
phenomenon.

The above argument assumes several things. One is that the student
comprehends the nature of the simulated environment and knows how to
create, test, and interpret hypothetical situations. Trial and error in a simulation
is not uncommon, and results for students who use this approach may be
uninterpretable.

Another assumption (not particular to simulations) is that the conceptual
change process is entirely rational. When user-determined conditions in a
simulation environment provide results, they can be rejected on any number of
non-rational grounds. Gorsky and Finegold (1992) used a dissonance-based strategy with the use of a physics simulation to achieve conceptual change. Dissonance, the learner's comprehension that what they expected is not what is taking place, can create dissatisfaction with an phenomenal explanation. West and Pines (1983) assert that a discrepant event may fail to initiate a conceptual change process if anomalies are seen as irrelevant, inappropriate, or useless. There are a variety of ways a student may react to an anomaly; Gorsky and Finegold have outlined five possible reactions. Students may:

- not perceive the anomaly,
- perceive the anomaly but not understand it,
- understand the anomaly but not accept it,
- accept the anomaly, but fail to reject their incorrect views, or
- reject their incorrect views and accept the scientific ones.

Other researchers suggest that students tend to assimilate conflicting information into a widening web of misconceptions rather than go through the process of accommodation, and that in the absence of some direct instruction, students use their own misconceptions to explain phenomena (Perkins & Simmons, 1988; Anderson & Smith, 1987). Other than manipulating direct personal experience, perhaps the most efficient way to present anomalies to students is by simulated experiences; the particular ways that students react to these anomalies is a topic for further study.

Students often believe that phenomena behaves one way in the classroom, and another in the real world. Some students regard computer representations as fantasy, and as such have difficulty in making conceptual connections to real phenomena around them. Some simulations are designed to show
counterfactual representations of phenomena that purposely violate natural laws. These "alternative realities" are designed to invoke dissatisfaction with learner explanations of how processes take place, but we know very little about user's perceived relation between the simulation and the actual physical phenomena they represent. Research by Hennessy and O'Shea (1993 p. 129) describes the tendency for some secondary school students to "explain away conflict arising between their informal theories and their observations of simulated events by attributing magic properties to the computer or deviousness to the programmer."

Yet another assumption is that the students are given the latitude to explore within the simulation. There are simulations that can be customized by the instructor to ensure certain types of interactions between the learner and the software. Some simulations are reduced to interactive tutorials by instructional directives. Objectivist instructors may set up simulation software for students that has a predetermined set of conditions and a prescribed set of instructions that force the students along a single path of non-choices. These conditions are excessive in their control and the scope of how learning can evolve is switched from individualistic to teacher-driven. A determination should be made on the continuum of objectivism-constructivism as to where students receive maximum benefit from this type of instructional technology, and how this technology fits into the larger view of instruction.

CONCLUSION

There is ample evidence that computer simulations can contribute to the conceptualization of phenomena and relationships. There is also evidence that
the process of conceptual change can be facilitated by the implementation of simulations in the learning environment. The idea that simulations or any other computer-related technology can serve as a stand-alone instructional method is unsupported. The review of literature shows that a simulation's efficacy in enhancing conceptual change is dependent upon:

- the simulation's support of conceptual change conditions that have been effective with other media (seeking out misconceptions, making misconceptions explicit, offering refutational evidence to the learner),
- the timing of the simulation's use with respect to other supporting instructional methods,
- the type of phenomena being simulated,
- the particular characteristics of misconception being addressed,
- the characteristics of the learner with respect to that particular misconception, and
- the general characteristics of the learner.

There are several challenges to researchers in the area of constructivist uses of simulations to promote conceptual change. One is that constructivist instructional theory offers an approach to learning that involves many variations from traditional instruction. Some of these variations are: the nature of the tasks given to students, the time frame students are given to work on projects, the complexity of the tasks, the multiplicity of resources and perspectives offered to students, the context-supported learning environment, and the way assessment is embedded into constructivist learning activities. Efforts to isolate and use single variables of a constructivist learning environment for empirical comparison with a type of "control" group destroys
the systemic nature of constructivist processes. This relates to another challenge related to constructivist uses of technology, that of measuring learning in the student.

Traditional fixed answer assessments may account for only 10% of variance in total functional knowledge in a student (Novak, 1987). Even complex, authentic product measures do not provide enough information about how learning occurs in certain situations. Process measures rather than product measures may offer the best insight into the conceptualizing process of students. Cognitive interviews, teach-back, and think-aloud protocols are time consuming and vulnerable to criticism from strict empiricists, but they offer potential for understanding the processes behind the persistence of misconceptualizations.

Computer simulations offer an ongoing activity that is amenable to the process measures described. Think-aloud sessions which record a learner's continuous hypothesis testing and personal reflections while using simulations may give insight into conceptualization processes that product measures fail to reveal.

Developing more refined typologies for: simulations, uses of simulations within the larger learning environment, conceptions, and alternative conceptions will help clarify the discourse in the area of conceptual change strategies. These challenges to discovering the full potential of simulations for enhancing conceptual change serve to create exciting alternatives to the traditional methods of instruction.
2. USING COMPUTER SIMULATIONS TO ENHANCE CONCEPTUAL CHANGE: THE ROLES OF CONSTRUCTIVIST INSTRUCTION AND STUDENT EPISTEMOLOGICAL BELIEFS

A paper to be submitted to the Journal of Computer-Based Instruction

Mark A. Windschitl

LITERATURE REVIEW

Alternative conceptions in science education

Overview

Students' informal ideas about natural phenomena often influence their ability to learn science. These conceptions have been described in areas such as the human cardiovascular system (Arnaudin & Mintzes, 1986), electric circuits (Dupin & Johsua, 1987), the reflection of light (Mohapatra, 1988), and simple mechanics (Viennot & Rozier, 1994). Such informal ideas, also known as 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; Posner, Strike, Hewson, & Gertzog, 1982; Pines, 1985). In some cases, this explanatory power makes such informal ideas highly resistant to change.
Terminology of alternative conceptions

Scientific explanations, with their characteristic rationality and generalizability are considered "correct" by content experts and are often at odds with the informal explanations of phenomena held by young learners; this gives rise to the term "alternative conception" for the learner's explanation (alternative to the scientific conception). Other terms used to describe these non-scientific conceptions are: alternative frameworks (Driver & Easley, 1978), naive conceptions (Champagne, Gunstone, & Klopfer, 1983), children's science (Gilbert, Osborne, & Fensham, 1982) and misconceptions.

Claims concerning alternative conceptions

Wandersee, Mintzes, and Novak (1994) have summarized the research evidence on alternative conceptions. They suggest that:

- learners have a diverse set of alternative conceptions with regard to objects and phenomena,
- alternative conceptions exist across age and ability, and
- success in leading learners to revise alternative conceptions is highly dependent upon instructional methods and the nature of the alternative conception.

The most resistant alternative conceptions are those in the physical sciences that are counterintuitive, such as forces being exerted by stationary objects (Gorsky & Finegold, 1992).
Concepts regarding the human cardiovascular system

Student ideas concerning the cardiovascular system typify the scope of alternative conceptions in a curricular area. Mintzes, Trowbridge, Arnaudin, and Wandersee (1991) questioned students in 5th, 8th, and 10th grade, as well as college freshmen/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. 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. Excepting 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. There was a trend towards selecting the correct circulatory pattern (including systemic and pulmonary circulation) with increasing age.
Identifying alternative conceptions common to a particular subject area facilitates a logical next step—attempting to determine the conditions under which learners revise these alternative conceptions.

Conceptual change

Conditions for conceptual change

There is no well articulated theory that describes the substantive changes in the process by which individuals' central, organizing conceptual frameworks are replaced by another set of beliefs which are incompatible with the first (Posner, Strike, Hewson, & Gertzog, 1982). It is commonly held that learning is the interaction between what a person is taught, and what he/she already possesses as conceptual structures.

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

1) There must be dissatisfaction with an existing conception. This can occur when a conception cannot be reconciled with new experiences (anomaly) or when the conception violates some epistemological criteria. 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, and that in the absence of some direct instruction, students use their own misconceptions to explain phenomena (Perkins & Simmons, 1988; Anderson & Smith, 1987).

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**. This presupposes that the new model is intelligible, but intelligibility is not sufficient. The new conception must also be congruent with personal standards of knowledge. Specious conditions of plausibility are generated when the classroom learning environment emphasizes authoritarian epistemology. Students may be socialized to believe that the "teacher is always right" or authors are infallible, thus, ideas directly transmitted from those 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.

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. The assumption is that school children seek to resolve discrepancies between their conceptions and natural phenomena as a primary goal of intellectual activity. In reality, 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 (Pintrich, Marx, & Boyle, 1993; West & Pines, 1983; Dweck, 1986; Entwistle, Entwistle, & Tait, 1993). 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, Entwistle, & Tait, 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 post secondary students' beliefs about the nature of knowledge and learning, Schommer (1993a) 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 (strong duality of right versus wrong) --> knowledge as context-dependent, and
4) deterministic innate ability--> ability to "learn how to learn."
She found that junior college students tended to believe in simple, certain, and quick knowledge when compared with university students, and that technological science majors tended to believe in quick learning when compared with non-technological science majors. A later study with 1,000 high school students (Schommer, 1993b) showed that belief in simple, certain, and quick knowledge decreased from freshman to senior year. Additionally there were many learners who were sophisticated in some aspects of epistemological belief but not in others.

Dweck (1986) suggests 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.

**Strategies for promoting conceptual change**

In a general sense, some conceptual change strategies focus on externalizing (exposing) the learner's knowledge structure, then modifying it (Lawson & Weser, 1990; Lawson & Worsnop, 1992). Other strategies emphasize the need for self-monitoring and controlling the events of learning. Anderson and Smith (1987) list three features of successful conceptual change instruction: presenting direct refutation to student misconceptions, immediate application of scientific conception to explanation of phenomena, and explicit emphasis with repetition. In a metanalysis of conceptual change strategies, Guzzetti, Snyder, Glass, and Gamas (1993) summarize the effective conceptual change methods as all
producing some form of cognitive conflict. Teaching practices that challenge
existing understandings, cause students to face contradictions and recognize
counterexamples all appear to facilitate conceptual change.

These conceptual conflict strategies are strongly associated with
constructivism; they are premised on the idea that learning is a complex process
in which the learner's conceptions interact with new information. This study
investigated the relationship between conceptual change and the use of
constructivist versus non-constructivist computer simulation exercises.

The use of computer simulations in instruction

Overview

The increasing availability of computer-related technologies in classrooms
(Becker, 1991) has prompted the investigation of their influence on learning and
achievement, including the processes of conceptual development and conceptual
change. Among types of computer applications, simulations seem to offer strong
potential as agents contributing to conceptual change. The ability of simulations
to portray phenomena and to allow users to interact with the dynamics of a
model system create an arguably unique way of helping learners conceptualize.

Educators use models as tools for helping students understand a process or
thing. A model acts as a metaphor for the student to access something that is less
well known by comparing it to something that is more familiar (Snir, Smith, &
Grosslight, 1988). A simulation is a dynamic execution of the processes within a
relational model system. One instructional advantage of a computer-based
simulation is the ability to make normally unobservable occurrences plainly
visible for the student. Additionally, real systems are often filled with non-relevant information, adding a distracting element to the cognitive load of understanding the concept. Computer-based simulations can eliminate (within limits) extraneous information and employ perceptual cues (also referred to as process highlighters) that draw the learner's attention to critical features and events that are functionally invisible (Chandler & Chaillé, 1993).

As with many computer based learning tools, much of the early research on simulations focused on their instructional effectiveness compared with non-computer-based media. Currently, more sophisticated research is being conducted on the uses of simulations with respect to other instructional elements (didactic instruction, collaboration, lab experiences, assessment).

Constructivist uses of technology

There are two distinct but complementary constructivist perspectives concerning knowledge construction (Cobb, 1994). The cognitive constructivist view emphasizes the unique way knowledge is configured and influenced within the individual learner. The sociocultural cognitive view emphasizes the development of shared knowledge through social interaction. This study uses the cognitive constructivist paradigm as its basis for investigation.

As learners try to systematize their understanding of phenomenological relationships, they may profit from judicious didactic instruction (Klausmeier, 1961), but the complex picture of the conceptualization processes that is emerging from research indicates that learners create their own idiosyncratic webs of knowledge that are highly dependent on their backgrounds. Learners are adept at different symbol systems such as language-based, logico-mathematical, or
iconic (Gardner, 1993 & 1994); they have different learning styles and can have vastly different motivations for doing tasks (Pintrich et al., 1993; Schommer, 1993a & 1993b). The variety of learner characteristics described here supports the rationale for a constructivist view of learning, but they also contribute to the design of constructivist instructional theory.

Constructivist learning environments do not require the learner to arrive at a predetermined answer, but rather allow students to form his/her own internal representations of phenomena. A constructivist application of 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 are accommodative of their way of solving problems. This is not to say that there is no place for the prescriptive in instruction. Unguided inquiry, especially using computer simulations can be an exercise in futility for the student (Rivers & Vockell, 1987).

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 not a "correct" answer. Specific task requirements are not furnished for them (Miller & Hamilton, 1992) and there is difficulty quantitatively comparing understanding among students. 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) assert that if naive conceptions are grounded in personal experience, then re-experience 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 showed that:

1) computer simulations can be credible representations of reality, and
2) remediation produced significant conceptual change in those students holding alternative conceptions.

There are studies that have found little or no effect using simulations to promote conceptual change. In an study on electrical circuits, Carlsen and Andre (1992) found that using text designed for conceptual change resulted a significant alteration of misconceptions, 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's domain, the user is faced with results that conflict with what the learner predicted. Asking students to make and explain 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). Also, the power
to set conditions and test them repeatedly can produce successive iterations of
inconsistency between predicted and actual results that parallel the activities of
confrontational class discussion and the argument of refutational text.
Dissonance-based conceptual change strategies have been used with mixed
results in the area of physics simulations (Gorsky & Finegold, 1992).

Objectivist approaches to instruction (antithetical to constructivism) treat
knowledge as directly transmissible to the learner from various sources.
Objectivist uses of simulations often become "cookbook" exercises that reflect the
simplistic confirmatory nature of many science lab exercises. This may
effectively promote complacency toward a critical examination of simulated
phenomena and fail to activate prior knowledge.

Intelligibility, a second criteria 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).
Also, simulations that display phenomena with multiple representation types
(below the level of distraction) give the user perceptual choices. These choices
can help make the system's relationships more intelligible and the intelligibility
of the system as a whole gives a clearer picture of phenomenological relations.
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 simulations 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 they can refine their conceptual understanding of a phenomena.

**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 (see the Procedures section). 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 (see the Procedures section).

Hypothesis 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.

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 the subjects with a higher degree of epistemological sophistication, differentially encouraging them toward deeper information processing and conceptual change.

Hypothesis 2: The degree of epistemological sophistication will more positively co-vary 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 non-biology majors at a large midwestern university. This subject group was composed mostly of freshman and sophomores who typically have taken no other life science courses at the university. These students were enrolled in a human anatomy and physiology survey course in the spring semester of 1995. This course introduced students to the anatomy of the human body as well as the physiology of the cardiovascular, nervous, digestive, muscular, and skeletal systems.
Design

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 one of two conditions:

1) In the confirmatory simulation condition, students used the cardiovascular simulation in prescribed steps, following written instructions that lead to the resolution of a set of 12 questions.

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

All procedures and materials were tested earlier in the semester in a pilot study. Two groups of 25 students enrolled in a Physical Education class at the same university were used as subjects 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 be selected
to display dynamic information in multiple forms such as line graphs, bar graphs, pie graphs, digital counters (see Fig. 1).

This information was reflective of the pictorial representations in the second window. The second window (see Fig. 2) 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 by the user. Additionally, the user could select a fitness level for the simulated figure.

Figure 1. Sample of simulation screen containing graphical display of physiological data (used with permission by Logal™ software).
Figure 2. Sample of simulation screen containing animated pictorial displays of physiological phenomena (used with permission by Logal™ software).

Written simulation guides

The manner in which the computer simulation was used was one independent variable. Alternative conceptions that students typically hold about the human cardiovascular system were identified in a pilot study. 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 (Figure 3 illustrates a confirmatory case).
The written guide for the exploratory group was based on a set of cases concerning a hypothetical individual. The contrast in the two guides is shown in Figure 3, and explained further in the Procedures section.

(Confirmatory) Case #7: At rest, are there any significant differences between an fit and unfit individual concerning heart rate and/or stroke volume?

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 here:

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 here:

(Exploratory) Case #7: 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 an fit and unfit individual concerning heart rate and/or stroke volume?

Write your prediction here and explain briefly:

Now test your prediction with the simulation. Briefly describe how you tested this case with the simulation, include specific numbers. State a conclusion.

Figure 3. Confirmatory and exploratory sample cases.
Epistemological survey

The students' epistemological beliefs comprised one set of independent variables and were determined by a previously tested instrument developed by Schommer (1993a). The 63-item instrument consists of 12 logical subsets. 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 learning is an innate ability, and belief in single answers to problems. A typical item (rated on a five point agree-disagree Likert-type scale) is "The most successful people have discovered how to improve their ability to learn."

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 activity on blood flow, pattern of blood flow through 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 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 terms (22 pair total). Studies have shown that this method can validly assess an individual's conceptual and structural knowledge (Stanners, Brown, Price, & Holmes, 1983; Diekoff, 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 pair intended to be perceived as having a high degree of association such as "heart rate" and "activity", and other pair 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 the pairs of terms on a one to five scale. After calculating the z-scores across and within expert raters, ten pair 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.

The concept pairs were:

ventricle           stroke volume
carbon dioxide     arteries
artery             high blood pressure
heart               lungs
stroke volume      high fitness
physical activity  heart rate
vessel diameter    blood pressure
low fitness        arteries
atrium             ventricle
Multiple choice posttest

Another posttest instrument was a multiple choice instrument parallel to the pretest instrument, using approximately the same number of questions. An example of a posttest question is:

In the atria of the heart, would you find blood that is relatively high in oxygen or low in oxygen?

a. low 

b. high 

c. high or low, depending on which atrium 

d. a mixture of high and low 

e. blood does not enter the atria
Procedures

The study took place in regular laboratory sessions of the class. In Week 1, all subjects were briefly shown the cardiovascular simulation in their laboratory class. This was done to acquaint all 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. All subjects also completed the epistemological survey and the multiple choice pretest on conceptual understanding of various aspects of the human cardiovascular system.

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 to follow. 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 to adjust and to select particular graphical outputs for display in order 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 participate in testing another sample hypothesis using their own computers, and the results were discussed. They were then given a general set of guidelines to follow in exploring their conceptions of the cardiovascular system. They 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 furnished the exploratory group with the same basic cases as the confirmatory group (Fig. 3). Individuals in the exploratory group were required to state explicitly 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, any 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 had 45 minutes to continue their experience with the simulation. Due to the constraints of the natural class setting, some students finished ahead of others. Because the posttests were administered immediately after the last individuals completed their cases, some individuals finishing later may not have had an opportunity to reflect upon their answers to the last case. For this reason, only information from the first 10 of the 12 cases were assessed in the posttests. The posttest was a multiple choice test, parallel to the pretest multiple choice, and a concept comparison test. These were given at the end of the class period.

There was a recitation class held weekly that was associated with the laboratory. Six of the fourteen recitation sections were taught by the head lab coordinator and the other eight were taught by a novice instructor. Recitation instructor then, was used as a covariate in later statistical analyses.

RESULTS

Reliabilities

The pretest internal consistency estimate was .52 (using Cronbach's alpha); this low estimate may have been 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 (Table 1). The correlation between the pre- and posttest multiple choice tests was .60.
Pretest

The pretest (multiple choice, covering cardiovascular concepts) served as a covariate for analysis of posttest measures and helped identify areas of alternative conception. The mean score for all subjects was 15.72 (24 was the maximum possible, SD= 3.12). Table 2 presents means on responses to two questions about computer use. 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= 1.1, Table 2). 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). The choices ranged from "very high" (value= 1) to "very low" (value= 5); the mean was 2.94 (SD=.74, Table 2). A composite of these two responses was used as a covariate termed "computer proficiency" in later analyses (alpha= .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 blood traveling to an extremity such as the toe and remaining 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 (double circulation) was selected by only 46% of the students (Table 3).
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 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%).
Correlations

To determine possible relationships among demographic, pretest, posttest, and treatment variables, correlations were computed (Table 4). As expected, the pretest and multiple choice section of the posttest were significantly related ($r=0.60$, $p<.01$). The concept comparison section of the posttest was significantly negatively correlated with the multiple choice section of the posttest ($r=-0.32$, $p<.01$). The concept comparison was a measure of each student's average deviation from an expert set of ratings. These ratings expressed the strength of relationships between pairs of cardiovascular concepts. Lower average deviation scores indicated greater understanding of relationships as expressed by experts in field.

Scores on epistemological beliefs were negatively correlated with both pretest and posttest scores ($r=-0.29$, $p<.01$ and $r=-0.19$, $p<.05$ respectively). Since higher epistemological scores reflect a more naive point of view, greater levels of epistemological sophistication were associated with higher pre- and posttest scores. Epistemological belief was also significantly negatively correlated with computer proficiency ($r=-0.14$, $p<.05$). Means and standard deviations for all measures mentioned above may be found in Table 5.

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 out 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 6).

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, MSe= .23, p<.05, means presented in Table 6).

Using those students who held misconceptions about 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, gender, and recitation instructor as covariates, the exploratory group performed significantly
better than the confirmatory group (F (1, 76)= 4.03, MSe= .23, p<.05, means presented in Table 6).

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, MSe= .22, p<.13, means presented in Table 6).

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, MSe= .25, p<.42, means presented in Table 6), about the flow of blood to the brain during activity (F (1, 117)= .10, MSe= .25, p<.76, means presented in Table 6), or about the oxygen content of blood in the atria of the heart (F (1, 136)= 1.14, MSe= .22, p<.29, means presented in Table 6).

A one-way analysis of covariance was computed on the posttest score totals, with treatment group as the independent variable, and pretest, computer proficiency, gender, and recitation instructor as covariates. For the multiple choice section of the posttest there was no significant difference between the groups (F (1, 216)=.05, MSe= 11.70, p<.83, means presented in Table 5). There were no significant differences between the treatment groups concerning the concept comparison measures (F (1, 216)=.20, MSe= .23, p<.65, means presented in Table 5).

Regression on posttests

The second hypothesis predicted that the degree of epistemological sophistication would more positively co-vary 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 there was any group X epistemological belief interaction. Predictor variables were entered in the following order: pretest score, recitation instructor, treatment group, epistemological belief, and group X epistemological belief (Table 7). 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 X epistemological belief was significant, with a Beta of -1.20 (p< .03).

In order to see the direction of the interaction, a two-dimensional projection of regression on posttest score with epistemological belief was graphed (with pretest score and recitation section set to their means). This graph illustrates that the members of the exploratory group with greater levels of epistemological sophistication performed better on the posttest, while members of the confirmatory group with greater levels of epistemological sophistication performed more poorly on the posttest (Figure 4).

Multiple regression was run on the posttest concept comparison scores entering predictor variables as described above (Table 8); there were no significant effects for group (p< .82), epistemological belief (p< .68), or group X epistemological belief (p< .79).
DISCUSSION

The primary purpose of this study was to compare an exploratory to a confirmatory simulation experience. I hypothesized that the exploratory experience would produce greater conceptual change than the confirmatory experience.

In the analyses of six questions used to identify alternative conceptions, two showed significant differences for treatment group favoring the exploratory learners. Four of the six means were higher for the exploratory group (for questions dealing with alternative conceptions). The confirmatory group outperformed the exploratory group on only one of the six questions. 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/his own idiosyncratic (but productive) line of reasoning from hypothesizing and from 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.

It was hypothesized that the level of epistemological sophistication and treatment would interact, with less sophisticated subjects in the exploratory group predicted to feel frustration at the lack of explicit direction in the simulation's cases. A regression on the posttest multiple choice score (controlling for recitation instructor) indicated not only treatment and epistemological belief to be significant predictors, but treatment group X epistemological belief to be a significant predictor of posttest score as well. The pattern of performance depicted in Figure 4 suggests that achievement for students with high levels of epistemological sophistication is optimized in an exploratory setting, and that students with low levels of epistemological sophistication appear to perform best under confirmatory conditions. Thus, the students' levels of epistemological sophistication and the treatment condition did produce the hypothesized interaction. Scores by students with moderate levels of epistemological sophistication did not appear to be influenced by the treatment conditions used in this experiment.

The misconceptions held by the subjects were consistent with those described in related studies (Arnaudin & Mintzes, 1986; Mintzes, Trowbridge, Arnaudin & Wandersee, 1991). In general, only about half the subjects exhibited a correct conception 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 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.

The concept comparison scores were significantly related to the posttest multiple choice scores. The reasons for using a concept comparison were to furnish a second type of measure for conceptualization and to contribute to knowledge in the area of alternative assessment types. Concept comparisons are easier to evaluate than multidimensional concept maps and may be a viable (supplementary) method of assessing understanding with large groups of students.

The natural class setting for this or any experiment helps support the intuitive external validity of the results. Many studies in computer-based learning have taken place in experimental settings. Results obtained in such settings are harder to generalize to classroom settings in which cross-talk between computer stations and other interpersonal phenomena are common.
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. Additionally, the students returned to their labs after the first two-hour 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 differ in many 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 to write conclusions after each case). Manipulating constructivist settings in order 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. I assumed that learners, without explicit instruction, 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. Additionally, 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.
Table 1  Internal Consistencies (Cronbach's alpha): Pretest multiple choice, computer proficiency composite, epistemological survey, posttest multiple choice, posttest concept comparison.

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>CRONBACH'S ALPHA</th>
<th>NUMBER OF ITEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest multiple choice</td>
<td>.52</td>
<td>24</td>
</tr>
<tr>
<td>Computer proficiency composite</td>
<td>.62</td>
<td>2</td>
</tr>
<tr>
<td>Epistemological survey a</td>
<td>.69</td>
<td>63</td>
</tr>
<tr>
<td>&quot;Seek single answers&quot; subscale</td>
<td>.34</td>
<td>11</td>
</tr>
<tr>
<td>&quot;Avoid integration&quot; subscale</td>
<td>.45</td>
<td>8</td>
</tr>
<tr>
<td>&quot;Avoid ambiguity&quot; subscale</td>
<td>.51</td>
<td>5</td>
</tr>
<tr>
<td>&quot;Knowledge is certain&quot; subscale</td>
<td>.29</td>
<td>6</td>
</tr>
<tr>
<td>&quot;Depend on authority&quot; subscale</td>
<td>.25</td>
<td>4</td>
</tr>
<tr>
<td>&quot;Don't criticize authority&quot; subscale</td>
<td>.51</td>
<td>6</td>
</tr>
<tr>
<td>&quot;Learning is innate&quot; subscale</td>
<td>.20</td>
<td>4</td>
</tr>
<tr>
<td>&quot;Can't learn how to learn&quot; subscale</td>
<td>.65</td>
<td>5</td>
</tr>
<tr>
<td>&quot;Success unrelated to hard work&quot; subscale</td>
<td>.46</td>
<td>4</td>
</tr>
<tr>
<td>&quot;Learn the first time&quot; subscale</td>
<td>.19</td>
<td>3</td>
</tr>
<tr>
<td>&quot;Learning is quick&quot; subscale</td>
<td>.40</td>
<td>5</td>
</tr>
<tr>
<td>&quot;Concentrated effort is a waste&quot; subscale</td>
<td>.13</td>
<td>2</td>
</tr>
<tr>
<td>Posttest multiple choice</td>
<td>.77</td>
<td>30</td>
</tr>
<tr>
<td>Posttest concept comparison</td>
<td>.64</td>
<td>23</td>
</tr>
</tbody>
</table>

a Epistemological total score was calculated by computing the means of each of the subscales; these subscale means were then averaged to produce the overall score used in subsequent analyses.
Table 2 Frequency distributions: Computer use, perceived proficiency.

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>VALUE</th>
<th>N</th>
<th>PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>FREQUENCY OF COMPUTER USE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Once a day</td>
<td>1</td>
<td>7</td>
<td>3.2</td>
</tr>
<tr>
<td>2-4 times per week</td>
<td>2</td>
<td>46</td>
<td>20.8</td>
</tr>
<tr>
<td>Once a week</td>
<td>3</td>
<td>53</td>
<td>24.0</td>
</tr>
<tr>
<td>Once or twice a month</td>
<td>4</td>
<td>73</td>
<td>33.0</td>
</tr>
<tr>
<td>Never</td>
<td>5</td>
<td>42</td>
<td>19.0</td>
</tr>
<tr>
<td>MEAN</td>
<td>3.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>1.11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| PERCEIVED COMPUTER PROFICIENCY |       |    |         |
| Very high                     | 1     | 10 | 4.5     |
| High                          | 2     | 38 | 17.2    |
| Average                       | 3     | 132| 59.7    |
| Below average                 | 4     | 35 | 15.8    |
| Very low                      | 5     | 6  | 2.7     |
| MEAN                          | 2.95  |    |         |
| SD                            | .79   |    |         |
Table 3 Frequencies: Selected pretest items and parallel posttest items.

<table>
<thead>
<tr>
<th>POSTTEST QUESTION NUMBER&lt;sup&gt;a&lt;/sup&gt;</th>
<th>PRETEST DISTRIBUTION (percent of all subjects)</th>
<th>POSTTEST DISTRIBUTION (percent of subjects who answered parallel pretest item incorrectly)</th>
</tr>
</thead>
<tbody>
<tr>
<td>answer number</td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>#2</td>
<td>4.1 59.3&lt;sup&gt;b&lt;/sup&gt; 20.4 14.9 1.4</td>
<td>20.0 35.6&lt;sup&gt;b&lt;/sup&gt; 31.1 11.1 2.2</td>
</tr>
<tr>
<td>#3</td>
<td>1.4 7.7 14.5 30.3 46.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.4 8.4 10.9 26.1 51.3&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>#5</td>
<td>46.6&lt;sup&gt;b&lt;/sup&gt; 0.5 4.5 46.2 2.3</td>
<td>58.5&lt;sup&gt;b&lt;/sup&gt; 0.0 8.5 33.1 0.0</td>
</tr>
<tr>
<td>#8</td>
<td>5.0 64.7&lt;sup&gt;b&lt;/sup&gt; 5.9 22.2 1.8</td>
<td>6.5 59.7&lt;sup&gt;b&lt;/sup&gt; 9.1 24.7 0.0</td>
</tr>
<tr>
<td>#15</td>
<td>0.9 11.8 9.1 51.8&lt;sup&gt;b&lt;/sup&gt; 26.4</td>
<td>0.0 9.4 0.9 61.3&lt;sup&gt;b&lt;/sup&gt; 28.3</td>
</tr>
<tr>
<td>#27</td>
<td>20.4 38.9 37.6&lt;sup&gt;b&lt;/sup&gt; 2.3 0.5</td>
<td>12.4 31.4 53.3&lt;sup&gt;b&lt;/sup&gt; 1.5 1.5</td>
</tr>
</tbody>
</table>

<sup>a</sup> questions can be found in Appendices B and G.

<sup>b</sup> correct answer.
Table 4  
Correlation coefficients: Demographic, epistemological, pretest, and posttest variables.

<table>
<thead>
<tr>
<th></th>
<th>GENDER</th>
<th>EPIST</th>
<th>GROUP</th>
<th>PROFIC</th>
<th>POST</th>
<th>PRETEST</th>
<th>CONC</th>
</tr>
</thead>
<tbody>
<tr>
<td>GENDER</td>
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<td>-.05</td>
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<td></td>
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<tr>
<td>EPIST</td>
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<td></td>
<td>.03</td>
<td>-.06</td>
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<tr>
<td>GROUP</td>
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<td></td>
<td></td>
<td>-.14*</td>
<td>-.02</td>
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<tr>
<td>PROFIC</td>
<td></td>
<td></td>
<td>.06</td>
<td></td>
<td>-.06</td>
<td>-.19**</td>
<td>-.05</td>
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<tr>
<td>POST</td>
<td></td>
<td></td>
<td></td>
<td>-.06</td>
<td>-.29**</td>
<td>-.10</td>
<td>.06</td>
</tr>
<tr>
<td>PRETEST</td>
<td></td>
<td>-.11</td>
<td>-.11</td>
<td>-.29**</td>
<td>-.10</td>
<td>.06</td>
<td>.60**</td>
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<tr>
<td>CONC</td>
<td></td>
<td>.12</td>
<td>.01</td>
<td>.04</td>
<td>-.07</td>
<td>-.32**</td>
<td>-.11</td>
</tr>
</tbody>
</table>

*p < .05  
**p < .01

Legend:
GENDER- gender of subject  
EPIST- epistemological sophistication (lower value=greater sophistication)  
GROUP- confirmatory (value=1), exploratory (value=2)  
PROFIC- composite computer proficiency self-rating  
POST- posttest multiple choice score  
PRETEST- pretest score  
CONC- posttest concept comparison score
Table 5 Means and standard deviations: Epistemological survey, pretest, posttest multiple choice, and concept comparison measures.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>CONFIRMATORY</th>
<th>EXPLORATORY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEAN  SD</td>
<td>MEAN  SD</td>
</tr>
<tr>
<td>Epistemological belief</td>
<td>2.57  .26</td>
<td>2.54  .25</td>
</tr>
<tr>
<td>Pretest</td>
<td>16.12  2.85</td>
<td>15.49  3.31</td>
</tr>
<tr>
<td>Posttest (multiple choice)</td>
<td>22.23  4.70</td>
<td>21.79  3.87</td>
</tr>
<tr>
<td>Posttest (concept comparison)</td>
<td>1.47  .45</td>
<td>1.51  .50</td>
</tr>
</tbody>
</table>
Table 6  Means and standard deviations for each treatment: Posttest questions 15, 8, 2, 3, 5, and 27.a

<table>
<thead>
<tr>
<th>QUESTION</th>
<th>CONFIRMATORY</th>
<th>EXPLORATORY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N  MEAN   SD</td>
<td>N  MEAN   SD</td>
</tr>
<tr>
<td>#15</td>
<td>55 .53 .50</td>
<td>51 .71 .46</td>
</tr>
<tr>
<td>#8</td>
<td>37 .51 .51</td>
<td>40 .67 .48</td>
</tr>
<tr>
<td>#2</td>
<td>42 .45 .50</td>
<td>48 .27 .44</td>
</tr>
<tr>
<td>#3</td>
<td>54 .48 .50</td>
<td>65 .54 .50</td>
</tr>
<tr>
<td>#5</td>
<td>58 .60 .49</td>
<td>60 .57 .50</td>
</tr>
<tr>
<td>#27</td>
<td>63 .49 .50</td>
<td>74 .57 .50</td>
</tr>
</tbody>
</table>

Legend:
Question #15 (structure of heart)
Question #8 (oxygen path after entering lungs)
Question #2 (blood flow to intestinal region)
Question #3 (path of blood in circulatory system)
Question #5 (blood flow to brain)
Question #27 (oxygen content of blood in atria)

a Full text of questions found in Appendix G.
Table 7  Multiple regression: posttest multiple choice score.

<table>
<thead>
<tr>
<th>PREDICTOR</th>
<th>B</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
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<tr>
<td>Pretest score</td>
<td>.97</td>
<td>.65</td>
<td>12.40</td>
<td>.01**</td>
</tr>
<tr>
<td>Constant</td>
<td>6.65</td>
<td></td>
<td>5.24</td>
<td>.01</td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest score</td>
<td>.96</td>
<td>.65</td>
<td>12.33</td>
<td>.01**</td>
</tr>
<tr>
<td>Recitation instructor</td>
<td>-.69</td>
<td>-.08</td>
<td>-1.52</td>
<td>.13</td>
</tr>
<tr>
<td>Constant</td>
<td>7.85</td>
<td></td>
<td>5.27</td>
<td>.01</td>
</tr>
<tr>
<td><strong>Step 3</strong></td>
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<tr>
<td>Pretest score</td>
<td>.96</td>
<td>.65</td>
<td>12.25</td>
<td>.01**</td>
</tr>
<tr>
<td>Recitation instructor</td>
<td>-.69</td>
<td>-.08</td>
<td>-1.51</td>
<td>.13</td>
</tr>
<tr>
<td>Group</td>
<td>-.05</td>
<td>-.01</td>
<td>-.11</td>
<td>.91</td>
</tr>
<tr>
<td>Constant</td>
<td>7.93</td>
<td></td>
<td>4.76</td>
<td>.01</td>
</tr>
<tr>
<td><strong>Step 4</strong></td>
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<td></td>
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<tr>
<td>Pretest score</td>
<td>.95</td>
<td>.64</td>
<td>11.49</td>
<td>.01**</td>
</tr>
<tr>
<td>Recitation instructor</td>
<td>-.71</td>
<td>-.08</td>
<td>-1.54</td>
<td>.13</td>
</tr>
<tr>
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* p< .05
** p< .01
Table 8  Multiple regression: posttest concept comparison score. a

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* p< .05

a Final solution.
GENERAL CONCLUSION

There is evidence that computer simulations can contribute to the conceptualization of phenomena and that the process of conceptual change can be facilitated by the implementation of simulations in the learning environment. The idea that simulations or any other computer-related technology can serve as a stand-alone instructional method is unsupported. A clearly defined advantage for exploratory over confirmatory simulation experiences for altering misconceptions is also unsupported by the results of this study. There is however, evidence that the level of epistemological sophistication of the learner can interact with the type of learning environment, resulting in greater achievement gains by those with higher sophistication levels when placed in a constructivist setting.

There are several challenges to researchers in the area of constructivist uses of simulations to promote conceptual change. One is that constructivist instructional theory offers an approach to learning that involves many variations from traditional instruction, making it difficult to isolate variables for experimental manipulation. Another challenge is to find accurate measures of conceptual change, perhaps by employing more process-oriented measures.

Developing more refined typologies for: simulations, uses of simulations within the larger learning environment, conceptions, and alternative conceptions will help clarify the discourse in the area of conceptual change strategies. The role of the learner's epistemological disposition in achievement and conceptual change is also a viable area for continued study.
As the role of computers expands in our schools it is necessary to chart a course of research that stays abreast of the emerging technologies and how they interface with the characteristics of the learner as well as the overall learning environment.
REFERENCES


APPENDIX A. EPISTEMOLOGICAL SURVEY
Directions: There are no right or wrong answers for the following questions. We want to know what you really believe. For each statement, fill in the oval corresponding to whether you disagree or agree.

(1=strongly disagree  2=disagree  3=neutral  4=agree  5=strongly agree)

27. If you are ever going to be able to understand something, it will make sense to you the first time you hear it.
28. The only thing that is certain is uncertainty itself.
29. For success in school, it is best not to ask too many questions.
30. A course in study skills would probably be valuable.
31. How much a person gets out of school depends mostly on the teacher.
32. You can believe almost everything you read.
33. I often wonder how much my teachers really know.
34. The ability to learn is innate.
35. It is annoying to listen to a lecturer who cannot seem to make up his/her mind as to what he/she really believes.
36. Successful students understand things quickly.
37. A good teacher's job is to keep her/his students from wandering off the right track.
38. If scientists try hard enough, they can find the truth to almost anything.
39. People who challenge authority are over-confident.
40. I try my best to combine information across chapters or even across classes.
41. The most successful people have discovered how to improve their ability to learn.
42. Things are simpler than most professors would have you believe.
43. The most important aspect of scientific work is precise measurement and careful work.

(1=strongly disagree 2=disagree 3=neutral 4=agree 5=strongly agree)

44. To me, studying means getting big ideas from the text, rather than details.

45. Educators should know by now which is the best method, lectures or small group discussions.

46. Going over and over a difficult textbook chapter usually won't help you understand it.

47. Scientists can ultimately get to the truth.

48. You never know what a book means unless you know the intent of the author.

49. The most important part of scientific work is original thinking.

50. If I find the time to re-read a textbook chapter, I get a lot more out of it the second time.

51. Students have a lot of control over how much they can get out of a textbook.

52. Genius is 10% ability and 90% hard work.

53. I find it refreshing to think about issues that authorities can't agree on.

54. Everyone needs to learn how to learn.

55. When you first encounter a difficult concept in a textbook, it's best to work it out on your own.

56. A sentence has little meaning unless you know the situation in which it was spoken.

57. Being a good student generally involves memorizing facts.

58. Wisdom is not knowing the answers, but knowing how to find the answers.

59. Most words have one clear meaning.
60. Truth is unchanging.

(1=strongly disagree  2=disagree  3=neutral  4=agree  5=strongly agree)

61. If a person forgot details, and yet was able to come up with new ideas from a
text, I would think they were bright.

62. Whenever I encounter a difficult problem in life, I consult with my parents.

63. Learning definitions word-for-word is often necessary to do well on tests.

64. When I study, I look for the specific facts.

65. If a person can't understand something within a short amount of time, they
should keep on trying.

66. Sometimes you just have to accept answers from a teacher even though you
don't understand them.

67. If professors would stick more to the facts and do less theorizing, one would
get more out of college.

68. I don't like movies that don't have an ending.

69. Getting ahead takes a lot of work.

70. It's a waste of time to work on problems which have no possibility of coming
out with a clear-cut and unambiguous answer.

71. You should evaluate the accuracy of information in a textbook, if you are
familiar with the topic.

72. Often, even advice from experts should be questioned.

73. Some people are born good learners, others are just stuck with limited ability.

74. Nothing is certain but death and taxes.

75. The really smart students don't have to work hard to do well in school.

76. Working hard on a difficult problem for an extended period of time only pays
off for really smart students.
77. If a person tries too hard to understand a problem, they will most likely just end up being confused.

(1=strongly disagree 2=disagree 3=neutral 4=agree 5=strongly agree)

78. Almost all the information you can learn from a textbook you will get during the first reading.

79. Usually you will figure out difficult concepts if you eliminate all outside distractions and really concentrate.

80. A really good way to understand a textbook is to reorganize the information according to your own personal scheme.

81. Students who are "average" in school will remain "average" for the rest of their lives.

82. A tidy mind is an empty mind.

83. An expert is someone who has a special gift in some area.

84. I really appreciate instructors who organize their lectures meticulously and then stick to their plan.

85. The best thing about science courses is that most problems have only one right answer.

86. Learning is a slow process of building up knowledge.

87. Today's facts may be tomorrow's fiction,

88. Self-help books are not much help.

89. You will just get confused if you try to integrate new ideas in a textbook with knowledge you already have about a topic.
APPENDIX B. MULTIPLE CHOICE PRETEST
Zoology 156 Lab

This questionnaire is designed to measure your understanding of the cardiovascular system. No names are needed.

* Fill in the appropriate oval for your gender (sex).

Fill in the oval on the answer sheet corresponding to the one best answer to each question.

1. How often do you use a computer (for any reason)?
   a. usually at least once a day
   b. usually 2-4 times a week
   c. usually about once a week
   d. usually once or twice a month
   e. never

2. As a student, how would you rate your general proficiency in using the computer?
   a. very high
   b. high
   c. average
   d. below average
   e. very low

3. During activity, what happens to blood vessels in the exercising muscle groups?
   a. they remain the same diameter as during rest
   b. they constrict slightly (smaller in diameter)
   c. they constrict substantially (smaller in diameter)
   d. they dilate (become larger in diameter)
   e. the exercising muscle groups do not require blood flow

4. 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
5. Which diagram best depicts the flow of blood after it leaves the heart on its way to an extremity such as the toe?
   a. The blood goes to the toe, and remains there. --(heart toe)
   b. The blood goes to the toe then back to the heart. --(heart toe heart)
   c. The blood goes to the toe, then to the lungs, then to the heart. --(heart toe lung heart)
   d. The blood goes to the lungs first, then to the toe, then back to the heart. --(heart lung toe heart)
   e. The blood goes to the toe, then to the heart, then to the lungs, then back to the heart. --(double circulation)
6. Going from rest to activity, what happens to the blood flow to the exercising muscle groups?
   a. it remains about the same as during rest
   b. it shuts off entirely
   c. it decreases slightly
   d. it increases substantially
   e. the major muscle groups do not require blood flow

7. Going from rest to activity, what happens to the blood flow to the brain?
   a. it remains about the same as during rest
   b. it is shut off entirely
   c. it decreases substantially
   d. it increases substantially
   e. the brain does not usually require blood flow

8. Where does oxygen go after it enters your lungs?
   a. air tubes from the lungs carry oxygen throughout the body
   b. blood in vessels carries oxygen from the lungs through the heart
   c. air tubes carry oxygen from the lungs through the heart
   d. blood in vessels carries oxygen directly to the body
   e. the oxygen remains in the lungs and is then exhaled

9. Arteries are vessels in the body that:
   a. transport air from the lungs to other parts of the body.
   b. transport air from the lungs to the heart.
   c. transport blood both to and from the heart.
   d. transport blood to the heart.
   e. transport blood away from the heart.

10. Veins are vessels in the body that:
    a. have higher blood pressure than arteries.
    b. have lower blood pressure than arteries.
    c. have generally the same blood pressure as arteries.
    d. usually have no blood pressure in them at all.
    e. have higher blood pressure in them if they are located in the top half of the body.

For questions 11 through 14, mark "A" on your answer sheet if the statement is TRUE, and "B" if the statement is false.
11. A function of the heart is to filter impurities from the blood.
12. A function of the heart is to pump blood.
13. A function of the heart is to create blood.
14. A function of the heart is to store blood.
15. What does the internal structure of the human heart look like? (as above)
   a. figure "a"
   b. figure "b"
   c. figure "c"
   d. figure "d"
   e. figure "e"

16. What is the relationship in blood pressure between arteries and veins?
   a. they have equal blood pressures
   b. arteries always have higher blood pressure
   c. veins always have higher blood pressure
   d. the vein pressure is higher only in a fit individual
   e. artery pressure will be greater only if the individual is engaging in exercise
17. Blood in some blood vessels of the body is high in oxygen. Blood in these vessels contain about what percent oxygen?
   a. 20%
   b. 40%
   c. 60%
   d. 80%
   e. 95%

18. When moving from rest to exercise, heart rate should
   a. increase
   b. decrease
   c. remain the same
   d. decrease substantially, then increase
   e. increase or decrease depending on your level of fitness

Definition: stroke volume = the amount of blood pumped in one heartbeat

19. When moving from rest to exercise, stroke volume should
   a. increase
   b. decrease
   c. remain the same
   d. decrease substantially, then increase
   e. increase or decrease depending on your level of fitness

20. At rest, a well trained runner will have
   a. a lower stroke volume than an unfit person.
   b. a higher heart rate than an unfit person.
   c. a lower heart rate than an unfit person.
   d. a higher maximal heart rate than an unfit person.
   e. both a and c are correct.

21. At rest, an unfit individual will have
   a. the same blood pressure as an athlete.
   b. slightly lower blood pressure than an athlete.
   c. much lower blood pressure than an athlete.
   d. higher blood pressure than an athlete.
   e. almost no blood pressure at all.

Definition: cardiac output = (heart rate) X (volume of blood pumped per heartbeat).
22. How does cardiac output change when you go from a resting state to a state of activity?
   a. it increases
   b. it decreases slightly
   c. it decreases substantially
   d. it remains the same
   e. it changes, but the direction is dependent upon the level of fitness

23. How is cardiac output different between a fit and unfit person when at rest?
   a. cardiac output is about the same for both
   b. cardiac output is greater for the unfit person
   c. cardiac output is greater for the fit person
   d. different, but the direction is dependent upon gender
   e. different, but the direction is dependent upon age

24. How is cardiac output different between a fit and unfit person when exercising?
   a. cardiac output is the same for both
   b. cardiac output is greater for the unfit person
   c. cardiac output is greater for the fit person
   d. different, but the direction is dependent upon your gender
   e. different, but the direction is dependent upon your age

25. In the atria of the heart, would you find blood that is relatively high in oxygen or low in oxygen?
   a. low
   b. high
   c. depends on which atrium
   d. a mixture of high and low
   e. blood does not enter the atria

26. How many chambers are there in the human heart?
   a. one chamber
   b. two chambers
   c. three chambers
   d. four chambers
   e. five chambers
The Cardiovascular System

You will be using a computer simulation of the cardiovascular system. You won't need to use the keyboard for this program, just the mouse.

For each step, please read the entire paragraph of instructions before making any moves in the simulation, some important cautions may be expressed later in the paragraph!

Sometimes you will be asked to click and hold the mouse button down (referred to as "click and hold"), sometimes you'll be asked to hold the mouse down and move the mouse (referred to as "click and drag"). Most of the time you will be asked just to click on an area. There is never a need to double-click in this program.

The left window will have line, pie and bar graphs and numerical counters that indicate any kind of information you choose. It is important to note the units used in the graphs. The horizontal axis on the line graphs represents brief cycles of time (not necessarily seconds).

The right window can have up to four smaller windows in it. They are explained on the next page...
Quick Guide to your Control Window...

You can click and hold the mouse down on most parts of the body or heart and see the name of that part.

- **Resets everything to original conditions**
- **The "Go" button**
- **Stops simulation**
- **Allows you to go step by step**

This detector (#1) has been dragged to an artery in the head and the blood pressure of that artery is shown in the monitor as 126.6. The #2 detector has been dragged to a neck vein, and is showing a pressure of 6.0 in the monitor window.

This displays the blood pressure of wherever the #1 detector is placed by you.

Click and hold here to select whether monitor shows blood pressure, % oxygen, % carbon dioxide, or % waste. Blood pressure selected here for example.

Click and hold to select "Normal", "Athlete", or "Couch Potato"

Make jogger run
Make jogger walk
Click here to make jogger stand still
In the left window of your computer you should see the words “Main Menu”. Read the names of the buttons. Click once on the tan button “Go to HEART RATE”. You'll see a graph of the heart rate in beats per unit time.

Because there are two windows (left and right), you sometimes have to click once anywhere in the window to make it “active” before you can click on a button. You can tell which window is active because it will have horizontal bars across the top of the title bar. Click once on the “Go” icon (the running figure). If you have trouble, don’t be afraid to ask for help.

Now, in the jogger window, click once on the middle circle to make the figure walk. Check the graph, are there any changes in the heart rate? Note that heart rate is also shown in digital form below the line graph.

*Important note! When making changes in the simulation, you should observe the graph changes for at least thirty seconds before making any judgments or recording data. It takes that long for the simulated body to react!

Now, at the bottom of the jogger window, click and hold on the word “Normal”. Drag the mouse down to the word “Athlete” and let up on the mouse button. Did this change the graph?

You may create any combination of resting, walking or running for a normal person, athlete (fit person), or “couch potato” (unfit person). We won’t use the other person types in this simulation.

Now click on the “Stop” icon (the stop sign with hand). If you now click on the “Reset” (crouched runner) all the original conditions will be reset.

There is a slider bar at the bottom of the screen labeled “cc’s of blood in body”.

Now let’s click on the “Go to MAIN MENU” button in the upper left. There are 12 cases that you will confirm by using the simulation, these conditions simulate actual responses by the human body.

Case #1: Where does blood flow when it leaves each chamber of the heart?

Go to the MAIN MENU and select CIRCULATORY PATHWAYS. Click on the GO icon and observe the path of the blood cell. You may want to use the “Step” rather than the “Running” icon to see the action in slow motion. Describe the where blood flows after it leaves each chamber:

Case #2: What is the pattern of blood flow between the heart and the lungs?

Go to the MAIN MENU and select CIRCULATORY PATHWAYS again. Click on the GO icon and observe the path of the blood cell. You may want to use the “Step” rather than the “Running” icon to see the action in slow motion. Pay particular attention to the pattern of blood
flow between the heart and lungs.

Write a brief conclusion here:

**Case #3:** Is there a difference in blood flow to specific areas of the body when exercising versus at rest? For example: Do the kidneys, intestines, brain and muscles all receive the same blood flow during exercise that they do at rest?

Now let’s find the answer to this question with the simulation. Make sure you are on the “MAIN MENU” screen, then click once on the button “VESSEL RESPONSES IN DIFFERENT AREAS.”

On this screen you will see a line graph and digital readings of blood flow through different areas of the body. Make sure your “jogger” figure is set to Normal and the figure is standing still. Now click the GO icon.

Remember, whatever action you take, let the simulation run about 30 seconds before making any judgments.

After about 60 seconds or 1200 cycles on the horizontal axis of the line graph, record the flow of blood through the five areas:

- kidneys:
- intestines:
- brain:
- exercising muscle groups:

Now click on the third circle up in the jogger window to make the figure run. After about 60 seconds or 1200 cycles on the horizontal axis of the line graph, record the flow of blood through the five areas:

- kidneys:
- intestines:
- brain:
- exercising muscle groups:

Write your conclusions here:

**Case #4:** Is there a difference between arteries and veins concerning the blood pressure within them and the direction of blood flow? If there are differences between arteries and veins concerning either of these two variables, are there any exceptions?

Click once on DETECT BLOOD PRESSURE AT SPECIFIC SITES. Click and hold on the different vessels on the picture of the body or the heart to see an identification of them.

Find the small green dot on the monitor window with the number “1” on it. Click and drag this dot to the red vessel leading to the leg; when the dot darkens, let up on the mouse. Find the small upside down triangle at the top of the monitor window, click and hold on it to select “blood pressure”. You will see the blood pressure of that vessel in the window to the right.

Click and drag the blue dot with “2” on it to the vein coming up from the leg, and select blood pressure at the bottom of the monitor window. When you click on the GO icon, the blood pressures will also be read on the line graph on the left side of the screen.

Start by making your jogger walk. Let the simulation run about 60 seconds before making any judgments.

Record here the blood pressures for the artery and vein in the leg:

- kidneys:
- intestines:
- brain:
- exercising muscle groups:

Repeat this procedure for the vessels in the neck and record the results here:

Write your conclusions here:

Click once on the MAIN MENU button for the next case.
icon. Note the circulating blood cell. You may click and hold on the vessels to see their names in this window. Write a brief conclusion about the general path of blood in arteries versus veins:

Case #5: Is there a difference between arteries and veins concerning the % of oxygen and carbon dioxide in the blood they carry? If there are differences between arteries and veins concerning this variable, are there any exceptions (be careful on this one!)?

Start at the MAIN MENU screen. Select the button "%OXYGEN AND CARBON DIOXIDE AT SPECIFIC SITES”.

As you did in Case #2, click and drag the monitor’s detectors (the #1 and #2 dots) to the vessels leading to and from the leg. Now, however, instead of selecting the detector to read blood pressure, select “% oxygen” for the #1 detector, and % oxygen for the #2 detector. Click the GO icon. Record the per cents here:

Now find the hepatic artery and hepatic vein. Place the detectors on these vessels and record the results here:

Now find the pulmonary artery and pulmonary vein. Place the detectors on these vessels and record the results here:

What is your conclusion?

Case #6: Stroke volume is the amount of blood pumped in one heartbeat. When moving from rest to exercise, what if anything happens to stroke volume? What happens to heart rate? Why? Go to the MAIN MENU and click on STROKE VOLUME.

Change the figure to normal and standing still, now click the GO icon, wait until the readings stabilize then record the stroke volume and heart rate here:

Case #7: At rest, are there any significant differences between an fit and unfit individual concerning heart rate and/or stroke volume?

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 here:

Case #8: Cardiac output= heart rate X stroke volume. Is cardiac output different between a fit and an unfit individual when they are at rest? How does cardiac output change when they are exercising?

Stay on the STROKE VOLUME window. Change the figure to couch potato and standing still, now click the GO icon, wait until the readings stabilize then record the cardiac output here:
Change the figure to athlete and standing still, now click the GO icon, wait until the readings stabilize then record the cardiac output here:

What is the mathematical difference between the athlete's cardiac output and that of the couch potato? Record here:

Change the figure to couch potato and walking, now click the GO icon, wait until the readings stabilize then record the cardiac output here:

Change the figure to athlete and walking, now click the GO icon, wait until the readings stabilize then record the cardiac output here:

What is the mathematical difference between the athlete's cardiac output and that of the couch potato when they are walking?

Write a brief conclusion here:

Case #9: Are there areas of different blood pressure within the heart itself?

Click once on DETECT BLOOD PRESSURE AT SPECIFIC SITES. Click and hold on the different vessels on the body or the heart to see an identification of them.

Find the small green dot on the monitor window with the number “1” on it. Click and drag this dot to the left atrium of the heart (be careful which you identify as the “left”); when the dot darkens, let up on the mouse. Find the small upside down triangle at the top of the monitor window, click and hold on it. Now go down and select “blood pressure”. You will see the blood pressure of that vessel in the window to the right.

Click and drag the blue dot with “2” on it to the left ventricle, and select blood pressure at the bottom of the monitor window. When you click on the GO icon, the blood pressures will also be read on the line graph on the left side of the screen.

Let the simulation run about 60 seconds before making any judgments.

Record here the blood pressures for the atrium and ventricle:

Repeat this procedure for the right atrium and ventricle, record the results here:

Write a brief conclusion here:

Case #10: How can you demonstrate which organ/s of the body are responsible for filtering waste products (other than carbon dioxide) out of the blood by using this simulation?

Go to the MAIN MENU. Click once on DETECT % OXYGEN OR CARBON DIOXIDE AT SPECIFIC SITES. Click and hold on the different organs in the body to see an identification of them.

Find the small green dot on the monitor window with the number “1” on it. Click and drag this dot to the red artery leading to the intestine; when the dot darkens, let up on the mouse. Find the small upside down triangle at the top of the monitor window, click and hold on it. Now go down and select “% waste”. You will see the % waste in the window to the right.

Click and drag the blue dot with “2” on it to the blue vein leading away from the intestine, and select % waste at the bottom of the monitor window. When you click on the GO icon, the % waste for both detectors will also be read on the line graph on the left side of the screen.

Let the simulation run about 60 seconds before making any judgments.

Record here the % waste for the artery and the
vein:

Repeat this procedure for the vessels leading to and from the leg muscle, record the results here:

Repeat this procedure for the vessels leading to and from the kidney, record the results here:

Write a brief conclusion here:

Case #11: Go to the Main Menu. Which of the following factors will cause the systolic blood pressure to rise in a person: being physically fit, going from rest to activity, raising the volume of blood in the body, or blocking major blood vessels? It may be more than one factor.

Choose the button “BLOOD PRESSURE”.

Make sure your jogger is set to Normal and is walking. Now click the GO icon. Wait until the pressure stabilizes then record the systolic pressure here:

Now as the figure is still walking, change it to an athlete. Wait until the pressure stabilizes, then record the systolic pressure here:

Change the figure to normal and standing still, wait until the systolic pressure stabilizes then record the systolic pressure here:

Now make the figure an athlete and standing, wait until the systolic pressure stabilizes then record the systolic pressure here:

Change the figure to normal and standing still, now click and drag the white bar in the left window so the blood volume is 6000 cc’s. Now click the GO icon. Wait until the pressure stabilizes then record the systolic pressure here:

How does this compare with your earlier reading of a normal individual standing still with a normal blood volume of 5000 cc’s?

Case #12: Diastolic blood pressure is measured during the relaxation phase of the heart. When a person who is standing still begins to exercise, does the diastolic pressure change significantly?

Stay in the BLOOD PRESSURE window. Change the figure to normal and standing still, now click the GO icon. Wait until the pressure stabilizes then record the diastolic pressure here:

Change the figure to normal and running, now click the GO icon. Wait until the pressure stabilizes then record the diastolic pressure here:

Write a brief conclusion here:

You are now done with your 12 cases, if you have finished ahead of others, go back and re-check your results!
APPENDIX D. EXPLORATORY GROUP STUDENT GUIDE
You will be using a computer simulation of the cardiovascular system. You won't need to use the keyboard for this program, just the mouse.

For each step, please read the entire paragraph of instructions before making any moves in the simulation, some important cautions may be expressed later in the paragraph!

Sometimes you will be asked to click and hold the mouse button down (referred to as “click and hold”), sometimes you'll be asked to hold the mouse down and move the mouse (referred to as “click and drag”). Most of the time you will be asked just to click on an area. There is never a need to double-click in this program.

The left window will have line, bar, and pie graphs and numerical counters that indicate any kind of information you choose. It is important to note the units used in the graphs. The horizontal axis on the line graphs represents brief cycles of time (not necessarily seconds).

The right window can have up to four smaller windows in it. They are explained on the next page...
Quick Guide to your Control Window...

You can click and hold the mouse down on most parts of the body or heart and see the name of that part.

- **Resets everything to original conditions**
- **The "Go" button**
- **Stops simulation**
- **Allows you to go step by step**

This detector (#1) has been dragged to an artery in the head and the blood pressure of that artery is shown in the monitor as 126.6. The #2 detector has been dragged to a neck vein, and is showing a pressure of 6.0 in the monitor window.

Click and hold here to select whether monitor shows blood pressure, % oxygen, % carbon dioxide, or % waste. Blood pressure selected here for example.

Click and hold to select "Normal", "Athlete", or "Couch Potato"

Click here to make jogger stand still

Make jogger run

Make jogger walk
In the left window of your screen you should see the words “Main Menu”. Read the names of the tan colored buttons. Click once on “Go to HEART RATE”. You’ll see a graph of the heart rate in beats per unit time.

Because there are two windows (left and right), you sometimes have to click once anywhere in the window to make it “active” before you can click on a button. You can tell which window is active because it will have horizontal bars across the top of the title bar. Click once on the “Go” icon (the running figure). If you have trouble, don’t be afraid to ask for help.

Now, in the jogger window, click once on the middle circle to make the figure walk. Are there any changes in the heart rate? Note that heart rate is also shown in digital form below the line graph.

*Important note! When making changes in the simulation, you should observe the graph changes for at least thirty seconds before making any judgments or recording data. It takes that long for the simulated body to react!

Now, at the bottom of the jogger window, click and hold on the word “Normal”. Drag the mouse down to the word “Athlete” and let up on the mouse button. Did this change the graph?

You may create any combination of resting, walking or running for a normal person, athlete (fit person), or “couch potato” (unfit person). We won’t use the other person types in this simulation.

Now click on the “Stop” icon (the stop sign with hand). If you now click on the “Reset” (crouched runner) all the original conditions will be reset.

There is a slider bar at the bottom of the screen labeled “cc’s of blood in body”.

Click and drag the small white rectangle on the slider bar to change the amount of blood in the person’s body.

Now let’s click on the “Go to MAIN MENU” button in the upper left.

Here is a summary of what the buttons in the main menu will show you...

CIRCULATORY PATHWAYS: Simply show path of single blood cell through circulatory system.

HEART RATE: Line graph and digital reading of heart rate.

BLOOD PRESSURE: Systolic and diastolic blood pressures (line graph and digital) as well as slider bars to change body’s blood volume and simulate the blockage of an artery.

CHAMBERS OF THE HEART: Bar and line graphs of volume and blood pressure in each chamber of the heart.
VESSEL RESPONSES IN VARIOUS AREAS:
Line graph and digital reading of blood flow through several areas of the body simultaneously.

STROKE VOLUME: Bar and line graphs of stroke volume, heart rate, and cardiac output (stroke volume X heart rate)

DETECT BLOOD PRESSURE AT SPECIFIC SITES: (*Nothing will show on this graph unless you place the detectors somewhere first!) Line graph with vertical axis scaled to read blood pressure (max of 200 mm Hg). The "Monitor" subwindow is shown on the right side of screen, and detectors can be clicked and dragged to specific places on heart OR body subwindows.

DETECT BLOOD FLOW THROUGH VESSELS AT SPECIFIC SITES: (*Nothing will show on this graph unless you place the detectors somewhere first!) Line graph with vertical axis scaled to read blood flow(max of 20000 cc’s min.). The "Monitor" subwindow is shown on the right side of screen, and detectors can be clicked and dragged to specific places on heart OR body subwindows.

DETECT % OXYGEN, CARBON DIOXIDE, OR WASTE AT SPECIFIC SITES: (*Nothing will show on this graph unless you place the detectors somewhere first!) Line graph with vertical axis scaled to read % of oxygen, carbon dioxide or waste (max of 100%). The "Monitor" subwindow is shown on the right side of screen, and detectors can be clicked and dragged to specific places on heart OR body subwindows.

Here are 12 cases that you will explore by using the simulation, these conditions simulate actual responses by the human body. Use your imagination to test the hypotheses that you state for each case (hypotheses= your prediction). All questions below can be answered using the simulation.

You will be exploring the story of Lynn Heartman, an Iowa State sophomore whose body will be used in this computer simulation. Lynn’s story, which is made up of 11 different cases, will furnish you with a theme that will help you understand the circulatory system better.

Case #1: Lynn is a couch potato who has not exercised for several years. The heart plays a major role in everyone's health and is central to the cardiovascular system. We should examine Lynn’s heart and discover how it functions before we move on to more serious questions about Lynn’s health.

Before using the simulation, write briefly where you believe blood flows when it leaves each chamber of the heart. Include all chambers in your explanation.

Now test your answers by using the simulation. Start on the main menu screen, and select the tan buttons on the left that you think will furnish you with information necessary. Record whether you were correct or not. If you weren’t completely correct about each chamber, record the correct answers below.

Case #2: Lynn notices that it is time for a yearly physical checkup and schedules an appointment. During the routine physical examination, Lynn’s doctor discovers blood clots in two blood vessels. The doctor says this is a serious condition since the clots are likely to move gradually through the vessels with
the flow of blood until they come to an organ. They will cause serious damage to the next organ they enter. One clot is in the pulmonary artery. If the clot moves with the flow of blood, what is the next organ that the clot is likely to encounter? Before using the simulation, write your prediction here:

Now use the simulation to determine where that clot is likely to go.

Describe briefly the path of blood between the heart and the lungs:

Write whether you were correct in your prediction.

The other clot is located in the pulmonary vein. Predict what organ will this clot encounter next and write it here:

Now use the simulation to determine where that clot will go. Write the result here:

Write whether you were correct in your prediction.

Case #3: After successful surgery to remove the two blood clots, Lynn decides it is time to start exercising. The first stop is the doctor’s office for a treadmill test. While walking on the treadmill, Lynn wonders about the flow of blood to different areas of the body during exercise versus at rest.

Is there a difference in blood flow to specific areas of the body when exercising versus at rest? For example: Do the kidneys, intestines, brain and the exercising muscles groups all receive the same blood flow during exercise that they do at rest?

Write your predictions here and explain briefly:

Kidneys:

Intestines:

Brain:

Exercising muscle groups:

Now make sure you start on the MAIN MENU screen. Test your prediction with the simulation. You may want to try the VESSEL RESPONSES IN DIFFERENT AREAS button. Remember, whatever screen you choose, let the simulation run at least 60 seconds before making any judgments, and don’t try changing two variables at a time; you won’t know which variable is causing the effect!

Briefly describe how you tested this case with the simulation, include specific numbers about each organ and whether the blood flow fluctuated more than 10%. State a conclusion.

Case #4: Is there a difference between Lynn’s arteries and veins concerning the blood pressure within them and the direction of blood flow? If there are differences between arteries and veins concerning either of these two variables, are there any exceptions? Be thorough in testing this one!

Write your prediction here and explain briefly:

Now test your prediction with the simulation. You may want to try a couple different windows for this case. Remember, whatever screen you choose, let the simulation run about 60 seconds before making any judgments, and don’t try changing two variables at a time; you won’t know which variable is causing the effect!

Briefly describe how you tested this case with the simulation, include specific num-
Case #5: The doctor takes a blood sample from Lynn. The doctor tells Lynn that when blood is in contact with oxygen it turns red. Is there a difference between arteries and veins concerning the % of oxygen and carbon dioxide in the blood they carry? If there are differences between arteries and veins concerning this variable, are there any exceptions (be careful on this one)? Write your prediction here and explain briefly:

Now test your prediction with the simulation. Remember to set Lynn’s condition as “Couch Potato”!

Briefly describe how you tested this case with the simulation, include specific numbers about the heart rate and stroke volume. State a conclusion.

Case #7: 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. Are there any significant differences between a fit and unfit individual concerning heart rate and/or stroke volume when they are at rest?

Before using the simulation, write your prediction here and explain briefly:

Now test your prediction with the simulation. You may want to try a couple different windows for this case. Remember, whatever screen you choose, let the simulation run about 60 seconds before making any judgments, and don’t try changing two variables at a time; you won’t know which variable is causing the effect!

Briefly describe how you tested this case with the simulation, include specific numbers. State a conclusion.

Case #6: The doctor places Lynn on a treadmill and mentions that he will measure several things during Lynn’s exercise. The doctor says he will measure heart rate at rest versus during exercise. He also says he will measure “stroke volume” which is the amount of blood pumped in one heartbeat. When moving from rest to exercise, what if anything happens to stroke volume? What happens to heart rate? Why?

Before using the simulation, write your prediction here and explain briefly:

Case #8: The doctor tells Lynn that heart rate and stroke volume work together to furnish the body with blood at certain rates. Cardiac output = heart rate X stroke volume. Is cardiac output significantly different between a fit and an unfit individual when they are at rest? Is cardiac output significantly different between a fit and an unfit individual when they are exercising?

Before using the simulation, write your predictions here.
Now test your prediction with the simulation.
Briefly describe how you tested this case with the simulation, include specific numbers. State a conclusion.

Case #9: Lynn can now understand from conversations with the doctor that the heart develops a powerful pumping action, and is also a complex organ. Are there areas of different blood pressure within the heart itself? List the chambers, and what you predict their blood pressure is (just write "very high", "low" ect.).

Before using the simulation, write your prediction here and explain briefly:

Now test your prediction with the simulation.
Briefly describe how you tested this case with the simulation, include specific numbers about each chamber. State a conclusion.

Case #10: By the end of the school year, Lynn has improved in cardiovascular fitness. Lynn does have one problem though; another visit to the doctor reveals that Lynn's blood contains too much metabolic waste. This isn't carbon dioxide, but other metabolic wastes that the body usually filters out of the blood. By using this simulation, how can you demonstrate which organ/s of the body are responsible for filtering waste products (other than carbon dioxide) out of the blood?

Before using the simulation, write your prediction here and explain briefly:

Now test your prediction with the simulation.
Briefly describe how you tested this case with the simulation, include specific numbers and names of organs. State a conclusion.

Case #11: Systolic blood pressure is the blood pressure measured during the strongest portion of the heartbeat. Which of the following factors will cause the systolic blood pressure to rise in a person: being physically fit, going from rest to activity, raising the volume of blood in the body, or blocking major blood vessels? It may be more than one factor.

Write your prediction here and explain briefly:

Now test your prediction with the simulation.
Briefly describe how you tested this case with the simulation, include specific numbers. State a conclusion.

Case #12: Diastolic blood pressure is measured during the relaxation phase of the heart. When a person who is standing still begins to exercise, does the diastolic pressure change significantly?

Write your prediction here and explain briefly:

Now test your prediction with the simulation. State a conclusion.

This concludes your case study of Lynn Heartman, if you are done before others, recheck some of your earlier conclusions.
Directions: This exercise is designed to measure how closely associated you believe two concepts are. All the concept terms deal with the cardiovascular system, but some pairs are more closely related than others. For each pair, determine how closely related you believe they are, then mark on the answer sheet a number 1 through 5:
1) no relationship ---> 5) very closely related

You may want to look at a few pairs before beginning to mark!

Closeness may be defined as:
• two terms that are direct opposites
• a term being a part or example of it's partner
• cause and effect relationships
• terms that directly share characteristics

Examples:

hair follicles   skin      1 2 3 4 5
(answer 3 or 4 indicating a moderate relationship)

stomach       earlobe   1 2 3 4 5
(answer 1 or 2 indicating little or no relationship)

digestion    excretion   1 2 3 4 5
(answer 4 or 5 indicating a strong relationship)

1) no relationship ---> 5) very closely related

31. ventricle  stroke volume
32. carbon dioxide  arteries
33. artery  high blood pressure
34. heart  lungs
35. stroke volume  high fitness
36. physical activity  heart rate  Continued...
1) no relationship ---+ 5) very closely related

<table>
<thead>
<tr>
<th>37. vessel diameter</th>
<th>blood pressure</th>
</tr>
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<tbody>
<tr>
<td>38. low fitness</td>
<td>arteries</td>
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<tr>
<td>39. atrium</td>
<td>ventricle</td>
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<td>40. blood vessel</td>
<td>heart</td>
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<td>45. oxygen</td>
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<td>stroke volume</td>
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<td>adrenaline</td>
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<tr>
<td>52. ventricle</td>
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<tr>
<td>53. cardiac output</td>
<td>capillary</td>
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APPENDIX F. EXPERT'S RATINGS OF CONCEPT COMPARISONS
Expert’s ratings of concept comparisons

<table>
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<td>carbon dioxide</td>
<td>arteries</td>
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<td>lungs</td>
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<td>ventricle</td>
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<tr>
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<tr>
<td>ventricle</td>
<td>heart</td>
<td>4.57</td>
</tr>
<tr>
<td>cardiac output</td>
<td>capillary</td>
<td>1.71</td>
</tr>
</tbody>
</table>

* Concept pairs rated by seven human physiology experts.
APPENDIX G. MULTIPLE CHOICE POSTTEST
This questionnaire is designed to measure your understanding of the cardiovascular system. *No names are needed.*

Please don't mark on the question sheet itself.

* In columns **B through J**, under identification number, please fill in your *social security number* on the answer sheet.

* In columns **O and P**, fill in your *section number*.

Fill in the oval on the answer sheet corresponding to the **one best** answer to each question.

---

1. During activity, what happens to blood vessels in the exercising muscle groups?
   a. they remain the same diameter as during rest
   b. they constrict slightly (smaller in diameter)
   c. they constrict substantially (smaller in diameter)
   d. they dilate (become larger in diameter)
   e. the exercising muscle groups do not require blood flow

2. 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
3. Which diagram best depicts the flow of blood after it leaves the heart on its way to an extremity such as the toe?
   a. The blood goes to the toe, and remains there. --(heart toe)
   b. The blood goes to the toe then back to the heart. --(heart toe heart)
   c. The blood goes to the toe, then to the lungs, then to the heart. --(heart toe lung heart)
   d. The blood goes to the lungs first, then to the toe, then back to the heart. --(heart lung toe heart)
   e. The blood goes to the toe, then to the heart, then to the lungs, then back to the heart. --(double circulation)
4. Going from rest to activity, what happens to the blood flow to the exercising muscle groups?
   a. it remains about the same as during rest
   b. it shuts off entirely
   c. it decreases slightly
   d. it increases substantially
   e. the major muscle groups do not require blood flow

5. Going from rest to activity, what happens to the blood flow to the brain?
   a. it remains about the same as during rest
   b. it is shut off entirely
   c. it decreases substantially
   d. it increases substantially
   e. the brain does not usually require blood flow

6. Adrenaline is a drug produced by the human body and is released during instances of fear or surprise; what is one effect this drug has?
   a. it constricts blood vessels in the intestinal region
   b. it dilates blood vessels in the intestinal region
   c. it constricts blood vessels in the leg muscles
   d. it constricts blood vessels leading to the brain
   e. it dilates blood vessels to the sex organs

7. When moving from rest to exercise, heart rate should
   a. increase
   b. decrease
   c. remain the same
   d. decrease substantially, then increase
   e. increase or decrease depending on your level of fitness

8. Where does oxygen go after it enters your lungs?
   a. air tubes from the lungs carry oxygen throughout the body
   b. blood in vessels carries oxygen from the lungs through the heart
   c. air tubes carry oxygen from the lungs through the heart
   d. blood in vessels carries oxygen directly to the body
   e. the oxygen remains in the lungs and is then exhaled

9. Arteries are vessels in the body that:
   a. transport air from the lungs to the heart.
   b. transport air from the lungs to other parts of the body.
   c. transport blood both to and from the heart.
   d. transport blood to the heart.
   e. transport blood away from the heart.
10. Veins are vessels in the body that:
   a. have higher blood pressure than arteries.
   b. have lower blood pressure than arteries.
   c. have generally the same blood pressure as arteries.
   d. usually have no blood pressure in them at all.
   e. have higher blood pressure in them if they are located in the top half of the body.

For questions 11 through 14, mark "A" on your answer sheet if the statement is TRUE, and "B" if the statement is false.

11. A function of the heart is to filter impurities from the blood.
12. A function of the heart is to create blood.
13. A function of the heart is to pump blood.
14. A function of the heart is to store blood.

15. What does the internal structure of the human heart look like? (as above)
   a. figure "a"
   b. figure "b"
   c. figure "c"
   d. figure "d"
   e. figure "e"
16. What is the relationship in blood pressure between arteries and veins?
   a. they have equal blood pressures
   b. arteries always have higher blood pressure
   c. veins always have higher blood pressure
   d. the vein pressure is higher only in a fit individual
   e. artery pressure will be greater only if the individual is engaging in exercise

17. Concerning the characteristics of arteries and veins you discovered using the computer simulation, where do you think arteries and veins are found in the human body (in general)? Select from the cross-sections of the upper leg shown below.

18. Blood in some blood vessels of the body is high in oxygen. Blood in these vessels contain about what percent oxygen?
   a. 20%       d. 80%
   b. 40%       e. 95%
   c. 60%
Definition: stroke volume = the amount of blood pumped in one heartbeat

19. When moving from rest to exercise, stroke volume should
   a. increase
   b. decrease
   c. remain the same
   d. decrease substantially, then increase
   e. increase or decrease depending on your level of fitness

20. At rest, a well trained runner will have
   a. a lower stroke volume than an unfit person.
   b. a higher heart rate than an unfit person.
   c. a lower heart rate than an unfit person.
   d. a higher maximal heart rate than an unfit person.
   e. both a and c are correct.

21. At rest, an unfit individual will have
   a. the same blood pressure as an athlete.
   b. slightly lower blood pressure than an athlete.
   c. much lower blood pressure than an athlete.
   d. higher blood pressure than an athlete.
   e. almost no blood pressure at all.

Definition: cardiac output = (heart rate) X (volume of blood pumped per heartbeat).

22. How does cardiac output change when you go from a resting state to a state of activity?
   a. it increases
   b. it decreases slightly
   c. it decreases substantially
   d. it remains the same
   e. it changes, but the direction is dependent upon the level of fitness

23. How is cardiac output different between a fit and unfit person when at rest?
   a. cardiac output is about the same for both
   b. cardiac output is greater for the unfit person
   c. cardiac output is greater for the fit person
   d. different, but the direction is dependent upon gender
   e. different, but the direction is dependent upon age
24. How is cardiac output different between a fit and unfit person when exercising?
   a. cardiac output is the same for both
   b. cardiac output is greater for the unfit person
   c. cardiac output is greater for the fit person
   d. different, but the direction is dependent upon your gender
   e. different, but the direction is dependent upon your age

25. Athletes exercise their heart as well as other muscle groups. What capacity might you see increase in their cardiovascular system?
   a. stroke volume
   b. breathing frequency
   c. cardiac output
   d. breathing rate and cardiac output
   e. cardiac output and stroke volume

26. If two individuals are jogging at the same pace, and they both have the same cardiac output, are both individuals equally fit?
   a. if they have the same cardiac output, they must be equally fit
   b. not necessarily, the more fit individual could have higher heart rate and lower stroke volume
   c. not necessarily, the more fit individual could have lower heart rate and higher stroke volume
   d. not necessarily, the more fit individual could have lower heart rate and lower stroke volume
   e. not necessarily, the more fit individual could have lower heart rate and higher blood pressure

27. In the atria of the heart, would you find blood that is relatively high in oxygen or low in oxygen?
   a. low
   b. high
   c. high or low, depending on which atrium
   d. a mixture of high and low
   e. blood does not enter the atria

28. How many chambers are there in the human heart?
   a. one chamber
   b. two chambers
   c. three chambers
   d. four chambers
   e. five chambers
29. If an excessive amount of metabolic wastes are found in the blood sample of a hospital patient, what kind of a medical test might be done to find the source of the problem?
   a. an electrocardiograph of the heart
   b. brain scan
   c. kidney analysis
   d. x-ray of the lungs
   e. analysis of fallopian tubes

30. This is a diagram of an amphibian heart. What is one drawback in having this type of heart?
   a. the blood pressure in an amphibian is always high
   b. a mixture of half oxygenated and half de-oxygenated blood circulates through the body
   c. the lungs receive only half the volume of blood they would if the heart was the same structure as the human's
   d. this structure provides no way for blood to circulate through the lungs
   e. blood sometimes reverses it's flow inside the heart