The Nature of Undergraduates' Conceptual Understanding of Oxygen Transport and Utilization in Humans: Can Cardiopulmonary Simulation Software Enhance Learning of Propositional Knowledge And/Or Diagnose Alternative Conceptions in Novices and Intermediates?

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THE NATURE OF UNDERGRADUATES' CONCEPTUAL UNDERSTANDING OF OXYGEN TRANSPORT AND UTILIZATION IN HUMANS: CAN CARDIOPULMONARY SIMULATION SOFTWARE ENHANCE LEARNING OF PROPOSITIONAL KNOWLEDGE AND/OR DIAGNOSE ALTERNATIVE CONCEPTIONS IN NOVICES AND INTERMEDIATES?

VOLUME I

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Curriculum and Instruction

by

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B.S., University of Kansas Medical Center, 1978
M.H.S., Louisiana State University Medical Center, 1986
December 1998
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ABSTRACT

The purpose of this research was to explore undergraduates' conceptual development for oxygen transport and utilization, as a component of a cardiopulmonary physiology and advanced respiratory care courses in the allied health program. This exploration focused on the student's development of knowledge and the presence of alternative conceptions, prior to, during, and after completing cardiopulmonary physiology and advanced respiratory care courses. Using the simulation program, SimBioSys (Samsel, 1994), student-participants completed a series of laboratory exercises focusing on cardiopulmonary disease states. This study examined data gathered from: (1) a novice group receiving the simulation program prior to instruction, (2) a novice group that experienced the simulation program following course completion in cardiopulmonary physiology, and (3) an intermediate group who experienced the simulation program following completion of formal education in Respiratory Care.

This research was based on the theoretical framework of Human Constructivism as described by Mintzes, Wandersee, and Novak (1997). Data gathering techniques were based on theories advocated by Novak (1984), Wandersee (1997), and Chi (1997). Data were generated using test results, clinical interviews, verbal analysis (Chi, 1997), and cognitive cartography.

Results suggest that simulation may be an effective instructional method for assessing conceptual development and diagnosing alternative conceptions in undergraduates enrolled in a cardiopulmonary science program. Use of simulation in conjunction with clinical interview and concept mapping may assist in verifying gaps in learning and conceptual knowledge. This study found only limited evidence to support
the use of computer simulation prior to lecture to augment learning. However, it was
demonstrated that students' prelecture experience with the computer simulation helped
the instructor assess what the learner knew so he or she could be taught accordingly. In
addition, use of computer simulation after formal instruction was shown to be useful in
aiding students identified by the instructor as needing remediation.
“To attempt to learn by lectures only is idle and unprofitable; take them as guides to
direct your observation, your reading, your meditation; but to suppose that the mere
listening to lectures should confer excellence would not be less futile than a traveler to
bestrside a guide-post and vainly expect that it should, without effort on his part, convey
him to the destination to which it points.”, *Lancet*, Nov. 5, 1825 p. 231

**INTRODUCTION**

An essential skill of the cardiopulmonary practitioner is to problem solve and
make decisions which ultimately benefit the patient he or she is caring for. To develop
a skill level that allows effective decision making requires a solid foundation in the
biomedical sciences and extensive experience in the care of patients in a clinical setting.
The mission of the LSU Medical Center, School of Allied Health and the Department of
Cardiopulmonary Science is to graduate competent practitioners who can function
competently at the bedside, act as change agents for policy, and procedures in health
care. In reaching this goal, learners must, in part, possess a good understanding of core
course material early in their professional education to allow subsequent learning of
advanced concepts. The role of early professional core course work, such as
cardiopulmonary physiology, is paramount in the development of a competent bedside
practitioner.

This researcher is dedicated to finding ways to improve teaching that results in
motivating the learner desire to want to learn and to develop a dynamic perspective of
biological phenomena. As educational practices evolve to meet the challenges of the
new millennium, teachers and school officials need to take a closer look at the processes
of teaching and learning and make necessary changes to produce a life-long learner who
can and will meet the challenges ahead.
Well-planned and implemented qualitative and quantitative research produces data which generate patterns, allow theory to emerge, and create new hypothesis which, in turn, will motivate others to do original research. It was the goal of this research to use the results to make a contribution to science and allied health education, learner, and the effectiveness of instruction.

A Brief Overview of the Study

This research examined the development of undergraduates' conceptualization of the physiology of oxygen transport and utilization, using diagnostic computer simulation software. The researcher has observed that Cardiopulmonary Science students are frequently unable to transfer understanding of critical concepts to patients with cardiopulmonary disease. This study examined the efficacy of cardiopulmonary simulation software as a learning tool at various points of instruction in an undergraduate cardiopulmonary physiology course. A primary interest was: Can simulation software foster conceptual development and aid in identification of alternative conceptions?

Research Questions and Overview of the Research Study

The primary research question this study attempted to answer: Can cardiopulmonary simulation software enhance learning of propositional knowledge and/or help diagnose alternative conceptions in novices and intermediates?

The subquestions were:

1. What are the effects of using cardiopulmonary simulation software prior to classroom instruction on initial concept development?
2. Does postinstructional use of cardiopulmonary simulation software aid in assessing conceptual development, and in identification and remediation of alternative conceptions?

3. Can cardiopulmonary simulation software be used by the instructor and learner (both novice and intermediate) to identify critical junctures in understanding associated with the physiology of oxygen transport and utilization?

A Gowin's Vee Diagram of the Proposed Research

A Gowin's Vee diagram (See Appendix A) provides an overview of the practical and theoretical framework of this project. The center of the Vee states the research question; the far left side of the Vee diagram indicates foundational knowledge (consisting of world view, theories, principles, and concepts) that, when integrated, provide a conceptual model for this research plan. The focus of this study is the objects and events located at the point of the Vee. The right side of the Vee indicates the object and event records and the transformations of collected data that this researcher made; and above these are some hypothetical knowledge and value claims that may or may not be supported by the results of this study.

Definitions of Terms

For the purpose of this study, the following definitions (divided into those terms related to science education and medical science with abbreviations) will be used:

Science Education-related terms:

Advance organizer—relevant and inclusive introductory materials or experiences
provided prior to instruction to foster a connection between what the learner
already knows and what he/she needs to know for meaningful learning to occur.

Alternative conceptions—a set of ideas about objects or events that is often at
odds or inconsistent with current accepted theory or explanations.

Concept—a perceived pattern or regularity in objects or events which is
designated by a label.

Critical junctures—certain points in a course where learners must possess
essential knowledge constructed from previously taught concepts in order to
understand the new information that follows.

Heuristic—a method of thinking or a learning tool to enable learners to discover
information for themselves.

Human constructivism—a process based on the use of language and experience
for “meaning-making” and the acquisition and modification of concepts and
concept relationships.

Intermediate—a learner with a knowledge level between a novice and expert.

Learning—an eventful process that results in a shift or change in the quality of
the meaning of experience.

Learning theory—a coherent set of principles about how individuals learn.

Meaningful learning—learning that involves the nonarbitrary, nonverbatim,
substantive incorporation of new knowledge into long-term memory.

New synthesis—a theory of learning in cognitive science that encourages the use
of domain specific learning skills combined with general learning skills.
Novice—a learner who has little or no previous or self-taught knowledge in a specific domain or area of interest.

Propositional learning—learning which express the meaning of new ideas with verbal statements consisting of concepts and relationships.

Simulation—a representation of reality as portrayed by a computer-based program under the learner's control.

Medical Science Terms

Afterload—the stress or wall tension that develops in the ventricular wall during systole

Cardiac output—The volume of blood pumped from the heart per minute

Compliance—The property of altering size and shape in response to application of force. When applied to pulmonary physiology, compliance is the willingness of the lung or thorax to expand.

Contractility—The force with which left ventricular ejection occurs.

Deadspace—Volume of gas in the lung that gas exchange does not take place. An abnormal deadspace is when alveoli lack blood flow around them so gas exchange is impaired.

Functional residual capacity—The amount of air in the lungs at the end of a normal expiration. Normal value is 2400 mL.

Minute ventilation—The amount of gas moved in and out of the lung per minute.

Preload—End-diastolic stretch of the myocardial muscle during diastole.

Shunt—Blood that flows from the right to left ventricle without gas exchange.
**Tidal Volume**—The normal amount of gas moved in and out of the lung during normal breathing. Normal value is 500 mL.

**Medical Abbreviations**

- **A-aD\textsubscript{O2}**—Alveolar-arterial difference in partial pressure of oxygen
- **Ca\textsubscript{O2}**—Oxygen content of arterial blood
- **Cv\textsubscript{O2}**—Oxygen content of venous blood
- **FI\textsubscript{O2}**—Percent of oxygen inspired
- **Hb**—Hemoglobin
- **Hct**—Hemotocrit
- **LVEDP**—Left ventricular end-diastolic pressure
- **LVEDV**—Left ventricular end-diastolic volume
- **MAP**—Mean arterial pressure
- **MPAP**—Mean pulmonary arterial pressure
- **PA\textsubscript{O2}**—Partial pressure of oxygen in the alveoli
- **Pa\textsubscript{O2}**—Partial pressure of oxygen in the arterial blood
- **PaC\textsubscript{O2}**—Partial pressure of carbon dioxide in arterial blood
- **PCWP**—Pulmonary capillary wedge pressure
- **PEEP**—Positive end-expiratory pressure
- **Pi\textsubscript{O2}**—Partial pressure of inspired oxygen
- **Sa\textsubscript{O2}**—Arterial oxygen saturation of hemoglobin
- **ST**—Surface tension
- **Sv\textsubscript{O2}**—Venous oxygen saturation of hemoglobin
Theory of Learning

Most people continue learning throughout life, whether intentionally in formal educational settings, or incidentally through experience. Although the human condition changes continuously as a result of learning, little is actually known about learning, despite many theories on how humans learn. Behaviors and verbal responses may be recorded, analyzed, and generalizations may be made—whereas mental processes that govern behaviors and verbal expression are much more elusive. Educational research is replete with schools of thought, theories, and perspectives concerning learning, thinking, and concept formation. This section will define theory, describe implications of theory in science education, and focus on a framework for a working definition of learning that guided this research.

When asked to define theory, most individuals provide an intuitive response (Driscoll, 1994). According to Wilson (1997):

Theories are meant to explain something, or to aid us in understanding the way things are within a certain domain. Theories work in one domain and do not work so well in another domain. Theories include a cluster of concepts organized together to form a whole. Not all concepts in a described theory are precise and exact; in fact, usually key concepts—the ones most central to the theory—are not operationally defined, but instead maintain flexibility and fluidity so they can be used in a variety of ways addressing various problems, issues, and conditions. Theories connect observations with evidence. Theories are linked to rules about what counts as evidence, what counts as good reasoning, and theorizing (p. 22).

Personal theories, according to Schon (1987), influence what people think while performing a task and how they reflect upon the task afterwards. Kelly (1963)
generated a personal construct theory founded on the belief that people have their own personal theories which guide their perceptions and actions. Kelly elaborates personal theory by emphasizing the importance of context. Langer (1989) asserts context governs self-generated theories and belief systems. These beliefs and personal theories have implications for teaching with regard to how propositional knowledge and alternative conceptions are formed, an interest of this study.

Many people believe science is based on an adherence to rigorous, scientific methods of inquiry that assure theory is generated from quantitative means. Scientific theory then results from careful analysis of data, weighing of evidence, and creating a plausible explanation of phenomena. Once accepted by the scientific community, a theory becomes a vehicle for gaining new knowledge and understanding. Wilson (1997) cautions that scientifically derived theories remain human constructs and are often culturally-biased. Despite our best efforts in crafting a theory, theories reflect imperfections, biases, weaknesses, and inward character defects inherent to humans. The human influence on theory development dictates cautious movement before embracing a particular theory, carefully studying a theory prior to placing it into practice, especially in the classroom. Educators are obligated to challenge learning theories, assumptions, and teaching strategies, and to seek to develop an effective learning theory to guide teaching and use of educational technologies.

**Learning Theory**

A theory about learning is a set of laws or principles about how individuals learn. Driscoll (1994) described learning theory as a set of constructs:
A learning theory comprises a set of constructs linking observed changes in performance with what is thought to bring about those changes. Constructs refer to the concepts theorists invent to identify psychological variables. Memory, for example, is a construct implicated in cognitive perspectives on learning. In other words, we look at the fact that people can demonstrate the same performance time after time and reason that they will do so because they have remembered it. We have invented the concept of memory to explain this result (p. 9).

Driscoll (1994) identifies three questions regarding theory that should be considered when doing educational research:

1. Can the results of this study be explained by learning theory?
2. Which cognitive processes brought about learning?
3. What triggers the learning process to occur and what resources are needed for learning to occur?

Two learning theories found in cognitive science; human constructivism and meaningful learning, were the underpinnings of this project's research questions. Each of these theories will be discussed, following a review of a theoretical and practical definition of learning.

**What is Learning?**

Despite awareness that human beings learn, defining learning is a difficult task. Descriptions and explanations of what actually takes place when learning occurs are not easily discerned. Little consensus exists as to what learning is and how it occurs. Two centuries of research and publications debating the causes, processes, and consequences
of learning have resulted in limited acceptance of a common theory of learning among educators and others involved with education. (Newby, Stepich, Lehman, & Russell, 1996).

Because learning takes place in a wide variety of situations, measuring learning and assessing quality of learning are difficult. Furthermore, previous learning and experiences greatly influence an individuals' present learning (Glover, Ronning, & Bruning, 1990; Gowin, 1981; Newby et al., 1996; Novak, 1977; Resnick, 1987). As Newby and colleagues (1996) state:

Two individuals with the same task to be learned, in the same setting, and with the same consequences for achievement will not necessarily learn the same thing. Differences in backgrounds and experiences have an impact on what is perceived, how it is associated within memory, and how and under what conditions it is recalled. Moreover, not only are the differences between individuals difficult to predict, but variances within a single individual also frequently impact learning over time. Our experiences and backgrounds influence the manner in which each task is approached and the way in which each is accomplished, making it difficult to predict what will occur during a single learning episode (p. 8).

The study of learning is further hampered by difficulty with observation and measurement. Because individuals learn differently and perceptions differ across a wide range of interpretations, the degree of learning achieved is difficult to assess. What has been learned by an individual is open for discussion, disagreement, and interpretation.

For this research, a working definition of learning, was adapted from Ausubel (1963), Gowin (1981) and Novak (1977). These theorists view learning as a shift in the
quality and meaning of experience, as the learner moves from not knowing to knowing. Learning is an eventful process which the learner chooses to undertake in order to change the meaning of his or her experience. Learning intends to make connections between what the learner already knows and what is to be learned. Because learning is personal and idiosyncratic (Novak & Gowin, 1984), it results in degrees of learning for individual learners in a given situation. In summary, beyond earliest childhood, learning can be defined as an active reorganization of existing patterns of meaning.

**Why Study Learning?**

The health science educator will be better prepared to assure effective instruction by knowing more about what learning is, how learning occurs, and which factors influence the learning process. By applying results of educational research conducted using learning theory, several learning and teaching outcomes may be realized: (a) increased instructional effectiveness, (b) increased instructional efficiency, and (c) increased desire by learners to learn and teachers to teach.

**Theoretic Framework from which this Study Evolved**

When psychology deviated from a philosophical orientation to a “science of the mind” orientation, sensation and perception became a major focus of study among psychologists (Bower & Hilgard, 1981). During the mid-1800s, a new interest in thinking and learning began to emerge resulting from the research of Hermann Ebbinghaus. Ebbinghaus began to appreciate a growing collection of research integrating science and psychology, and was encouraged to study learning from a psychological perspective (Herrnstein & Boring, 1968).
During the mid-1800s, the major theory of learning was the classic doctrine of associationism. Learning by association constituted the basic learning-retention mechanism (Ausubel, Novak, & Hanesian, 1978). An empiricist perspective defines association as connecting ideas through repeated exposure to the connection. The more frequently a particular idea is associated with an experience, the stronger the associative bond becomes. This simple premise was often used to explain learning (Driscoll, 1994). Association was thought to bridge learning and enhance retention. Thus, rote memorization was the method of choice for learning during the middle 1800s (DeBoer, 1991).

Ebbinghaus assumed that if ideas are connected by the frequency of their association, then learning should be predictable, based upon the number of times ideas or experiences are encountered (Driscoll, 1994). This idea led Ebbinghaus to pursue his famous “nonsense syllables” research, attempting to quantify the laws of association. His classic work, published in 1885, revealed several critical aspects about memory and forgetting. Ebbinghaus concluded the more material to be learned, the longer it takes to learn it. This idea was illustrated by the now-classic “forgetting curve” (Ebbinghaus, 1885). Ebbinghaus' work on forgetting, association, and meaning (indirectly) remains a driving force within several modern cognitive theories of learning (Driscoll, 1994).

David P. Ausubel, an educational psychologist who was influenced by Ebbinghaus, continued his working with verbal learning. Ausubel claimed that knowing, meaning, and understanding were cognitive functions, and thus provided a framework for the science of (and a theory of) learning. Unlike Ebbinghaus, who believed human
learning and memory could be studied without previous learning contaminating study results, Ausubel proposed that meaning (from previous learning) was at the core of all cognitive experiences. Discarding Ebbinghaus' use of meaningless syllables, Ausubel turned to prose, text, and material of some length with rich meanings in order to study learning (Driscoll, 1994).

Ausubel continued his work during the late 1960s, in opposition to the cognitive theories developed during the 1950s and 1960s. Popular cognitive learning theories during this period included the "data-processing and storage mechanism" that compared the human mind with computer operations. Computer models became the framework for learning studies performed by Newell, Simon, and Shaw in the 1950s (Driscoll, 1994). In contrast to the computer analogy, Ausubel viewed learning as more than information processing, rather a product of how learners actively interpret their experience and use cognitive processes. Ausubel's theory led to the development of the theory of meaningful reception learning which, directly or indirectly, continues to influence learning research and educational practices today (Ausubel et al., 1978; Driscoll, 1994).

According to Ausubel, meaningful reception theory and research were based on the premise that a person's existing cognitive structure (i.e., organization, stability, and clarity of knowledge) of a particular subject at any given time, is the principal factor influencing learning and retention of new material (Ausubel, 1963a). Ausubel described memory structure as hierarchically organized. He described an integrated cognitive structure containing a body of knowledge that a person uses to think. This
cognitive structure consists of sets of ideas organized in a hierarchical fashion and by topic. By nature of this arrangement, more inclusive ideas are the most stable or retrievable. The most general ideas, located at the top of the hierarchy, are more likely to be remembered than specific ideas, located lower in the hierarchical structure. In other words, as ideas become more focused or narrow, they become more unstable and are more likely to be forgotten.

This hierarchical framework of cognitive structure allowed Ausubel to derive the notion of “anchoring ideas”. Anchoring ideas are specific or related ideas in the learner's cognitive structure that provide what Driscoll (1994) describes as an, “entry point for new information to be connected” (p. 114). Anchoring ideas allow the learner to construct meaning from new information and experience. Ausubel claims for a connection to be made between existing ideas anchored in cognitive structure and new information or experiences, the new information or experiences must be potentially meaningful to the learner. For example, without successful completion of human anatomy and physiology in the sophomore year of college, students entering the junior year of the Cardiopulmonary Science Program would lack many of the anchoring ideas needed for effective learning of cardiopulmonary physiology. Another example includes the learner who has an incomplete understanding of the structure and function of a red blood cell and would therefore not be able to fully understand subsequent concepts such as how oxygen is transported by the red blood cell.

Ausubel states that meaningful learning requires a cognitive structure organized in such a manner that anchoring existing knowledge with new knowledge is a necessity.
for learning to take place. Ausubel continued to explore how knowledge is actually connected and incorporated into existing cognitive structure with his theory of meaningful reception learning (Driscoll, 1994).

Ausubel first described two types of learning: reception and discovery learning. When the entire knowledge content of a lesson or class is delivered to the learner in its “final form”, reception learning occurs. With reception learning, the learner is expected to understand incoming information while internalizing the entire knowledge set. With discovery learning, learners are expected to rearrange and integrate new information in anticipation of discovering “a missing means-end relationship” (Ausubel, 1961, p. 17). Ausubel warns that once the learner discovers new ideas or relationships, new content is internalized in the same manner as reception learning (Ausubel, 1961). Discovery methods include experience with in-class laboratory experiments or everyday problem solving. Ausubel was critical of both reception and discovery learning in that neither was inherently ideal for acquiring knowledge, and, depending upon on how they were used both could result in rote learning.

Ausubel also distinguished between rote and meaningful learning. When the learner is expected to memorize material and can not or does not make connections between memorized information and his/her existing knowledge, rote learning is occurring. Memorized information remains isolated from existing cognitive structure and is more likely to be forgotten. In contrast, meaningful learning relates new information to existing knowledge in a nonarbitrary and substantive way (Driscoll, 1994). Ausubel claims two conditions must be present for meaningful learning to take
place. First, the learner must employ a meaningful learning set and second, the material must be potentially meaningful (Ausubel et al., 1978).

To illustrate the difference between rote and meaningful kinds of learning, a student may be able to recall, from rote memorization, an equation to calculate a physiologic parameter (e.g., deadspace to tidal volume ratio) and arrive at the correct answer, but lack understanding of how the equation is derived (Tobin, Tippins, & Gallard, 1994). With meaningful learning, the learner would understand the idealized relationship of the variables in the equation (e.g., arterial and end-tidal carbon dioxide levels in the Bohr equation to determine deadspace ratio) to actual patient data (e.g., minute ventilation).

Ausubel further differentiates meaningful learning into three types. These are:

1. Representational learning

   Representational learning is learning the meaning of words or symbols. According to Ausubel, representational learning is the most basic form of learning and must take place before other types of learning can occur (Ausubel et al., 1978). An example of this learning would be the learner hearing the words “lung compliance” (only potentially meaningful) for the first time. When the learner makes the connection between the sound of the word and its meaning, representational learning has occurred.

2. Concept learning

   Concept learning refers to learning by relating a representation
to other relevant experiences. The learner not only knows the meaning of the word, but understands the critical attributes that makes the word what it is. For example, the concept of lung compliance includes the relationship between volume and pressure. Concept learning allows the learner to understand the effects pressure has on lung volume, for a given lung compliance.

3. Propositional learning

Propositional learning is learning that contains meanings of new ideas expressed in verbal propositions. Ausubel states that by combining words or concepts, a new idea is formed, which is more than the sum of the meanings of the individual words (Ausubel et al., 1978; Driscoll, 1994).

When a learner constructs new knowledge from combining words and concepts, propositional learning is said to occur. An example of propositional learning includes a learner connecting the concept of dissolved oxygen to the concept of oxygen combined with hemoglobin to form a third concept called oxygen content.

In an effective learning situation, according to Ausubel, a learner would experience all three types of meaningful learning in a sequence that mimics hierarchical learning; is, representational learning occurring first, followed by concept learning, then forming new knowledge by propositional learning. A major focus of this research plan was to determine the role simulation software plays in promoting meaningful learning to better understand the physiology of oxygen transport and utilization.
To conclude the discussion of the influence of Ausubel's research on science education, the principles of meaningful learning will be expanded. How does learning take place in Ausubel's hierarchical model of cognitive structure? Ausubel claims information is added to existing cognitive structure by subsumption. Subsumption occurs when new ideas are anchored to existing related ideas. "That is, new, incoming ideas are subsumed under more general and inclusive anchoring ideas already in memory" (Driscoll, 1994, p.118).

As incoming ideas enter a learner's cognitive structure, subsumption occurs by either derivative or correlative subsumption. Derivative subsumption occurs when a newly learned concept or idea is related to existing propositions or concepts. For example, once the learner understands the concepts of flow and resistance as applied to electricity, the learner could better understand the concept of gas flow and resistance in the respiratory system. Correlative subsumption is a "process of elaboration, extension, or modification of the previously learned concept or proposition by the subsumption of the incoming idea" (Driscoll, 1994, p. 119). An incoming piece of information enters the learner's cognitive structure and interacts with existing related ideas to change the learner's initial understanding. For instance, once the learner understands the concepts of oxygen content, cardiac output, and blood flow, the metaconcept (construct) of oxygen transport can be subsumed.

Ausubel states not all learning takes place via subsumption. He proposed two additional types of learning processes; superordinate and combinatorial learning. Superordinate learning takes place through the synthesis of established ideas. "That is,
a new inclusive proposition or concept is learned under which already-established ideas can be subsumed” (Driscoll, 1994, p. 120). If several ideas exist in the learner's cognitive structure, and a relationship between these ideas is discovered, superordinate learning has taken place. For example, once the learner understands the concepts of heart rate, preload, afterload, and contractility (physiologic determinants of cardiac output), the concept of cardiac output (amount of blood the heart pumps per minute) may be better understood.

The final type of learning process is combinatorial learning. With this type of learning, the learner encounters a new idea not directly anchored to related information in the learner's cognitive structure. Due to the learner's broader background information, the new idea forms a new concept or modifies an existing one. This is due to the matching of the new idea with similar attributes of the overall cognitive structure allowing for further understanding. Ausubel refers to this recombination of new and existing knowledge as integrative reconciliation. As new information enters cognitive structure, the learner's initial confusion or uncertainty may be minimized. Integrative reconciliation can be enhanced for the learner by the instructor identifies possible content that may be confusing or poorly understood. This teaching strategy may help the learner resolve inconsistencies or conflicts between incoming learning material (Ausubel et al., 1978).

According to Ausubel combinatorial learning is a necessity for concept formation. For a particular topic or subject, some concepts exist in both coordinate (at the same level in the structure) and subordinate form (lower in the structure).
Relationships between related concepts must be learned and understood. Furthermore, the relationships between old and new information formed under the subsuming concept must be understood. For example, understanding the concepts of pressure, flow, resistance, and volume under the subsuming concept (construct) of cardiac output allows learning a general understanding of the cardiovascular system and also allows for learning other related concepts. Ausubel states most new generalizations the learner retains are a result of combinatorial learning. Application of this idea can be illustrated by the Cardiopulmonary Science curriculum with learners first completing cardiopulmonary physiology prior to entering a course in cardiopulmonary pathophysiology. Gaining a strong conceptual basis for lung and heart disease requires learning foundational concepts of normal lung and heart physiology.

Ausubel combines the ideas of subsumption, superordinate, and combinatorial learning into a single framework referred to as assimilation theory. Earlier versions of this theory were limited to the idea that new information became a part of, or was retained with, existing, more stable propositional knowledge. As information was received, it was anchored to existing knowledge (Ausubel, 1963a). As Ausubel's research continued, assimilation theory took on a broader scope and encompassed the belief that as new information was received, it became linked to existing related meaning or knowledge, resulting in a more highly differentiated cognitive structure (Ausubel et al., 1978).

Retention of new knowledge becomes enhanced if new material is potentially meaningful and becomes anchored in the learner's cognitive structure. As time passes,
the learner tends to use more stable concepts during thinking and problem solving. Concepts that are more specific or less distinguishable, tend to be used less frequently and become more difficult to retrieve. In other words, once concepts become separated and distinct from the basic concept, they tend to be forgotten (Driscoll, 1994).

According to assimilation theory, how new information is encoded influences retention and memory. Ausubel described two methods of forgetting based on encoding using rote or meaningful learning (Ausubel et al., 1978). When propositional knowledge acquired through subsumption can no longer be retrieved or recalled, Ausubel contends obliterative subsumption has occurred. Unless the propositional knowledge is used or refreshed, it will fade and eventually be lost. According to Ausubel, unless there is continued retrieval of retained propositional knowledge, memory loss occurs. In contrast to obliterative subsumption, Ausubel describes the loss of knowledge obtained by superordinate or combinatorial learning as obliterative assimilation.

Ausubel further differentiates between rote and meaningful learning, and describes the characteristics of forgetting. Information from either rote or meaningful learning can be forgotten if not used. However, there is a net gain in a cognitive structure following meaningful learning. The concept allowing anchorage for meaningful learning to occur is better differentiated than it was previously, allowing for residual memory. Ausubel describes this as “memorial residual of ideational experiences which enables the concept or proposition to be more functional for future learning and problem solving” (Driscoll, 1994, p. 123).
The learner's existing knowledge and cognitive development determine readiness to learn new material. The degree of development dictates the level of understanding of abstractions that can be achieved within a subject area. One of Ausubel's most well-known contributions to education was his emphasis on the function of previously acquired knowledge. This dictum of his is often quoted: "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him [sic] accordingly." (Ausubel, 1963b; Ausubel et al., 1978; Driscoll, 1994).

Once the learner's cognitive structure becomes highly organized and stable, related learning can be enhanced. In contrast, if the learner's fundamental concepts are disorganized, ambiguous, or poorly structured, meaningful learning and retention of knowledge is compromised and learning is less likely to occur.

This study was influenced by Ausubel's theory of meaningful learning, especially the need to link concepts related to oxygen transport and utilization. Other questions that Ausubel's theory may inform include: Can simulation software allow discrimination of new ideas in the learning material from both similar and dissimilar anchoring ideas in the learner's cognitive structure and can simulation software aid stabilization and clarification of anchoring ideas to facilitate their use for additional learning or problem solving?

This research, although not addressing these questions specifically, considered the nuances of these theoretical questions to gain a better understanding of how to apply Ausubel's learning theory to medical education.

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**Advance Organizers**

Ausubel provides several instructional strategies to enhance the opportunities for meaningful learning. These strategies are based on his theory of meaningful learning. Ausubel states that by using relevant and inclusive introductory material prior to instruction (what he refers to as an advance organizer), there is greater likelihood that a connection will be made between what the learner already knows and the new (incoming) information.

To experience meaningful learning, the learner must apply what he/she knows to the learning task at hand. In instruction, this may be accomplished by providing an advance organizer (an example or experience using a higher level of abstraction, generality, and inclusiveness) for the new material to be learned (Ausubel, 1978). However, since each learner has somewhat idiosyncratic cognitive structure, each learner, in theory, should receive an advance organizer unique to his or her specific learning needs. As Driscoll (1994) points out, this is not practical if instruction occurs at one general level to the class, “Thus organizers should be sufficiently general to function for a variety of learners” (Driscoll, 1994, p.127).

Research literature contains numerous studies both favoring and opposing the effectiveness of advance organizers (Driscoll, 1994). Mayer (1979a, 1979b) supports the use of advanced organizers and has outlined criteria for an effective advance organizer. These criteria include: (a) providing a short set of verbal or visual information presented prior to learning a larger body of to-be-learned information, (b) containing no specific content from the upcoming information, (c) providing a logical
connection between variables that are to be learned, and (d) aiding the learner's encoding process. According to Mayer:

> The manner in which an organizer influences encoding may serve either of two functions: To provide a new general organization as an assimilative context that would not have normally been present or to activate a general organization from the learner's existing knowledge that would not have normally been used to assimilate the new material (p. 382).

Mayer provides further guidelines for assessing effectiveness of advance organizers. He recommends that to evaluate a teacher-generated advance organizer, the organizer should: (a) provide a logical relationship of the to-be-learned material with the learner's existing knowledge, (b) allow the learner to use the organizer, and (c) determine if the learner would likely not use the organizer due to inexperience or some other influence (Mayer, 1979a; Mayer, 1979b). Recent research continues to emphasize the importance of the learner's prior knowledge and use of advance organizers. Current knowledge in the learner's cognitive structure must be activated by the advance organizer, allowing creation of effective connections between existing knowledge with incoming information (Mannes, 1987; Sui, 1986; West, Farmer, & Wolff, 1991).

West, Farmer, and Wolff (1991) have added several other recommendations for constructing advance organizers. These suggestions include: (a) identifying prerequisite knowledge and reteaching if necessary, (b) determining if learners know the identified prerequisite material, (c) providing a summary to the learner of the major principles of the new material, and (d) create an organizer emphasizing main concepts and similarities that cross old and the new to-be-learned material. West, Farmer, and Wolff,
(1991) further suggest using examples from the text to enhance the organizer and sequencing new material in the same order the organizer presents them. In summary, use of advance organizers continues to be a subject of research. Advance organizers appear to play a vital role in helping learners bridge from old to new information, provided the organizers are properly developed. The use of computer program simulation software prior to instruction may be shown as an effective advance organizer.

An understanding of Ausubel's work is necessary due to the impact it has had on the development of human constructivism and newer theories of learning (e.g., Bruer, 1993). This research identified implications of Ausubel's theory for the health sciences and the use of cardiopulmonary simulation software.

**Human Constructivism**

Ausubel's influence led other researchers, including Joseph Novak and D. Bob Gowin, to expand the principles of meaningful learning and apply them to other aspects of cognitive science (Gowin, 1981; Novak, 1977). Novak and Gowin built upon Ausubel's recommendation to determine what the learner knows and teach him or her accordingly. This principle was the foundation of this researcher's dissertation, while being framed by the influence of the Ausubel-Novak-Gowin theory of learning.

Significant work has been published by Novak and Gowin, along with other science educators such as Bruer, Mintzes, and Wandersee, that complements the theory of meaningful learning and draws upon emerging findings of cognitive science (Ausubel et al., 1978; Bruer, 1995; Mintzes, Wandersee, & Novak, 1998; Novak & Gowin, 1984). Cognitive science strives to understand how people learn and make meaning from
perhaps educational and everyday experiences. How learners make meaning is a major focus of human constructivist theory and is of great interest in science education research. To understand human constructivism, several essential elements must first be explored. These elements include concepts, meaningful learning, theory ladenness, and information processing.

**Concepts**

Concept learning, making meaning, and conceptual change are integral to learning science (Nussbaum, 1989). A concept can be defined as all the knowledge a person has about a term (White & Gunstone, 1989). Thus a person may know an oxygen cylinder is made of metal, comes in a range of sizes, stands in a holder, and holds a gas. The learner may have had an opportunity to handle a cylinder when administering oxygen to a patient. This collection of propositions, images, and episodes, together with the ability to recognize the cylinder, makes up the person's concept of a "gas cylinder" (White & Gunstone, 1989). Others define a concept as a basic unit of meaning, as discerned by regularities in objects or events that are designated by a sign, label, or symbol (Mintzes, Wandersee, & Novak, 1997). As Novak (1977) illustrates, "red" is a concept describing a color, but in contrast, "red" can also describe a political stance an individual or group may have. Although the concept of the color red may be simple, the concept of red in the political sense is more complex and highly differentiated. Theories connect concepts in order to explain how concepts are related. Theories are higher level concepts that suggest order and relationships between less inclusive concepts.
Novak and Gowin (1984) view a concept primarily as a part of a network of related concepts. This idea complements the underlying theory of meaningful learning promoted by Ausubel (Abrams, 1994).

Concepts are formed at an early age as a result of interactions with an object, person, or event. Over time, concepts are modified, altered, expanded and/or contracted as experience and interaction with the environment occurs. As concepts change and connect with other concepts within cognitive structure, complex ideas may be built up in a highly organized, hierarchical manner, producing propositional knowledge resulting in meaningful learning.

"Making meaning" includes changing or altering a concept, which is often the intent of science teaching. As meaning occurs or changes within the learner's cognitive structure, concepts develop, are modified, and can become differentiated. As meaning and concepts change, so does theory and the learner's overall cognitive structure. The learner's conceptual framework can become more stable, allowing increased understanding and recall.

There are two major theories on the nature of concept formation. Traditional theory, known as the theory of abstraction or "copy theory," proposes that concepts are created when a person forms an abstraction of certain resemblances among otherwise dissimilar stimuli. With this view, a concept is a representation of generalities observed from multiple perceptions. An alternative view describes a concept as being formed, not by the person merely attending to general features, but by having a specific hypothesis about certain features of the environment (Bolton, 1977). Once a hypothesis has been
formed, a search is conducted for evidence to support or validate it. As concepts develop, a particular view of the world, events, or phenomenon is formed. Of course, concepts will change with time and additional processing of incoming stimuli. The dynamic nature of conceptual change influences how researchers conduct educational research.

**Meaningful Learning**

Briefly defined, meaningful learning is learning involving deliberate linkage of new concepts with propositions with existing knowledge in the cognitive structure of the learner. Meaningful learning requires new material to be potentially meaningful and the learner to assume a meaningful learning set (Abrams, 1994; Mintzes et al., 1997). A meaningful learning set occurs when the learner deliberately attends to linking the new material to his/her prior knowledge in anticipation of learning it.

As new concepts are added to the learner's cognitive structure, either through subsumptive or superordinate learning, the existing network of concepts is progressively differentiated, resulting in the modification of the learner's conceptual makeup (Abrams, 1994; Mintzes et al., 1997). As further learning occurs, concepts become increasingly organized and stable.

Mintzes, Wandersee, and Novak (1997) describe the concept of theory-ladenness as a link between the theory of learning based on the Ausubelian principles and personal knowledge construction. This theory proposes that learners attend to and recognize patterns in environmental cues (i.e., objects and events) quite selectively, based on their prior knowledge, and that selective attention and pattern recognition
govern perceptions, and that perceptions in turn constrain meaningful learning (Mintzes, Wandersee, and Novak, 1997). This interaction between prior knowledge, perception, and meaningful learning is the core of the human constructivist's view. Information processing is a major theme of study with human constructivism.

**Information Processing**

Early research on memory established a model of information processing that influenced current theories of memory and encoding (Atkinson & Shiffrin, 1968). Components of the information processing model of memory include sensory, short-term, and long-term memory.

The first stage of information processing is associated with the senses (visual, auditory, tactile, olfactory, or gustatory). Sensory memory functions to hold information in memory for a brief moment to allow for further processing. A separate sensory memory exists for each sensory input, but all are assumed to operate in a similar manner (Driscoll, 1994). Once an incoming stimulus is attended to, it is rapidly processed into short-term memory, which includes processing by iconic and echoic buffers. Iconic buffers process visual stimuli while echoic buffers process sound. While retention of both types of stimuli is very brief, incoming auditory stimuli tends to be retained longer than visual stimuli (Searlman & Herrmann, 1994).

The second stage of information processing, short-term memory, links new, incoming information with relevant aspects of existing knowledge (Bruer, 1995; Mintzes et al., 1997; Norman, 1988). Because short-term memory capacity is limited and "acts as a bottleneck" (Bruer, 1995), incoming information is either transferred into
long-term memory, or, if not rehearsed, decays rapidly and is forgotten. Time
requirements for processing information in short-term memory are estimated to be about
15-30 seconds (Searlman & Herrmann, 1994).

In order to link information in short-term memory to long-term memory,
Mintzes, Wandersee, & Novak (1997) state:

The formation of linkages requires retrieving knowledge
from long-term memory, consciously interpreting,
evaluating, comparing, and contrasting new information with
prior knowledge, and ultimately reconciling and assimilating
new information by subsumption and superordinate learning
(p. 422).

Information in long-term memory becomes activated and spreads to other related
concepts stored in the brain. As stimulated or "primed" concepts spread through a
network of related concepts, they can re-enter the short-term memory for conscious
thought and use (Driscoll, 1994; Mintzes et al., 1997; Searlman & Herrmann, 1994).
This spreading of related concepts is referred to as spreading activation and is a widely
accepted assumption among human constructivists (Searlman & Herrmann, 1994).

Implications of this memory model for meaningful learning include that, for
retention in long-term memory to occur, the structure of knowledge needs to be
organized and hierarchical in nature. Rote learning fails to achieve any degree of
organization in long-term memory and thus, is easily forgotten. Meaningful learning,
spaced learning, and rehearsal have all been shown to be effective in transferring
incoming stimuli from short-term to long-term memory where it has opportunity to
become organized (Driscoll, 1994; Mintzes et al., 1997; Searlman & Herrmann, 1994).
Mintzes, Wandersee, and Novak (1997) succinctly captures the current viewpoint about memory that parallels their learning theory:

In our view it is probable that knowledge in Long Term Memory is represented in a highly redundant network of tightly integrated, hierarchically-organized conceptual nodes, and that the semantic, iconic and echoic forms of representation are inseparably linked. Furthermore, it is most probable that brain centers storing these cognitive representations are also tightly linked to cerebral and lower centers that control and regulate affective responses. Unfortunately, to our knowledge, research in this area is progressing at a relatively slow pace (pp. 422-423).

**Dual-Coding as a Mechanism for Aiding Information Processing**

Explaining the processing of stimuli using dual-coding theory has been attempted by Paivio in his book, *Imagery and Verbal Processes*. Dual-coding theory attempts to explain cognition, comprehension, and memory for text and graphics. Paivio explains that humans process information verbally and visually. Humans possess a verbal system to process language and a visual (or nonverbal system), to process textual information. The nonverbal system is often referred to as the imagery system because its main function is to generate, analyze, and integrate images. According to dual-coding theory, people can encode information as either language-like propositions or picture-like mental representations, or, by a combination of both components. Processing stimuli with both verbal and visual processes increases comprehension and recall. A visual-verbal linkage occurs in long-term memory, resulting in visual imagery. This imagery is the effective variable in recall of concrete verbal information (Braden, 1996; Paivio, 1971). Research has shown that pictures and graphics contain information
that is not contained in text, that graphic information is easier to recall because it is encoded in *both* memory systems, not just text, and that verbal concepts are "hung on graphic pegs" (an over simplification of Paivio's conceptual-peg hypothesis, see Braden, 1996).

Dual-coding theory further assumes that information which has been dual-coded will be remembered twice as long as information singly encoded (e.g., abstract language). This relationship may be further enhanced by increasing readability, contextual effects, content familiarity (Sadoski, Goetz, & Fritz, 1993), animation (Hannafin, Hannafin, Hooper, Rieber, & Kini, 1996), and computer-based simulation (Gredler, 1992). Although the dual-coding theory is not a memory model, it has significant implications for the information-processing model of memory.

Bruer eloquently issued a call to re-think how teachers teach and how people learn in the classroom. Bruer advocates applying educational and cognitive science research findings from the past three decades to current theory to arrive at a clearer understanding of teaching and learning (Bruer, 1995). Bruer's (1993) views complement the Novak-Gowin-Ausubel philosophy of learning. Bruer states:

> In the ensuing decade there has been a steady stream of reports, recommendations, articles, and books on the deficiencies of American education. The reports tells us that to improve schools we must change curricular content, raise school standards, embrace site-based management, increase school and teacher accountability, lengthen the school year, and allow parents to choose which school their child attends. These suggestions are surely part of the reform agenda, but they do not go deep enough. None of these reform themes addresses the fundamental need to change how teachers teach and how children learn (p.1).
This research project was based on a theoretical framework formed from the works of Ausubel, Gowin, Novak, Mintzes, and Wandersee (Ausubel et al., 1978; Gowin, 1981; Mintzes et al., 1998; Mintzes et al., 1997; Novak, 1977; Novak & Gowin, 1984). The framework of human constructivism and meaningful learning guided this research proposal and acted as a referent for its research methods. Novak's contribution to science education is exemplary and will continue to influence science educators research for years to come.

**Human Constructivism**

A central theme to the emerging stance of Novak, Gowin, Mintzes, and Wandersee, is the notion that the learner's knowledge is, in part personal, idiosyncratic, and socially-negotiated. Brains organize knowledge in a hierarchical manner. The theory of knowledge construction has led to an emerging learning theory called human constructivism (Mintzes et al., 1997). The literature describes several key points of the theory of human constructivism, including: (a) learning is an active process of constructing rather than acquiring knowledge, and (b) instruction is better conceived as a process of supporting that construction rather than transmitting knowledge (Duffy & Cunningham, 1996). The conventional approach to learning includes making information available to the learner so he or she can process it. Duffy and Cunningham (1996) describe the traditional approach to learning theory as promoting the learner as a vehicle for receiving and processing information.

Traditional science teaching attempts to transmit the concepts and ideas held by the teacher that are supposed to be relatively precise and unambiguous, but at times are
actually quite vague, unconnected, and laden with facts. Carr et al. (1994) describe a traditional view of science teaching by stating many teachers “hold the view that science knowledge is unproblematic, science provides the right answers, truth in science is discovered by observing and experimenting, and choices between correct and incorrect interpretations of the world are based on common sense responses to objective data” (p.147).

Traditional science teaching is also compromised by teachers who are insecure or unfamiliar with information to-be-taught and find an uncomplicated presentation of the material to be attractive. As students receive such uncomplicated, “objective” data as information, and primarily “facts” are emphasized, learners may appear to understand the science content, but then fail to transfer their knowledge in a meaningful way or develop a deeper understanding of the relationships among the concepts they learned. According to constructivists, teachers who emphasize to-be-tested material by encouraging copying from the chalkboard, textbook, or overheads; assigning teacher-generated worksheets, using confirmatory laboratory exercises, and listing facts in a disconnected manner, place the learner at a competitive disadvantage (Tobin et al., 1994). Often traditional teaching approaches described instantiate Ausubel's definition of rote learning. Current practices in many science classrooms, across all grade levels, conform with this version of interaction between the teacher, learner, and content. This has even been pointed out as a particular weakness in medical education (Fensham, 1985; Whitman, 1990).
Concerns with traditional education as observed by the researcher include overdependence on vocabulary lists, emphasis placed on memorizing from the textbook, placing lists of terms on the board for learners to copy and memorize, and lack of faculty knowledge of science education and learning theory. A number of allied health faculty begin to teach as a result of becoming master clinicians, and are often placed in the medical classroom with few or no teaching guidelines. Allied health curricula, as do other science curricula (Ogens, 1991) often fail to motivate students to appreciate learning for the sake of becoming an expert and a life-long learner.

In addition, science education research indicates a gap between what is taught in the science classroom and what is actually learned (Yager, 1989). This became clear in a recent research project presented at the 27th Annual Conference of the Association of Schools of Allied Health Professions, November, 1994, at Richmond, VA by this researcher and Dr. James Wandersee using concept mapping to diagnose alternative conceptions. Student research subjects' conceptions of causes of asthma, its clinical signs, and treatment were examined. A group of four LSU Medical Center Cardiopulmonary Science students (two juniors and two seniors at the therapist level) and four Respiratory Care students (two technicians and two at the associate degree level) from a local community college participated in the study. All student-subjects had successfully completed college-level didactic instruction in pulmonary disease and clinical education in the care of the patient with asthma. Using concept mapping and clinical interviewing (Novak, 1984), the researchers were able to identify significant alternative conceptions in student-subject's understanding of asthma. Once the
alternative conceptions were identified, corrective instruction was provided followed with concept mapping and re-interviewing. Results of this intervention indicated most of the formerly latent misconceptions and alternative conceptions were successfully addressed, resulting in better practitioner understanding of asthma. This study received a national award in the category of curriculum and instruction.

Another in-classroom study completed by this researcher during the 1997 Spring Semester further supported Yager's statement about the gap between what is taught and what is learned. Ten senior cardiopulmonary science students were given a list of ten common lung diseases. The students were explicitly instructed to use one or two words to describe and differentiate the pathophysiology of each lung disease. The word limit was designed to encourage students to use precise, descriptive terms to describe and differentiate each disease. Instructions were repeated using a variety of explanations to insure all students clearly understood the task. Results revealed a wide variety of alternative conceptions existed about the defining characteristics of various lung diseases. This study was repeated in Spring 1998 with similar results. Because these data reflected a shocking lack of basic understanding about lung disease, medical faculty were motivated to be concerned about course instruction and teaching strategies.

Human constructivism views learning as a social endeavor where knowledge construction depends, in part, upon the context in which it is offered. This view supports the learner examining and understanding interrelated concepts, main ideas, and the larger framework from which the knowledge stems (Mintzes et al., 1998). Human constructivism has serious implications in science teaching which require teachers to
rethink traditional and pedagogical views (Carr et al., 1994). Carr et al. (1994) state that a human constructivist pedagogy is derived from the history and philosophy of science where human perception and influence of previous experiences makes science learning a human affair. Observations are enmeshed by previous experiences and beliefs about the world. Humans construct meaning from how the world is viewed and from efforts to make sense of their environment. Constructivists dispute the traditional view of a single scientific method that objectively scrutinizes a hypothesis by rejecting an incorrect or alternative hypothesis which does not agree with gathered facts or data. Human constructivism builds an argument that science is less clinical and more human; although always indexed to and tested against nature.

Newer theories of learning stemming from “what the learner already knows” and its interaction with new, incoming information, also recognize an affective component to learning that traditional learning theories ignore. Learner affect appears to influence how information, either abstract or concrete in nature, is processed. How one feels about the topic influences knowledge processing and subsequently influences which concepts develop and organize meaningfully within a cognitive structure (Carr et al., 1994; Craxton, 1991). Framing instruction with awareness of context and sensitivity to the learner’s affect may result in more effective linking of concepts and building of knowledge (Carr et al., 1994).

The focus of this research study was to examine how learners understand central concepts in the domain of cardiopulmonary physiology, specifically, the physiology of oxygen transport and utilization. Research in science education continues to examine
how learners structure and use knowledge in science-related domains such as biology, health, and the life sciences. There are ideas in cognitive science which complement Ausubel-Novak-Gowin theory including elaborations proposed by Mintzes, Wandersee, and Novak (1997).

Building upon Ausubel's "prior knowledge" hypothesis, Mintzes, Wandersee, & Novak (1997) cite a number of knowledge claims that foster understanding of the relationships between what the learner brings to the science classroom and effects of instruction on subsequent learning. These knowledge claims result from analysis of several decades of published research data (Novak & Gowin, 1984). Novak and his associates claim with there has been sufficient research done to isolate several emerging themes and knowledge claims with potential for improvement of science education. These claims have implications for this study in that they assist in interpreting collected data in order to better understand the learner's conceptual development of oxygen transport and utilization principles. An earlier version of these claims can be found in Wandersee, Mintzes, & Novak, 1994.

Claims were cited by Mintzes, Wandersee, & Novak (1997) include:

1. Learners are not blank slates or empty vessels; rather they bring with them to their formal study of science concepts, a finite but diverse set of ideas about natural objects and events; often these notions are inconsistent with explanations offered by scientists and science teachers (p. 408).
2. The alternative conceptions that students bring to formal science instruction cut across age, ability, gender, and cultural boundaries, and furthermore these ideas are often tenacious and resistant to extinction by conventional teaching strategies (p. 410).
3. Learner's prior knowledge interacts with knowledge presented in formal instruction, resulting in a diverse set of unintentional learning outcomes (p. 411).
4. Student explanations of natural phenomena often resemble theories offered by previous generations of scientists and natural philosophers (p. 411).
5. Alternative conceptions are a product of a diverse set of personal experiences including direct observation of natural objects and events, peer cultural, everyday language and the mass media, as well as teacher's explanations and instructional materials (p. 413).
6. Teachers often subscribe to the same alternative conceptions as their students (p. 413).
7. Successful science learners develop elaborate, strongly hierarchical, well-differentiated and highly integrated frameworks of related concepts as they construct meaning (p. 414).

The driving theme of this study is found in the first claim viewing the learner as entering with prior learning, which the teacher must relate to and assess for effective instruction to occur. In other words, the learner comes to class with a prior knowledge base influencing future learning. The learner's existing knowledge includes various experienced-based beliefs used by the learner to understand and filter new information. This knowledge base, in part, may stand in opposition to the reality the teacher is attempting to impart during teaching. This opposing knowledge has been labeled alternative conceptions (Hewson, 1992; Miller, 1989; Wandersee, Mintzes, & Novak, 1994).

The term alternative conception means a set of ideas about objects or events that are often at odds or inconsistent with current accepted theory or explanations offered by scientists or science teachers. Novak describes the term alternative conception as being parallel to Ausubel's learning theory. The term describes every learner's weakness in
underlying cognitive structure relevant to new subject matter. Therefore it is, intentionally, a non-pejorative term. The term also underscores that conceptual reorganization is necessary for the learner to form valid scientific conceptions. Novak's description of alternative conceptions is compatible with human constructivism and was a major underpinning for this research.

In contrast, the term prescientific conception has been suggested as a substitute for alternative conception because it too, has a less negative tone than misconception and implies that the learner will eventually understand the concepts presented by the teacher (Good, 1991). Good contends that the levels of understanding science are not distinct, but fall along a continuum (1991) and the term alternative conception does not reflect this variation.

A common term used in allied health education is misconceptions. The argument against use of this term is that a misconception is specifically a vague, imperfect, or mistaken understanding of an idea or phenomenon. Furthermore, the term implies misconceptions serve no useful cognitive functions and may have a negative influence on learner understanding. This is not the case with alternative conceptions. The term alternative conception implies the learner possesses a knowledge base that has been constructed in an attempt to understand natural phenomena and objects and can possibly augment the development of new (or even novel) scientific conceptions.

Additional terms used to represent learner's conceptual variance include naive beliefs (Caramazza, McCloskey, & Green, 1981); erroneous ideas (Fisher, 1983); personal models of reality (Champagne, Gunstone, & Klopfer, 1985); and persistent
pitfalls (Mayer, 1987). However, because alternative conception is the most widely accepted, this term was used in this study (Wandersee et al., 1994).

Substantial research on concept formation continues to occur as a part of the Alternative Conceptions Movement (ACM) (Miller, 1989). Research efforts continue to derive potentially valuable knowledge that, when interpreted for use in the science classroom, could have a profound impact in the quality and effectiveness of teaching.

ACM research divides into two distinct camps or hybrids of the two: nomothetic and ideographic studies. With a nomothetic study, a learner's knowledge or understanding is compared to current scientific theory or thinking to assess the degree of conformity or deviation. This approach, when describing differences between correct scientific thinking and what the learner is actually thinking, uses terms such as errors, erroneous beliefs, conceptual difficulties, naive theories, unfounded beliefs, and conflicting schema (Wandersee et al., 1994). A quantitative approach to nomothetic studies is customary, with use of paper-and-pencil examinations, inferential statistics, along with randomization, control, and variable manipulation.

In contrast, idiographic studies use qualitative research design to assess the learner's personal understanding of natural phenomena, events, and objects. These studies may approach a research question using an ethnographic approach to uncover patterns in thinking, identify perspectives that interfere with concept development and related cognitive difficulties. Wandersee, Mintzes, & Novak (1994) list terms used with idiographic research, such as alternative conceptions, personal models of reality, pupil's ideas, alternative frameworks, personal constructs, and multiple private versions of
science. Idiographic studies tend to use a limited number of subjects and are conducted in a natural setting where the learner may be found in order to seek a deeper, richer understanding of personal cognitive structure. These studies use qualitative research strategies such as clinical interviews, videotaping, transcript analysis, verbal analysis, protocol analysis, and fieldnotes (Wandersee et al., 1994). This research applied the principles of idiographic research while focusing on a limited number of subjects enrolled in an undergraduate program.

The knowledge claims as promoted by Mintzes and associates can serve as powerful benchmarks in the understanding of why discrepancies occur between what the learner learns and what the teacher teaches. By identifying preconceived ideas, prejudices, and misunderstandings, better teaching strategies that promote meaningful learning can be developed.

Efforts to identify the learner's alternative conceptions in the biological sciences have increased substantially in recent years. Studies concerning alternative conceptions about biological topics include cellular respiration (Songer & Mintzes, 1994), sexually transmitted diseases (Benton, Mintzes, Kendrick, & Solomon, 1994), and evolutionary theory (Trowbridge & Wandersee, 1994). These studies have implications for this study. Work performed by Songer and Mintzes (1994), in particular, parallels this research.

Songer and Mintzes (1994) were able to identify not only which alternative conceptions were interfering with learning, but also why the identified alternative conception may have been created. Songer and Mintzes' study reported a persistent, tenacious array of alternative conceptions held by beginning biology students with
regard to cellular respiration. One difficulty reported was lack of experience with thinking at the cellular level (i.e., understanding biological phenomena in terms of what occurs within the cell). The study's results indicated a need for deliberate preliminary assessment of the learner's alternative conceptions about cellular respiration and the need for instructional activities that placed emphasis on connecting new knowledge, with existing knowledge, and encouraged the learner to rethink his/her original understanding. The authors caution educators to avoid instructional practices that result in compartmentalization and rote learning when providing instruction on cellular respiration, for it is these practices that resulted in the beginning biology student developing persistent alternative conceptions that tended not to change, despite later, advanced education. The authors concluded some alternative conceptions about cellular respiration often remain intact throughout undergraduate education, despite repeated instruction with progressively more difficult material. Songer and Mintzes (1994) presented evidence that upper-level course work was unsuccessful in altering these alternative views.

Results of Songer and Mintzes' study can be applied to this research. Learners in this study had difficulty grasping some concepts associated with oxygen transport and utilization because they lacked an understanding of cellular gas exchange. This was evident with the lack of propositional knowledge demonstrated by research participants regarding cellular oxygen utilization. Emphasis of this study was directed to study participant's general understanding of cellular gas exchange as applied to oxygenation. Traditionally, principles of cellular oxygenation have not been a part of the course in
cardiopulmonary physiology which this researcher is involved. Songer and Mintzes (1994) suggests the common practice of locating instruction in cellular respiration in the first part of a biology course needs rethinking. Cellular physiology may be more appropriate following instruction about gas movement into and out of the lungs. This research provided additional data to support this recommendation.

Another related study concerning alternative conceptions in biology is Given's research with non-major biology college students and their understanding of hyperventilation (Given, 1997). Given's work illustrated how prior beliefs can counter physiologic principles by using an in-class experiment. This study looked at a learner's preconceived beliefs regarding hyperventilation and their influence on understanding the physiology of pulmonary hyperventilation. Despite instruction in pulmonary physiology and the concept of hyperventilation, more than half of the students thought hyperventilation was a result of physical exertion (i.e., exercising the body results in fatigue, thus, the person needed to increase his or her respiratory rate). Despite an in-class demonstration, learner's preconceived ideas remained resistant to change. Given was successful in correcting the identified alternative conceptions with focused debriefing.

Langer's book, *The Power of Mindful Learning*, discusses similar findings with subjects who failed to actively pursue multiple perspectives of phenomenon (Langer, 1997). Langer reports failure to view the world and events from several perspectives can result in persistent beliefs that are either counter-intuitive or oppose reality. In an earlier book, Langer proposed people often resist changing a personal belief, despite receiving
accurate data or having first hand experience (Langer, 1989). According to Langer these findings leave people compromised in expanding their understanding of life and the world (Langer, 1997).

Wandersee, Mintzes, and Novak (1994) warn not all “...alternative conceptions are tenacious. It is important to differentiate between conceptions that might require high-powered conceptual change strategies and those that are equally likely to yield to well-planned, conventional methods” (p.186).

It was necessary with this research to identify concepts related to oxygen transport and utilization that may be successfully taught in the classroom using alternative strategies such as computer simulation, concept mapping, and other metacognitive approaches. For example, this researcher found integration of pulmonary and cardiac function as a total system was more difficult for students to understand and this may have resulted from these topics being taught as separate entities. Since all of the students were a product of traditional education in biological and medical sciences, they were ill-equipped to integrate and conceptualize the larger systems involved in cardiac and pulmonary physiology.

In order to identify concepts learners that will have or are currently having difficulty understanding and which instructional strategies are needed, the teacher must have a sound sense of the prior knowledge and diverse ideas those learners bring to the classroom. Thus, preinstructional assessment, such as pretesting, evaluation using simulation software, preinstructional concept mapping, and clinical interviewing may be warranted. Once learners' understandings and beliefs (or alternative conceptions) are
identified, their subsequent modification, elaboration, or resistance to change can be monitored and addressed. However, monitoring conceptual development or change, "at present, is a speculative intellectual enterprise" (Wandersee, 1992; Wandersee et al., 1994).

Compromised learning can occur when the teacher possesses alternative conceptions or misunderstandings. If the teacher is not prepared or lacks understanding of the science and theories that make up the major ideas of the course or lesson, learners will continue to subscribe to their existing alternative conceptions and misunderstandings.

In allied health, particularly in respiratory care, the educational preparation of faculty often consists of either an associate or baccalaureate degree. As a result, faculty may lack a thorough understanding of related sciences, such as biochemistry and molecular biology. In addition, allied health faculty, specifically respiratory care faculty, often lack formal education in learning theory and classroom management skills. This results in the teacher having alternative conceptions about teaching and learning and failure to recognize the learner's alternative conceptions (Smith, 1989).

Wandersee, Mintzes, & Novak, (1994) encourage teachers to strive to understand conceptual change when teaching natural sciences. Teaching methods should not attempt to totally change the learner's views, but enable the learner's current understanding to be, “deleted, replaced, augmented, paralleled, exchanged, or refined” (p. 200). “Conceptual restructuring (or more simply put, conceptual change) lies at the heart of science teaching and learning” (p. 201). As teachers and curriculum planners
seek better understanding of how learners conceptualize and learn, a natural
collaboration and cooperation among educators may arise, resulting in the growing
awareness of the scientific community.

**Research Tools for Assessing Alternative Conceptions**

Assessing conceptual development and alternative conceptions using both
nomothetic and ideographic orientation has recently been reported (Wandersee,
Mintzes, & Arnaudin, 1989). The clinical interview is the predominant study method.
Other methods used include traditional testing formats, questionnaires, concept
mapping, open-ended tests, and questionnaires. Diagnostic tests combined with
unstructured interviews have also been suggested (Treagust, 1988) to identify alternative
conceptions. Recent studies have supported the use of prediction, observation, and
explanation (POE), concept circle diagrams (Mintzes et al., 1997), Vee diagrams
(Gowin, 1981; Novak & Gowin, 1984), and other knowledge probes for tools to assess
learning and alternative conceptions. Songer and Mintzes (1994) used concept mapping
and clinical interviews to assess degree and number of alternative conceptions in
cellular respiration. In addition, Songer and Mintzes utilized a panel of science-content
experts to identify critical propositions necessary for each research participant (student)
to possess to form accurate concepts regarding cellular respiration. This research
employed a similar panel of experts in cardiopulmonary physiology who are aware of
the learning needs of undergraduate students in cardiopulmonary science along with
other allied health and medical students (see Methods).
This research used clinical interviewing with field note analysis, verbal analysis, concept mapping (discussed later in detail), and computer simulation software. Assessment strategies focused on entry-level cognitive structure, conceptual development, and post-instructional analysis of alternative conceptions and understanding.

This research, based upon an idiographic orientation of ACM research, attempted to observe conceptual change over two semesters that included cardiopulmonary physiology and respiratory critical care. Methods included assessment of conceptual change at key points within these two course. In lieu of identifying isolated alternative concepts and misunderstandings, this research aspired to “identify propositional relationships between key concepts as they occur in vivo” (Wandersee, Mintzes, & Novak, 1994, p. 201).

In addition, critical junctures were identified. Critical junctures are defined as “conceptual watersheds” certain points in a course where learners must either possess essential knowledge based upon previously taught concepts or they will have difficulty understanding all the new information that follows (Trowbridge & Wandersee, 1994). Once identified, instructional strategies may be planned accordingly to assure progressive conceptual development (Mintzes et al., 1998). This research identified critical junctures in a cardiopulmonary physiology and respiratory critical care course.

This research did not attempt to assess general reasoning ability, however, effort was placed on identifying domain-specific knowledge and its situated applicants. Bruer (1993) identifies weak methods, including traditional learning strategies such as taking
notes, outlining, underlining, and figuring out words from context as widely applicable
skills and knowledge for learning or problem solving across a variety of domains. Weak
methods were not assessed in this study because studies have shown weak methods are
no more effective than reading and rereading the text to be learn (Anderson, 1980).

Bruer (1993) reports “research shows that either the teaching of traditional study
skills has no impact on learning or else the skills fail to transfer from the learning
context to other situations. Either way, teaching these general skills is not the path to
expertise and enhanced performance” (p.64). Bruer (1993) also states “research suggests
that domain-specific knowledge and skills are necessary for expert performance but may
not be sufficient to be responsible for expert performance. There is more to intelligent
and expert performance than domain knowledge” (p. 67). The focus of this study was on
strong methods which Bruer describes as situation-specific problem solving using
metacognitive methods.

The ACM’s research attempts, in part, is to expand understanding of the novice-
to-expert continuum as it relates to specific science domains. Another aim of ACM
efforts is the interaction of cognition and affective domains (Mintzes et al., 1997),
because evidence of a relationship between concept formation and learner's affect has
been demonstrated. In consideration of this, Gowin (1981) suggests a shift from
knowledge-centered learning to person-centered learning. Gowin states that although the
learner is responsible for learning, other influences must also be considered, such as
learner affect, teacher, curricula, and social milieu of the learning environment. In,
Educating, Gowin (1981) claims, “A powerful moment in educating occurs when
grasping meaning and feeling significance come together” (p. 43). Value of an experience is a result of felt meaning, more so than learning something for the sake of an expectation or course outcome. It is the connection between learning something and feeling its meaning that Gowin says is the basis of value in an experience (e.g., learning something new). Once the learning opportunity provides the learner with new personal meaning, there is increased motivation to reorganize understanding to eliminate alternative conceptions and align one’s understanding with current scientific thinking.

Since the purpose of this research was, in part, to add to the body of ACM research, it was necessary to address criteria established by Wandersee, Mintzes, & Novak (1994) for studying alternative conceptions. According to these science educators, doctoral research with the alternative conceptions should include researchers having at least five years teaching experiences in science (this researcher has been in health science education for fifteen years), have experience in physical or biological science research (this researcher has presented six science related abstracts, completed four major funded scientific studies using the canine model, and published a modest number of articles and chapters related to cardiopulmonary science), and have a foundation in science education involving literature search, curricula, instruction, and current topics in education, cognitive science, and both qualitative and quantitative research methods (this researcher completed a Masters in Health Sciences with emphasis on allied health education and clinical respiratory care, completed doctoral course work overseen by a committee of nationally known science educators). This researcher’s major professor places emphasis on inquiry into how people think and learn
in a scientific domain, and what constitutes scientific literacy while expecting (from the researcher) content mastery. This researcher's framework for teaching includes a background in cognitive psychology, an awareness of habits of the mind, an appreciation of idea formation, and having motivation to employ teaching strategies to aid the learner in moving from novice toward expert. As Wandersee, Mintzes, & Novak (1994) state “This kind of knowledge is not made available to those who opt to pursue more parochial training, rather than an interdisciplinary education at the graduate level. We must move beyond training science educators. We need persons who can ask good questions, not parrot past answers to old questions” (p. 202).

**Alternative Conceptions in the Health Sciences**

Cardiopulmonary Science students arrive at this researcher's classroom after completing a number of science-related courses, including human cadaver science, human physiology, physics, chemistry, and biology. It is implied that these learners possess alternative conceptions capable of impeding the development of new concepts in the health sciences, such as cardiopulmonary physiology.

An example of this relationship between previous learned information and alternative conceptions can be illustrated with the concepts of pressure, flow, and volume presented in physics and chemistry. These concepts have direct application in pulmonary and cardiovascular physiology. Pressure, flow, and volume concepts can be applied to the characteristics of gas flow in and out of the lung and blood flow within the vascular system. This researcher has observed students who begin a cardiopulmonary physiology course with poorly differentiated concepts of flow and
volume, resulting in their subsequent difficulty in understanding concepts of lung volume, gas inspiratory and expiratory flow, and so forth.

An in-class study conducted by this researcher during the Fall, 1996 semester using clinical interview techniques (Novak & Gowin, 1984) found 30% of the class being studied could not differentiate peak expiratory flow rate from a vital capacity (a volume) measurement. Study results also indicated these learners could not distinguish between the concepts of flow and volume. Until these concepts were clarified, concepts provided in subsequent course work (Advanced Techniques I & II, Pulmonary Diagnostics) may not have been understood due to resistant alternative conceptions.

The development of resistant alternative conceptions was studied by Feltovich and associates (1989) with medical students learning the concept of congestive heart failure. This study reported a widespread tendency for the development of significant errors in conceptual understanding and general maladaptive biases in the thought processes used to deal with complex concepts. Feltovich and associates found mutually reinforcing and resistant alternative conceptions prevailed, despite clinical experiences. The authors assert that faculty tend to over simplify and misrepresent the concept of heart failure to learners, resulting in a persistent number of alternative conceptions and/or misconceptions.

Conclusions of the study performed by Feltovich and associates (1989) regarding development and persistence of alternative conceptions have implications for this research. The Feltovich study illustrated important factors observed in the development of a variety of biomedical and physiologic alternative conceptions. These
factors include three variables that influence how concepts are formed and how alternative conceptions can develop. These variables include:

1. Multiplicity. Many influences contribute to the acquisition and maintenance of alternative conceptions, some of which are associated with the learner, some with the educational process, and some with the practices of biomedical science research.

2. Interdependency. Complex alternative conceptions can be represented as reciprocating networks of faulty component ideas which mutually bolster each other and, in turn, support the overall alternative conceptions.

3. Oversimplification. Oversimplification of complex biomedical phenomena and concepts appears to be a major force in the acquisition and maintenance of alternative conceptions (p. 114). This is further supported by work with medical students and the concept of congestive heart failure done by Patel and her group (Patel, Evans, & Kaufman, 1990).

**Stage Theory of Expertise**

Within the problem-solving and medical reasoning literature, a domain of perceptual cognitive science differentiates a learner as an expert, novice, intelligent novice (Bruer, 1995), or intermediate (Patel et al., 1990; Patel & Groen, 1991).
Novice learners have been described as learners with no self-taught knowledge or no training (formal or informal) in a specific domain or area of interest (Benner, 1982; Patel & Groen, 1991). Novices are unable to use discretionary judgement and need to follow rules to guide performance and decision making. Novices can develop into expert learners through several stages which includes moving from following rules and textbook explanations to seeing patterns, setting goals, and developing proficiency in performing a particular task or series of tasks while modifying plans and responses as needed. A novice becomes an expert learner when he or she no longer relies on rules and guidelines, but through experience develops an intuitive grasp of the situation to enable problem solving (Benner, 1982; Patel & Groen, 1991).

Sternberg and Horvath (1995) describe experts as differing from novices in that:

Experts bring knowledge to bear more effectively on problems within their domain of expertise than do novices. The second difference pertains to efficiency of problem solving. Experts do more in less time (in their domain of expertise) then do novices. The third difference pertains to insight. Experts are more likely to arrive at novel and appropriate solutions to problems (within their domains) than novices (p.10).

Simon and colleagues, as cited in Patel & Groen (1991), describes an expert as having efficient ways of retrieving information from memory to solve a given problem. Long-term memory contains a set of production rules (See Bruer, 1993) that dictate performance across a wide variety of domain-specific situations. An expert has an elaborate set of production rules, uses strong methods in lieu of weak ones, and uses forward reasoning to proceed from facts to a solution (in contrast to a novice who uses
backward reasoning, proceeding from hypothesis to fact). Biller's (1993) description of strong methods includes the use of heuristic methods that limit the amount of search or information necessary to solve a problem.

Processing critical cues during clinical problem solving appears to be a key difference between novice and expert. Results of a study comparing physicians and medical students revealed physicians recognized patterns of familiar problems by using critical cues, and students did not (Coughlin & Vilma, 1987).

The typical learner or novice arrives in the science classroom with both related and unrelated prerequisite knowledge to learn from a teacher who is considered an "expert" in the subject to be learned (Bruer, 1995; Carmichael et al., 1990). Differences between an expert and a novice lie in the coherence and complexity of their cognitive structure and understanding (Carmichael et al., 1990). Novices attempt to understand new information using naive beliefs or shallow understandings that are often "general, holistic, and disjointed, coherent, and confused, logical and illogical, speculative and experience-based" (Carmichael et al., 1990, p. 1). The novice is unable to rely upon a strong knowledge base or a strong set of production rules to seek solutions to problems.

Bruer (1993) describes another distinct group of learners, the intelligent novices. Bruer defines an intelligent novice as a person capable of learning new information or ideas more expertly than most, regardless of the amount of domain-specific knowledge possessed. Bruer takes issue with an earlier view of cognition contending general learning skills and reasoning abilities are at the center of human learning and problem solving. In contrast, Bruer (1993) states, "cognitive research suggested that general
domain-independent skills couldn't adequately account for human expertise.

Researchers then began to think that the key to intelligence in a domain was extensive experience with and knowledge about that domain. Expertise was domain specific” (p. 52).

Bruer (1994) further describes intelligent novices as learners who use a variety of general independent skills that enhance learning in a variety of situations, thus implying expert performance is based on more than domain-specific knowledge. This deviation from recent thinking, that expert performance is domain-specific is, referred to as the Theory of New Synthesis (Perkins & Salomon, 1989). The Theory of New Synthesis encourages the use of domain-specific skills combined with general learning skills. This theory also implies that, in addition to focusing on subject matter, teachers should focus on methods to inspire and assist the learner to move from either novice or intelligent novice towards expert.

Patel and Groen (1991) propose an additional term within the novice-expert continuum, the intermediate. As defined by Patel and Groen, an intermediate is an individual with a knowledge level between novice and expert. An intermediate learner possesses basic science knowledge but has limited clinical experience, in contrast to expert learners with both basic science knowledge and substantial clinical experience. The former learner fails to recognize patterns and relationships, and misuses gathered information. The intermediate learner poorly identifies patterns and uses available information selectively in generating solutions (Patel, Groen, & Scott, 1988). According to Patel and Groen (1991), the intermediate learner will have learned aspects of the
study domain after completing course work, self-study, and other intellectual endeavors, whereas the novice will have had limited course work and no related experience.

Patel and Groen identifies a subgroup of intermediates as subexperts. Subexperts are learners having expertise in a closely related domain. The authors cite a series of experiments examining clinical problem-solving skills of newly board-certified medical specialists when dealing with clinical problems falling within and outside their domains of expertise. Research subjects were asked to make a diagnosis from a provided case history. Researchers found that if the problem fell within the speciality area of study subjects, forward reasoning was utilized to arrive at a correct diagnosis, but inappropriate problem-solving skills were used with clinical situations falling outside their domain of expertise, resulting in erroneous medical diagnoses. However, accuracy of recall of clinical knowledge and collected medical patient data was similar to subjects making accurate diagnosis. Patel and Groen conclude, “This led us to make a distinction between generic expertise, which is what is involved in comprehending the description of a clinical case, and specific expertise, which is required to generate an accurate diagnosis. Intermediates at lower levels may, of course, lack both” (p. 159). This study provides support to Bruer's (1993) recommendation for combining general learning skills with domain-specific skills.

Another study by Patel and Groen (1991) compared verbal protocols of seven “expert” cardiologists to a standard textbook diagnostic approach in a clinical situation involving bacterial endocarditis. Using protocol analysis and probing for propositional knowledge of related concepts, the researchers focused on processes used by the expert
physicians in generating a diagnostic explanation. Both physician groups demonstrated use of standard schema established in medical school course work, however results revealed physicians making accurate diagnoses used forward reasoning; conversely those with inaccurate diagnoses used backward reasoning. The researchers concluded that when a physician is unsure of a diagnosis (such as intermediate learners are), he or she will begin to problem solve by testing a hypothesis and working backward, a top-down type of processing, whereas the physician with an accurate diagnosis, will have first gathered facts to arrive at a diagnosis (Patel & Groen, 1986). These data support similar research findings concerning the distinction between intermediates and expert learners (Benner, 1982; Bruer, 1995; Caramazza et al., 1981; Glover et al., 1990; Patel et al., 1990; Patel & Groen, 1991).

Learning is assumed to accelerate as a learner gains increased experience in a specific learning domain, however Patel and Groen (1991) propose that intermediates undergo a unique developmental phenomenon that results in a reduced level of learning as the intermediate progresses to expert. This unanticipated decrease in learning found in intermediates is referred to as the intermediate effect or non-monotonicity, and is exemplified by a U-shaped learning curve (Strauss & Stavy, 1982). A series of studies examining the clinical problem-solving skills of medical students (representing the novice learner), residents (the intermediate learner), and physicians (the expert) produced results illustrating the intermediate effect. These studies compared the problem-solving processes used by medical students, residents, and senior physicians to arrive at a medical diagnosis. A full spectrum of clinical resources was available to each
study group (laboratory tests, physical exams, patient interviews, and other diagnostic tests) to obtain data to utilize for problem solving. Study results indicated that as level of expertise increased, so did diagnostic accuracy. The intermediates were able to recall the most clinical data to utilize for problem solving. However, if intermediates were evaluated within context, their performance was no better than the novice. Intermediates tend to overuse clinical resources and diagnostic tests to arrive at a higher number of differential diagnoses. In other words, the medical residents relied on a higher number of medical tests, data, and measurements to arrive at a diagnosis than did the novice medical student or senior physician. This “extra” information was actually considered irrelevant and unnecessary, thus an overuse of clinical resources. Additional information made available from extraneous tests was not necessary to make an accurate diagnosis and resulted in excess cost and additional discomfort to the patient (Arocha & Patel, 1991; Patel, Evans, & Kaufman, 1989; Patel et al., 1990; Patel & Groen, 1986; Patel & Groen, 1990; Trottier & Patel, 1986).

Patel and Groen (1991) advocate cautious application of stage theory in medicine and adult cognition because, despite empirical evidence from other disciplines, the medical sciences lack strong evidence for the existence of staged learning. Research in other domains such as chess and physics provides more substantial evidence of learning stage development. Context is important, it appears.

This research anticipated adding to the research base of the intermediate’s problem-solving and reasoning skills within the cardiopulmonary science domain involving oxygen transport and utilization in both normal and abnormal physiologic
states. Assumptions made by the researcher that new students entering the junior year of the Cardiopulmonary Science Program are novice learners, and senior students, who have completed one year of course work and clinical instruction in respiratory care, were intermediate learners.

Clinical Reasoning

Clinical reasoning in a medical situation is somewhat similar to reasoning by other experts in other domains and disciplines. As a frame of reference for comparing how novice and intermediates reason, a brief summary of the process undertaken by medical experts (e.g., physicians) during clinical reasoning (Coulson, 1983) will be presented.

According to Coulson (1983), to determine a medical diagnosis the expert physician begins the process of clinical reasoning, or problem solving, as he:

- confronts the patient, perceives cues from the environment and the subject, and assembles an initial mental formulation of the problem. Very rapidly multiple hypotheses are generated as possible explanations of the problem. An inquiry strategy is engaged which involves, among other things, the use of clinical skills to acquire data which may be used to refine the initial problem formulation. The refined problem formulation is then compared to the hypothesis generated. This hypothesis is retained, discarded, or enlarged. Further inquiry is pursued until a particular hypothesis attains sufficient confidence to form the basis of management decisions (p. 220).

Conceptual Development in Cardiopulmonary Science

A cardiopulmonary science practitioner (CPSP) must possess sound understanding of cardiopulmonary physiology in order to care for patients with pulmonary and/or cardiac disease. In addition to understanding cardiopulmonary
physiology, the CPSP must be capable of applying this information in a variety of clinical settings. Physiological measurements and information obtained by the CPSP must be integrated, and not used as isolated facts, or, taken out of context. The educational experiences the cardiopulmonary science student undergoes should prepare him or her to integrate course work in cardiopulmonary science with clinical reasoning. To reach this outcome, the teacher must be aware of the typical novice alternative conceptions.

Although the nature of the novice is to have alternative conceptions in science, perhaps classroom strategies can be altered or changed to aid the learner in avoiding conceptual pitfalls previous learners encountered. These conceptual difficulties first need to be identified, then addressed. Once alternative conceptions are identified, the medical educator can obtain a clearer idea about the learner's scientific knowledge in the topic. After obtaining a keen awareness of student alternative conceptions, the teacher may then be inclined to remedy the problem by developing and/or utilizing conceptual change teaching strategies involving metacognition or computer simulation to address them. This research attempted to identify salient alternative conceptions in novice students prior to formal instruction in cardiopulmonary physiology.

**Conceptual Change**

Mintzes, Wandersee, and Novak (1997) summarized twenty-five years of work and 3,500 ACM studies on learners' concept formation in the sciences. They state “most learners who fail to understand key concepts found in, for example, a lesson or course results from difficulties encountered in attempting to construct meaning” (p. 414). They
add that failure to form accurate concepts occurs across all races, ages, abilities, and genders. Furthering a central issue in science education is to determine how to effect lasting change in the way that learners build their knowledge and understand concepts. Eloquently, these authors state, “the research community has spent many years ascertaining “what the learner already knows; the time has come to focus attention on how to teach him accordingly” (p. 414). Mintzes, Wandersee, and Novak (1997) suggest there is now sufficient research data available to identify additional knowledge claims to guide future research in how conceptual change occurs in science learning. Such claims include:

1. Successful science learners develop elaborate, strongly hierarchical, well-differentiated and highly integrated frameworks of related concept as they construct meaning.

2. The ability to reason well in the natural sciences is constrained largely by the structure of domain-specific knowledge in the discipline.

3. Conceptual change requires a restructuring of the knowledge framework, and this, in turn, results from the making and breaking of connections between concepts, and sometimes the replacement or substitution of one concept for another.

4. Successful learners in the natural sciences habitually employ strategies that enable them to plan, monitor, control and regulate their own learning (p. 414). (See also Bruer, 1993, Carr, 1984, Driscoll, 1994, Duffy & Cunningham, 1996, and Gowin, 1981.)
This research focused on conceptual change and helping undergraduates learn medical science. To achieve the knowledge claims listed above, this researcher employed methods to assess the effects that non-traditional approaches (involving computer simulation) to classroom instruction have on conceptual development and problem solving.

Both generic and novel human constructivist-type strategies were used in this science education research. These strategies used in this research (see Methods) they are discussed here.

**How Does One Construct Personal Knowledge?**

The literature is rich in research studies supporting several heuristic devices designed to encourage learners to construct meaning, make connections, and learn meaningfully. These include devices such as the concept map (Beissner, 1992; Novak, 1990; Wissing, 1994), Vee diagram (Gowin, 1981; Novak, 1977; Novak & Gowin, 1984; Wissing, 1994; Wissing, 1995), Concept circle diagram (Wandersee, 1987), concept web (Mintzes et al., 1997), simulation software (Collet & Shiffler, 1985; Gredler, 1992; Kang, 1996; Keegan, 1995; Krahn & Blanchaer, 1986a; Lavoie & Good, 1988), and semantic network (Fisher, 1990). This discussion will be limited to concept maps, Gowin's Vee diagrams, and computer simulations, as applied to this research.

**A Traditional View of Science Learning**

Traditional science teaching has included use of both precise and ambiguous language and ideas, overemphasis of facts, and presentation of one-dimensional ideas. Transmission of these ideas and statements from expert (teacher) to novice (learner)
expects that both will share the expert's meaning and thus reception learning is often the
mode of learning found in science classrooms today. This model implies the teacher is
active and the learner passive, and it is one of several science teaching strategies that
results in reduced cognitive demands.

Science course material is often emphasized verbatim at a lower cognitive level,
with limited effort to make connections between related concepts or statements. Small-
group classroom strategies, where learners copy work from one another, experience
open-book tests, complete worksheets with key-based answers, and perform
assignments which de-emphasize conceptual development and, instead, promote rote
memorization. Whole-class activities such as the lecture, group discussion, oral
textbook reading, and the teacher's continual reference to subject-material-to-be-tested
tend to minimize cognitive demands (Tobin et al., 1994). Teachers may have students
summarize segments of text, complete end-of-chapter questions, or encourage
memorization of facts in an effort to promote "success" on tests. Textbooks often follow
a passive/transmissive format that includes vocabulary-driven text with an over
abundance of facts, limited elaboration, and poor development of higher-order cognition
skills. These approaches discourage cognitive development of complex scientific
concepts and the connection of new material to existing knowledge.

College course work is traditionally partitioned to fit into a predetermined
number of weeks. The focus of the implemented curriculum tends to be to "cover"
planned content rather than insuring that learners develop an adequate level of
understanding (Tobin et al., 1994). A wide breadth of material is usually addressed by a
traditional approach with the consequence of limited teacher-probing to determine if learners understand key concepts in class. A further limitation to effective development of higher-order cognition is the tendency to present new material in class without relating the new material to the learner’s frame of reference in the real world. As learners fail to make important connections (at critical junctures) between course and world, their attitudes toward learning are frequently impaired by the resultant lack of interest.

Studies demonstrate most course material memorized by the learner for examinations is forgotten or not subject to recall within a short time after instruction (Miller, 1967; Miller, 1978). Realizing undergraduates tend to rely heavily upon memorization when faced with a large amount of information, re-thinking how and what we teach in cardiopulmonary physiology and advanced respiratory care was a dominant theme in this research. Traditional teaching strategies can discourage active integration and processing by learners and thus promote a passive role for learning. As research on emerging teaching strategies surfaces, science educators can begin to promote more meaningful learning and conceptualization.

**Use of Heuristics**

Heuristics can aid the learner in learning and conceptualizing science (Novak, 1984, 1990). Heuristics such as concept mapping and computer-based simulations can be thinking tools to improve learning by encouraging learners to process information by explicitly linking new information with the learner’s existing knowledge and world view, in an attempt to make sense of the new information. Heuristics also encourage
considering multiple explanations of phenomena and analyzing relationships among complex ideas and theories.

New trends in science education encourage development of metacognitive strategies to inspire students to undertake an informed, self-directed approach to recognition, evaluation, and reconstruction of existing ideas and beliefs (Gunstone, 1994). These metacognitive strategies include concept mapping and Gowin's Vee diagraming.

Concept mapping is a knowledge-construction tool designed to help learner's organize concepts into a meaningful spatial representation (Jegede, Alaiyemola, & Okebukola, 1990; Mintzes et al., 1997). Concept maps are schematic devices for representing a set of concept meanings imbedded in a framework of propositions (Novak & Gowin, 1984). Concept maps represent hierarchical connected concepts based on Ausubel's theory of meaningful learning. A concept map is a two-dimensional branching, visual device that begins with superordinate concepts, and concludes with subordinate concepts and examples. Key concepts are linked together as propositions; verbs and adjectives and form the links. These propositions, involving sets of more concepts, when verbally and spatially linked together, form a concept map. The map represents the mapmaker's conceptual framework. A result of concept mapping, as reported by Novak and Gowin (1984), is that both the teacher and the learner find new relationships and hence new meanings in concepts. Mapping may be used to allow learners to understand the "whole" topic the teacher is attempting to relate, especially if the map is coconstructed by learner and teacher (Wandersee & Abrams, 1994). In
addition, Jegede, Alaiyemola, and Okebukola, (1990) report that concept mapping can reduce the learner's anxiety and perceptions of concept difficulty in science courses.

Evaluating learner generated concept maps can reveal how well (scientifically) the learner conceptualizes a topic or concept. Mintzes, Wandersee, and Novak (1997) explain that evaluation of maps can be done by:

...noting the number and quality of scientifically-acceptable propositions; the number and insightful cross-link connections; the number and appropriateness of the map's hierarchal nature; the extent of branching within the map; precision of the linking words used in generating propositions; the number and quality of novel examples, and the aptness and choice of the superordinate concept” (p. 425).

In addition, by using Novak and Gowin's (1984) scoring guidelines, the teacher can compare the frequencies of salient features in a series of maps over time, and, thus provide a measurement of conceptual change. Mintzes, Wandersee, and Novak (1997) caution that a learner generated concept map represents 50% or less of the total learner's understanding of a topic. Wandersee (1990) points out that a completed concept map is a “snapshot” of the learner's partial understanding at the time the map is completed, realizing conceptual development is an ongoing, differentiating process that is difficult to depict in a final form. A complete assessment of the total meaning held by the learner for any given concept is impossible to make, regardless of the evaluative tool or research approach.

Over 150 studies have been published on using concept mapping as a tool for teaching and learning. These studies cross age groups, gender, and a variety of disciplines. Mintzes, Wandersee, and Novak (1997) provide a summary of these studies
and reach guarded conclusions about the use of concept mapping. They conclude concept maps:

1. may be a source of meaningful learning for learners;
2. appear to enhance integration and retention of knowledge;
3. may increase recall and reading comprehension;
4. may improve test scores;
5. may improve understanding of conceptual relations and patterns;
6. may increase classroom participation;
7. may improve learner perception of course topics;
8. may stimulate critical reading and change students' metaphors of reading;
9. may help learners become more strategic in developing their own understanding; and knowledge base; and
10. may lead to student-centered, active participation in class.

Construction of concept maps is a dynamic, interactive, and challenging process that results in focusing on concepts and developing of linkages between concepts (Starr & Krajcik, 1990). As mapping occurs, conceptual change may take place. Concept mapping has been recommended for use in science, literature (Moreira, 1985), chemistry, (Novak, Gowin, & Johansen, 1983) social studies (Wease, 1986), medical curricula, (Edmondson, 1995) and reading, (Gold, 1984). Another graphic heuristic device aiding learning is the Gowin's learning Vee diagram.
**Gowin's Vee Diagrams**

In 1981, Gowin reported the use of Vee diagraming as a tool to improve science laboratory instruction (Wandersee, 1990). A Vee diagram is a graphic device in the form of a large “V” (see Appendix A) divided into two sides and a center. The left side harbors the epistemological information that describes the theoretical view of an event under scrutiny. The right side is methodological in nature, describing how it is to be done. Both sides support a central question the investigator is attempting to answer. Vee diagrams can assist in forming new knowledge by making explicit the linkages between the theoretical underpinnings of a question and the practical aspects being used to solve the question. It depicts the process of knowledge construction.

Constructing a Vee diagram helps the student grasp the meaning of laboratory work and helps the student “know how we know” in science. Teacher and learner can construct the diagram together to better understand the nature of knowledge and research, in a complementary fashion.

**Authentic Teaching**

Coconstruction of concept maps and Vee diagrams meet five standards of authentic teaching suggested by Newman and Wehlage (1993). According to these authors authentic teaching requires: (a) an emphasis on higher-order learning, (b) stress on in-depth knowledge, (c) subject matter closely connected to questions of the human condition, (d) inquisition, focus and coherence, and (e) learners and teachers share mutual respect and demonstrate strong effort and performance (Newman & Wehlage, 1993). As the teacher and learners negotiate the learning environment using heuristic
devices, such as concept mapping or Gowin's Vee, the five standards of authentic learning may be realized, resulting in improvement in conceptualization and attitudes towards learning.

This researcher reported support for using heuristics in a small-scale study using Vee diagraming with allied health students. During the 1995 Spring Semester, students enrolled in the Cardiopulmonary Science Program at LSU Medical Center, Shreveport, Louisiana and in the Respiratory Care Program at Bossier Parish Community College, Bossier City, Louisiana were studied (Wissing, 1995). Using qualitative methods, this study revealed allied health students placed value on the role of the Vee in learning difficult concepts and praised the Vee as an effective learning tool that should be a part of course work in several of the professional courses, especially in revealing the basis of our knowledge.

Concept mapping and Vee diagrams may be applicable in allied health education to assist with reaching the goal of providing opportunity for meaningful learning. As allied health disciplines continue to grow and emphasize critical thinking, use of higher order learning aids, such as concept mapping and Vee diagraming may result in better teaching and effective learning.

Before discussing use of computer simulations as a heuristic, a review of research findings on new, emerging technologies, and theoretical considerations of educational gaming and simulations will be presented. This will be followed with a discussion of computer simulations in the classroom, with a literature review supporting their use.
A Brief Review of Research on Emerging Technologies

The launching of Sputnik, an unmanned Soviet satellite, in 1957, resulted in a significant shift in the nation's interest in education, specifically science and technology education. Major reform in education resulted in a national change in philosophy of schooling that moved from a position of mass education available to most students to a view of education for all. Since the 1950s, education has evolved to meet the needs of a changing society, a global economy, an explosion of scientific information, a longer living populace with adult learning needs, and rapid growth in computer and communications technology sector.

Computer-based instruction and related terms began to appear in the literature in the early 1960s during a period in which educators and scientists were using large, non-user-friendly mainframe computers to conduct research. During the 1960s, the computer was recognized as a potential tool for education, but the high cost and inaccessibility prevented widespread computer applications for educational use.

The mid-1980s witnessed public schools and universities beginning to use computers in education on a wide scale basis with the introduction of the microcomputer and declining computer technology costs. Although computers were first used in education for low-level activities, such as simple drill and practice, tutorials, and limited simulations, educators began to appreciate computer-based instruction in the classroom. By the late 1980s, computer technology began to have a significant influence in education and learning. Public awareness of technology and educator's effort to secure additional computer applications spread the costs and, by the 1990s, improved
technical design provided powerful microcomputers, digitalized voice and video, high fidelity software, authoring software, and sophisticated free-inquiry-based simulations.

Instructional computing can be divided into at least four application categories. The first is drill-and-practice, which provides the user with a series of factual questions responded to, offers feedback, and offers a summative evaluation of effort. The second type of application includes tutorial programs which present the user with material and ask related questions about the material. The user’s response dictates how the tutorial software responds in directing the user to other relevant aspects in the program. The third category is problem-solving software. Specific problems are presented to the learner and answers or calculations are sought with feedback on errors and correct answers. And a fourth category is simulation and gaming software, programs that allow the user to work with a simulated reality, sometimes in game-format. The last format was a focus of this research.

**Computer-Based Instruction**

Computers have revolutionized the representation and manipulation of information by becoming an extension of the human senses and intuition (Molar, 1997). Research has shown human intuition increases with use of computer models, simulations, and other symbolic representations of information. Computers have been found to facilitate the evolution of scientific abstractions to concrete laws and experiences for the learner (DiSessa, 1986). Computer use has resulted in educators and scientists reevaluating management of complex information and preventing information overload. Use of new symbol systems, visualization techniques, and virtual reality have
led to a new level of perception and understanding. As a result of developments in computer technology, a host of related issues have become evident including the question as to what role computers should have in education.

Computer-based instruction can also be described on the basis of the learner's association with the computer, rather than the software or program characteristics. Computer-based technology can present information, allow the user to manipulate the information, and provide immediate learner feedback. Computer-based technology has been shown to increase user motivation, by providing features such as immediate feedback, animation, sound, active interaction, and individualization (Yang & Chin, 1996). As a result of the growing appreciation of what computers are capable of providing in the classroom, teachers have a new attitude toward technology-based education, as demonstrated by the blossoming use of computer-based technology at all levels of formal education.

Meta-Analysis and Computer Technology

Meta-analysis is a statistical process which aims to answer global questions that individual studies are often unable to answer. With meta-analysis, multiple studies are pooled in an effort to draw inferences about a collection of research data (Hannafin et al., 1996).

Early research (prior to the microcomputer), performed to evaluate the use of computers in education, focused on computer formats such as tutorials, simulations, and drill-practice used primarily in elementary school mathematics. Meta-analysis of related studies revealed computer use improved computational and other mathematical
skills. Research data from the 1980s related to computer use in education indicated an additional emphasis was placed on the use of microcomputers and computer-assisted instruction. As cited in Hannafin et al. (1996), meta-analysis by Kulik and associates and other researchers such as Clark, found contradictory results in terms of overall educational effectiveness of computer technology during the 1980s. Limited evidence surfaced suggesting computers afforded an advantage over other methods of instruction. Research performed at that time focused on the use of computers as a communications medium, not their effectiveness in learning. Research interests moved away from questioning “if” computers are effective to how to best utilize computers to redefine, support, or complement teaching and/or learning (Hannafin et al., 1996). This change in research focus resulted in a shift from using computers as an adjunct to conventional instruction methods, to that of unleashing a completely new paradigm of electronic media and data processing as teaching strategies.

Hannafin et al. (1996) describes results about computer instruction that included accessibility to lesson content and how complex information is integrated and presented. A continuum for degree of difficulty of cognitive demand exists with the methods computers utilize to present instructional material. High cognitive demand methods include decision-making applications such as hypermedia learning environments, simulations, and laser disk.

Although computer programs can provide an opportunity for learners to interact and receive computer feedback, the degree of feedback available from effective human teachers is lacking from the computer learning environment. To counter this lack of
human feedback, computer programs can “establish expectancies for, and perspectives on, forthcoming lesson content” (Hannafin, 1996, p. 381). Having the computer provide learning cues concerning what is expected can aid the learner by helping to link existing knowledge with new knowledge and information.

Precomputer instructional activities can be grouped into two primary formats. The first format is the behaviorist orientation which provides precise statements about anticipated learning outcomes and behaviors following instruction. The second format uses an advance organizer which is more abstract and general than the knowledge to follow and assists the learner to better integrate incoming information with existing cognitive structures as promoted by Ausubel (1978).

A major aspect of behaviorist theory is the use of behavioral objectives for structuring instructional material. The basis of task analysis and programmed instruction is to provide a framework of statements outlining intended observable behaviors for the learner to demonstrate following a particular lesson. Behaviorists promote use of behavioral objectives in measurable or observable terms. Traditional behaviorists such as Bloom, Mager, and Glaser have promoted use of behavioral objectives, not based on cognitive learning theory, but on behavioral learning theory (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956; Glaser, 1962; Mager, 1962). These and other researchers in the 1950s to 1970s established a rationale for the use of behavioral objectives. This rationale included assisting with learner evaluation, designing instructional sequences, and communicating expectations for learning. While still popular with older teachers, research has provided limited support for the use and
effectiveness of behavioral objectives (Kibler, Cegala, Miles, & Barker, 1974). Hannanfin et al. (1996) suggest that explicitly stated behavioral outcomes are fact-oriented and often limit the learner’s ability to use new information in situations dissimilar to the original learning experience. In contrast, they state, advance organizers “tend to stimulate higher-level learning” (p.318) to encourage learning of more than facts.

While behavioral objectives and advance organizers are widely used in text-oriented media, how to best orient learners to a computer environment has evoked new concerns for instructional planners. The term, “disorientation” or “lost in hyperspace” has been coined to describe an aimless interaction with the computer program, during which the learner is unable to determine where he is in the computer program or what to do next. The learner may remain disoriented if insufficient or misleading instructions are provided. Before the learner encounters a hypermedia or other computer-based program, adequate preparation and orientation are necessary (Edwards & Hardman, 1989).

**Computer-Based Technology**

Computer-based technology has become a mainstay in the health science classroom. Computer presentation formats such as drill-and-practice, tutorials, games, simulations, interactive laser and video disk programs, hypermedia programs, and authoring software applications are becoming widely used. Benefits of instructional technology are found by providing multisensory delivery, and enhancing active learning, communication skills, self-paced learning, and motivation (Hardin & Reise, 1997).
However, the critical issue in instructional computing lies in the creative application of instructional theory and computer-based program design to meet the learning needs of the learner.

Because computers provide instructional material within a technological setting, the teacher needs to evaluate both the instructional content and the technological medium. Evaluation of the program may involve alpha and beta testing, formative evaluation, small-group field testing, and finally a summative evaluation by the developers. Evaluation of the computer-based product is essential to determine if the material is having the desired instructional impact on the learner, and if the learning experience meets learning goals. Only an informed teacher, aware of issues related to learning technology and the limitations of the computer-based products will be able to prudently select an appropriate product or format. The following sections outline several considerations on emerging technology that provide a literature-derived framework for the informed teacher to use in evaluation of computer-based programs or products.

Most teachers agree delivery of instruction via a variety of formats, such as graphics, sounds, and text, is likely to improve encoding and retention of learned material. In addition, use of computer-related technology providing rich, interactive environments is widely accepted as more effective than traditional teaching methods (Clark, 1985). However, Hannafin et al. (1996) caution that research on cognitive resources allocation has shown that more is not always better when presenting various stimuli. Individuals possess limited ability to process information, especially that presented simultaneously via multiple channels (e.g., aural and visual). Typically, one
channel is largely ignored by the learner since the message causes undue competition for, and overload, of cognitive resources. In contrast, other theorists have explored information processing and mental coding claims such as Paivio's dual-coding theory.

Using Paivio's Dual-Coding Theory (Paivio, 1979), multimodal presentations may be effective in presenting multimedia instruction. Paivio states learning may be enhanced if information is encoded via multiple channels. Learners do possess several channels to receive stimuli. Stimuli may be encoded either visually or verbally. Paivio suggests that enhanced processing of stimuli occurs when both channels are use for encoding. Paivio's work has shown that retrieval of learned material increases when stimuli are presented and processed both visually and verbally.

Use of illustrations in the introduction of the new material serve three functions within multimedia presentations. First, illustrations permit the introduction and clarification of important concepts, along with how they are related to the to-be-learned material. Second, illustrations enhance recall of learned material; and third, studies indicate illustrations and other visuals help learners integrate lesson content during computer-based instruction (Hannafin et al., 1996).

Hannifin et al. (1996) cited several studies on animation and learning, concluding that animation along with oral presentation methods supported dual-coding theory. A physics simulation was cited that resulted in enhanced learning by providing visual feedback from animation of problems associated with Newtonian physics. As learners manipulated variables, an immediate response was provided with animation, which in turn provided learner feedback. Other studies concluded that animation
enhanced learning and increased attention and reinforcement of content as compared to static visuals (Rieber, 1992). However, limited benefits with animation may occur with novice learners when they lack sufficient entry-level knowledge to understand moderately complex animated material.

Rieber (as cited in Anglin, Towers, & Levie, 1996) reported a summary of 13 empirical studies on the role of animation in computer-based instruction and made note of the following considerations for animation when used with computer-based programs (Anglin, Towers, & Levie, 1996; Rieber, 1990):

1. Animation should only be employed when it supports or augments the intent of the learning material.
2. Novices may not be alert to relevant cues in the simulation and thus fail to benefit from their use.
3. Interactive animations have the greatest potential for learning.

Others have recommended animation can be useful as visual guides by providing visualization of structures and movement normally not seen and also aid the learner in viewing abstract concepts and relationships (Park & Hopkins, 1993).

Fidelity describes the extent to which the computer-based program approximates the form and function of the stimuli it represents (Gredler, 1992; Hannafin et al., 1996). Debate occurs regarding effectiveness of high versus low fidelity computer-based instruction. Hannafin et al. (1996) suggest studies seem to support novices doing better with low fidelity programs, due to the limited number of stimuli that must be attended by the learner. High-fidelity instruction may tax memory and create a high cognitive
demand on the user, reducing the overall effectiveness of the program. It may be shown,
especially in this study, that effectiveness of high-fidelity instruction depends on the
degree of the learner’s preparation or understanding of the material prior to use of the
simulation software. In other words, the effectiveness of a high fidelity simulation is
determined by the level of existing knowledge of the learner (Hannafin et al., 1996).

Although research on human interaction with the computer screen, ergonomics,
and optimal design for text processing has yet to reach stable conclusions, Aspillaga (as
cited in Hannifin, et al., 1996) suggests placement of images, text boxes, and other
graphic devices in a manner consistent with their intended use and organization.
Aspillaga concluded that organized, consistently placed of screen visuals and images
were better processed than randomly placed visuals, and that learning is influenced
positively by consistent use of screen space and visual orientation. Grabinger suggests
that computer software developers should divide the screen into consistent placed
functional areas; use organizing techniques to design the structure of the screen; and
provide an interesting, but not overly complex, total screen. Grabinger’s suggestions (as
cited in Hanninfin et al., 1996) have implications for this study, due to the nature of the
cardiopulmonary simulation software being studied.

In related work, Bly and Rosenberg (1986) evaluated the effects of tiled versus
overlapped windows. They found tiled windows (although smaller) and not overlapping
were more effective for novices, and overlapping windows were more efficient for
expert or experienced users. Overlapping windows required additional screen
manipulation and an increase in the user’s cognitive load (Bly & Rosenberg, 1986). The
cardiopulmonary simulation software used in this research allowed either option for the operator. During simulation work novice student-participant utilized the tiled screen whereas the intermediate student-participant worked with the overlapping windows.

When learners recognize errors in their performance and receive feedback concerning the cause of the error or its consequence, better understanding and conceptualization of the material can occur (Allen, Lipson, & Fisher, 1989). The nature of feedback is a key issue influencing the learner's willingness to receive and benefit from feedback. Feedback may be ineffective if only acknowledgment of a correct response is given. Effectiveness increases if feedback contains a degree of elaboration, (Hannafin et al., 1996). The type of feedback the learner receives while engaging a computer-based program or learning session influences the quality on learning.

Two general types of feedback are provided during or following computer based instruction, and have been shown to improve learning: verification and elaboration. Verification feedback provides the learner with an assessment of the accuracy of his response. Elaboration feedback refers to additional information made available to the learner. A study of undergraduates using computer-based instruction revealed higher examination scores following receipt of the correct response coupled with a brief explanation concerning the correct answer, compared to simply finding out if a response was correct or incorrect (Pridemore & Klein, 1991).

Feedback provided during and following a computer-based instructional session can be used to clarify key elements or choices the learner encountered, and provide strategic information such as diagnosis, degree of learning, and specific lesson content.
According to Hannafin et al. (1997) research on error detection and correction has concentrated on feedback. These authors summarize that if, feedback is provided in a timely, meaningful, and relevant manner, it is a valuable tool for learning and conceptual development.

**Learning Sequence**

Using authoring software or existing multimedia tools, teachers can create instruction programs that allow specification of the sequence of topics in order to achieve a desired learning goal of understanding. Commercial computer-based programs vary as to who controls the lesson-sequencing. With some computer programs sequencing changes as the needs of the learner change. This type of control is deliberate in providing personally relevant material to the user. As the lesson unfolds, the computer can control the “order of the presentation of a lesson, amount of complexity of information presented, the nature of feedback, and all related decisions” (Hannafin, et al., 1996, p. 385).

In contrast, a learner-centered computer-based program allows the learner a wide variety of influence and choice over the components of the lesson. In addition, the learner can often control context, level of difficulty, and the amount of feedback received. A learner-centered program allows the learner to choose a desired learning sequence and develop a relationship among lesson concepts through exploration, manipulation, and experimentation. A learner-centered program can provide varying degrees of support, dependent on learner ability. There are many examples of instruction-related activities that fall within the framework of computer-based “learner
control.” Examples of this format include standard computer-based and multimedia formats (e.g., CD-ROM, videodisk, drill- and-practice, and tutorials), computer-based simulations, tools for indirect learning such as word processing, telecommunications, databases, technologies based on hypertext and hypermedia formats, and some on-line computer documentation and other instructional aids.

Research continues to focus on the influence of learner control on computer-based applications during instruction. Debate continues whether learner-control is an advantage or liability in a computer-based learning environment. Some research supports the belief that learner-controlled programs increase learning and motivation (Hannafin et al., 1996). Learner control can improve self-attribution, achievement, and behavior (Kohn, 1993, September). Hannafin (1984) found learner-controlled technology promotes a deeper, more permanent effect on memory. Another long-term study revealed that computer-based programs which allow the learner to control the interactive computer environment promoted a higher degree of skill than was acquired by learners with a more passive format (Avner, Moore, & Smith, 1980).

In contrast, some research has shown discouraging effects of learner-controlled technology. A variety of studies with learner-controlled programs indicate the learner or user may be a poor judge of his or her own learning needs, often seeking information in excess or irrelevant to the task at hand or terminating the program prematurely (Hannafin, 1984). Inexperienced (computer “illiterate”) learners can experience frustration with the learner-controlled lesson. Hypermedia specifically has several attributes that may discourage learning. With hypermedia, the user may have difficulty
navigating the hypermedia format, or experience difficulties locating and linking information to create meaningful learning (Hannifin et al. 1996).

Hannafin et al. (1996) describe results from a variety of studies reporting better performance associated with a varying degree of program-control versus a learner-control orientation. These authors summarized most of the cited studies by stating that users of learner-controlled, computer-based technology often fail to utilize appropriate strategies to manage their learning environment themselves. Hannafin and associates continue with a dramatically contrasting view by summarizing research data that claim no difference between program-and-learner-controlled environments. Despite the substantial amount of research cited that supports the previous finding, Hannafin et al. (1996) suggests an overall flaw in either the research designs or the interpretations of results that support these findings.

Despite widespread use of computer-based technology, many learners are relatively inexperienced with computers, and find use of computer programs difficult. Issues with learner engagement include motivation to begin and follow through with the computer-based lesson or program.

Motivation can be described as being either intrinsic or continuing. Intrinsic motivation describes a state within the learner that encourages him or her to participate in the learning activity for personal gratification. In other words, the activity generates motivation for the participant. Continuing motivation is evident when learners continue with the computer-based program with little or no encouragement from faculty or peers (Kinzie & Berdel, 1990). Several researchers claim environments created with the use of
simulation software can be inherently motivating and encourage self-directed learning (Malone, 1981; Rieber, 1992). Computer simulations may claim several attributes that motive learners. These attributes include: (a) attention getting, which arouses and sustains performance; (b) relevance, which addresses how instruction helps the learner achieve personal learning goals; (c) confidence, which refers to the degree to which a learner has confidence in the task at hand, and (d) satisfaction, the learner's perception about the outcome of the instructional lesson (Keller & Suzuki, 1988). This study revealed that learners utilizing cardiopulmonary simulation software experienced a degree of continuing motivation and become self-directed learners. Characteristics of this study's simulation software include high learner-control and feedback; that increased learner motivation and willingness to utilize this software to enhance their learning during their course work.

**Instructional Use of Computers in Higher Education**

Faced with an array of computer usages, the instructor must be cautious to select those modalities that best fit the learner's learning needs. Instructional use of computers in higher education include drill-and-practice to master basic skills, development of writing skills, problem-based learning, understanding abstract mathematics and science concepts, simulations in science, mathematics, and social studies, manipulation of data, acquisition of computer skills, access and communication for traditionally under served populations, access and communications for teachers and learners in remote locations, and for individualized and cooperative learning (Deaton, 1991).
Emphasis of this research study was on the role of a computer simulation in conceptual development and identification of alternative conceptions. The task of preparing learners to apply knowledge and skills to effectively influence the outcome of the patient with cardiopulmonary disease is a serious one. Finding new ways of relating concepts of cardiopulmonary physiology while rethinking which advanced concepts should be included in the program to better prepare a new practitioner to problem solve and respond to novel situations in a clinical setting is a focal point of this study. Perhaps educational needs of the cardiopulmonary science student may be met with the use of computer simulation software.

**Computer-Based Simulations: A Theoretical Framework**

Simulations have been a part of education since the 1950s and early 1960s, when business and military groups used simulations to teach the development of winning and competitive strategies. By the late 1960s, passive teaching strategies predominated in formal education, whereby teachers reduced material to be taught to key concepts, demonstrations, and laboratories. In the 1970s, the need to simplify information was challenged by educators who believed that both complexity and depth of material should be taught (Hanna, 1991).

The word simulate originally meant to imitate or feign. Recent authors define simulation as representations of reality (Jones & Keith, 1983). During a simulation, some aspect of the real world is revealed or depicted. Simulation strives to portray an accurate and balanced image of the world by bringing in all relevant elements. (Crookkail & Kiyoshi, 1995). This suggests an important characteristic of simulations is
to imitate something. Simulation generally involves some kind of model or simplified representation. A simulation model may be a physical model, a mathematical model, a free-entry computer-based model, or a combination of these (Roberts, Anderson, Deal, Garet, & Shaffer, 1983).

Many simulations involve physical models. For example, the United States Army Corps of Engineers constructed small-scale models of the Mississippi River to study the effects of flooding. Engineers can create wind tunnels to test aerodynamics of aircraft design, and wave tanks to provide a study medium for ship design (Roberts et al., 1983).

Because physical models can be relatively expensive to build and operate, a mathematical model or simulation is often substituted. With a mathematical model, calculations using the model's equations are performed repeatedly to represent the passage of time. Simulations can be tedious and costly if these calculations are performed by hand. Over the past forty years, hand-generated simulations have been replaced with more efficient computer-based technology. Mathematics-based simulations have become a mainstay in solving theoretical and practical problems in science, mathematics, and engineering.

Computer-based simulations are currently used in a wide variety of applications in the physical, social, and biological sciences. For example, what is known about the behavior of nuclear reactors during accidents is derived from computer simulation models because testing an actual nuclear reactor has ominous risks. Hospital patient experiences within a health care system can be created and evaluated using a computer-
based simulation program entitled “Blood Money” (Makar Joos, 1984). Computer simulations are used in meteorology to predict the weather by simulating movement of heat, pollution, moisture, and air. The WORLD 3 computer simulation depicts a model of global social and economic problems (Meadows & Meadows, 1973). Another computer simulation, The Limits to Growth, analyzes relationships between population, pollution, natural resources, and economic growth (Forrester, 1969).

Simulations are particularly useful in medical science for several reasons including: (Jones & Keith, 1983):

1. Clinical medical simulations allow the user (learner) to experience key aspects of reality without risk to a real patient.
2. Simulations allow exposure to unusual cases which might not otherwise be available to a particular learner.
3. Alternative solutions may be attempted and evaluated by the user without disrupting the “real” state of affairs.
4. Simulations allow reusable, standard opportunities for evaluation of the decision-making skills of the user (p. 108).

Hanna (1991) illustrates an advantage of medically-oriented simulations to allow variable control in a realistic setting by citing the example of eliminating real-world time delays involved with actual diagnostic tests. This allows time to be used more efficiently within simulation-based learning than in the actual clinical setting. Additional advantages for medical use include enhancing the cost effectiveness of clinical instruction by decreasing the need for direct faculty supervision. Small group or
individual learning with computer simulation software can effectively replace a part of
the learner's clinical experience (Hanna, 1991; Jones & Keith, 1983). Nursing educators
have utilized computer-based simulation software to simulate patient management cases
for learners prior to clinical experience with patient care (Kolb & Shugart, 1984). These
authors listed this strategy of simulation use as a supplement to preparing nursing
students for clinical education.

Human surrogate patients (actors) are often used in teaching medical and allied
health students such skills as physical examination and other noninvasive procedures.
The obvious disadvantages of using human "simulators" (in terms of cost and time)
underscores the need for a human, physiologic-based, simulation program such as
SimBioSys™ (Samsel, 1994) produced by Critical Care Concepts, Inc., of Chicago,
Illinois.

Simulations encourage an active response from the learner and can provide
continual, immediate feedback. Computer simulations, similar to the real-world
interactions they mimic, do not build behavior by a series of small steps. Rather, the
learner is exposed to a situation or problem-set requiring learning by trial and error.
Most simulations provide a situation that call for the user to initiate an action, thus
encouraging an active response, followed by realistic consequences.

Computer simulations provide learners with a way of viewing and understanding
a problem or process that lectures and books are unable to provide. The computer
simulation format offers a sense of reality along with a sense of purpose and
participation. Such experiential learning may enhance learning.
Simulations provide goal-directed, active learning experiences conducted in a controlled setting. In its purest form, a simulation is role-playing that relates to real-life roles or dilemmas. Simulations provide realistic experiences for learners without the constraints and distractions usually found within a real-life situation (Hanna, 1991). Simulations vary widely in approach and appearance. They may include computer-based simulations, videotape, pen-and-pencil, and laser disk formats.

Simulations should adhere to four principles of instructional design as outlined by Vargas (1986). According to Vargas, simulations: (a) require a high rate of overt response by the user, (b) require the user to make appropriate responses to related stimuli, (c) provide rich and immediate feedback, and (d) direct the user to a subsequent response during the simulated development of the given problem-set. The quality of simulations centers on how well they actually approximate reality in the situation they are intended to simulate. A simulation should require the learner to make decisions similar to those required in a real situation, and deal with realistic consequences of those decisions.

An ideal simulation has high fidelity, is flexible, portable, and responsive to the user's response and needs (Pickell, Medal, Mann, & Staebler, 1986). Pickell and associates further describe the ideal simulation as based on the principles of problem-based, self-directed learning that can be useful in either individual or group learning, allow for evaluation of data management, and increase clinical reasoning skills. The intent of this research was is to evaluate the use of simulation software with respect to individual conceptual development, learning, and problem solving. Although it has been
suggested that group work with simulations can be beneficial, this project will not employ group work such as cooperative learning. It is worth noting that based on the research conducted at the University of Minnesota with simulations used by groups, cooperative learning was shown to be successful while providing peer support, aiding learners to achieve mutual goals, and share cognitive labor involved with problem solving (Johnson & Roger, 1985).

Published literature indicates simulations can enhance learning, reinforce lecture content, and provide cost-effective alternatives to clinical experiences. Furthermore, simulation may be used to evaluate and test learners in professional programs (Hanna, 1991).

Simulation modeling differs from dynamic modeling by using an existing model to examine a system. Dynamic modeling is the process of developing a model to replicate a process or system. When a learner constructs a model, he or she must confront all assumptions about the dynamics of a given system and render them concrete and specific. Model building with programs such as Stella II (Stella II, 1996), requires deeper comprehension and organization of ideas about the system being modeled.

Hanna (1991) described several disadvantages of simulations, based upon the findings of simulation research. Disadvantages of simulations are related to the process of simulation itself, such as time and expense involved in designing, creating, implementing, and evaluating simulations. Timing of the simulation in the sequence of instruction can also be problematic. This was examined in the prospectus for this study.
Kolb and Shugart (1984) reported using simulations for evaluation purposes was more time consuming than using written tests. This was especially true when simulations were used with large groups.

Another disadvantage cited was the inadvertent encouragement of competition among users to successfully complete the simulation rather than stimulating interest in learning. Additionally, simulations may not be appropriate for all learners, since some learners may have difficulty following directions, remaining on task, or finishing it. Some simulation programs may end prematurely and frustrate or confuse the operator. Hanna (1991) contends students preparing for professional practice should be capable of following instructions and remain on task; therefore, these disadvantages of simulations are less relevant than others.

Simulations can be found in a variety of settings where it is necessary to examine and solve problems. In business, simulations may answer "what if" type questions in a highly interactive manner, as well as model relationships between supply and demand, or among pricing, sales, and profits. In addition, business schools have relied upon simulations to introduce case histories and other problem-solving techniques.

In engineering, simulations can support a variety of functions such as the modeling of complex systems, experimentation with processes that would otherwise occur too fast or slow in reality to observe the effects during class time, and observation of phenomena that, when observed in the real world, would be very costly or dangerous.
In medicine and the life sciences, simulations enable the learner to see things otherwise unobservable. Simulations allow the learner to perform skills that would be otherwise impractical, such as patient management skills in early medical school without risk of causing bodily harm through misdiagnosis and improper treatment.

Simulations can also be used in the physical sciences such as physics. A computer simulation program called Interactive Physics (Knowledge Revolution, 1989) focuses on kinematics, a branch of dynamics concerning aspects of motion apart from considerations of mass and force. Simulations in physics allow learners to observe a number of kinematic phenomena. Another valuable characteristic of computer simulations in physics is that they may simulate idealized physical phenomena not found in the real world, such as a frictionless environment.

Chemistry related simulations, although less common due to the widespread use of laboratory work, may be used in situations where hazardous materials or unsafe conditions must exist to see the results of a process or reaction. Lastly, simulations are becoming popular in the social sciences, to help understand perceptual phenomena, relationships, and participatory types of events (such as elections). Social simulations can be also used to model emotions and behavior under a variety of situations.

**Theoretical Framework for Simulation Programs**

Gredler (1992) calls for a comprehensive theory regarding the use of simulations in education. Although simulations have been used in the classroom since the 1960s, this form of learning exercise is associated with several problems in research design.
The first problem facing simulation research is identifying poorly-designed exercises that are mislabeled as simulations. Gredler (1996) cites several examples of simulation programs that were actually context-based problems, static computer screen tests, animations, or inventories of test questions requiring a response followed by grading of the user's selections. Some investigators have confused animation with simulation. Animation is intrinsically predetermined rather than predictive, and should not be considered a major component of simulation. Such poorly designed programs are not effective in meeting learning goals associated with simulations, which include increasing problem-solving skills. Problems encountered due to mislabeled or poorly constructed simulation software often provides a stimulus to develop an effective design model for simulation-based programs.

The second research issue is the lack of well-defined research studies. Published research on simulations consists of anecdotal reports and testimonies, or weakly designed comparative studies resulting in vague descriptions of simulations as a learning tool. Furthermore, research on simulations fails to accurately reflect user interpretations and reactions to simulation use (Gredler, 1996).

Many research studies compare simulation to traditional classroom strategies such as lecture and class discussion. However, the learning goals for each of these formats differ. Lecture and discussion attempt to provide the learner with information while simulation-based strategies are also aimed at increasing problem-solving skill (Gredler, 1996). Thus, the results of a meta-analysis of research comparing simulations to standard classroom strategies that indicate no difference in posttest scores may be
misleading (Dekkers & Donnatti, 1981). This researcher found a lack of research data in
the literature concerning how learners interact with simulations, what effects learner
characteristics have on simulation effectiveness, and what tradeoffs occur between
informed decision making and information overload. Further research is required in
these and related areas (Gredler, 1996).

The third issue in simulation research is the inconsistent application of the terms
gaming and simulation. Some learners can not differentiate between the two terms
(Jones, 1987). An example is a group of users engaging in a business simulation (often
referred to as a “game”) and having the overall desire to win. Winning, from their point
of view, would include using business or trading to maximize profit. Participants not
doing as well as the more successful participants may become frustrated and act like
game players, choosing to “crash the system” (Lundy, 1985). This behavior is
counterproductive to the intent of the simulation.

Further confusion can be found in the literature itself with respect to the terms
gaming-simulation and simulation-gaming. Both represent different learning strategies
aimed at different outcomes. The latter has characteristics of a game with participants
attempting to win or reach a successful end that may be defined as a victory (Abt, 1968).
The former lends itself more to the complex interaction of identifying patterns in
phenomenon to aid problem solving and creating a strategy to reach a conclusion.

One reason for confusion in terminology is that interactive exercises are often
categorized according to surface features. Surface features refer to paraphernalia and
observable mechanics of an exercise such as objects on the screen, board layout, cards,
or tokens (Vanments, 1984). Instead, gaming and simulations should be analyzed in terms of their fundamental defining terms or “deep structure”. In contrast to surface features, deep structure is defined as the psychological mechanism operating in the interactive exercise (Gredler, 1990). Deep structure refers to the complex and demanding nature of the interaction between the user and program. This includes the interaction between the learner and the major tasks of the exercise and also between the learners themselves. Deep structure allows us to differentiate between games and simulations, and identify key differences in the types of simulations.

**Games vs Simulations**

Games and simulations are classified as interactive exercises (or more recently, experiential exercises) because these formats provide opportunities for learners to interact with a particular task or knowledge domain (Gredler, 1992; Gredler, 1996). Each format serves a particular function for the participants.

A game can be defined as “any contest (play) among adversaries (players) operating under constraints (rules) for an objective (winning, victory, payoff)” (Abt, 1968, p.66). A competitive exercise has three characteristics. First, a game does not represent the real world and has its own set of particular rules and consequences, experienced by the participants but not carried over into the real world. Second, game paraphernalia and consequences resulting from the rules may be any of several combinations of objects and events allowing a player or team to defeat an opponent (e.g., athletic and board games). And lastly, a game involves winning by taking any course of action allowed by the rules to defeat an opponent. A game is defined by a
particular set of rules that validate wins and losses. A game seldom represents the real world or carries over knowledge a learner can apply to solving real-world problems. In contrast, simulations vary from games in several characteristics.

Simulations differ in deep structure in a variety of ways. Simulations, unlike games, require participants to take on either demanding, responsible roles such as caregiver, manager, or pilot; or professional tasks such as managing a nuclear reactor or piloting an airliner. Instead of attempting to win, participants in a simulation take on responsibilities that carry privilege and consequences (Gredler, 1996).

A game is typically described as linear, whereas a simulation is nonlinear in its approach. With games, the player responds to a stimulus and typically advances or does not advance until another rule is engaged. This sequence is repeated by each player or team at each turn. A simulation allows each participant to face a different problem, issue, or event, based on previous decisions or actions taken. As decisions are made, participants usually have to deal with the consequences of those decisions. This trait is referred to as branching.

Simulations fundamentally relate to a real-world problem or situation, and have a dynamic set of relationships that are occurring among several variables. Relationships among simulation variables change over time, reflect actual causal processes, and allow for reaction or responses to be verified.

**Experiential Simulations**

Two broad categories of simulations exist. One type is the experiential simulation which places the participants in defined, real-world roles. Participants carry
out a role within a real-life domain and are held accountable for consequences.

Experiential simulations require an initial scenario or problem, followed with an assigned role to pursue a variety of paths through the simulation. As the participant engages the various paths, he or she controls the route taken to solve the problem or to reach a successful end to the task (e.g., save a patient from a disease process).

Experiential simulations are designed to engage the participant in a complex, changing situation, in which the learner is one of the simulation's functional components.

An example of the experiential simulation is the latent image clinical simulation used for credentialing advanced practitioners in respiratory care. Candidates for the credential of advanced practitioner attempt to successfully complete ten simulations to meet part of the requirements for this credential. This paper-and-pencil simulation consists of three components: (a) the scenario, or opening scene, which is followed by (b) information-gathering sections, and (c) decision-making sections. These three parts are interrelated and the participant must understand each part and its relationship to the whole, in order to be successful in passing the simulation.

**Symbolic Simulations**

The other type of simulation is the symbolic simulation. A symbolic simulation is a representation of a dynamic situation such as a system, set of processes, or other phenomena provided by another system, in most cases, a computer. A symbolic simulation represents behavior over time with interactions between or among variables, with interaction being a critical component.
Symbolic simulations differ from experiential simulations in several ways. The first difference is that the symbolic simulation participant is not a functional part of the simulation. Instead the participant chooses from a variety of events or interactions in order to see results or manipulate responses. The participant manipulates and interacts with the variables of interest, in hopes of discovering scientific relationships, predicting behavior or events, or confronting alternative conceptions (Gredler, 1996). The next difference is the symbolic simulation participant works from an initial scenario or problem set and responds to the consequences of decisions made during the running of the simulation. The participants must address the changes that take effect within the simulation as a result of action taken by the learners themselves or others involved with simulation. The consequences of the participants' actions while trying to solve the problem are a characteristic of the symbolic simulation. Random strategies for management of the problem will result in unsuccessful completion of the simulation problem, such as patient death in a medical simulation (Gredler, 1996).

Gredler (1996) questions the role of prior knowledge in the simulation domain in affecting participant success. That author claims participants will be more likely to succeed with the problem or scenario within the simulation if they have domain-specific knowledge and research skills. This research looked, in part, at the effects of a symbolic simulation, SimBioSys Physiology Labs™ (Samsel, 1994) provided to students at different points in the learning process during courses in cardiopulmonary physiology and respiratory critical care. Results from this study expanded Gredler's assumptions and provided an alternative view.
Relationship Between Simulation and User

Simulations are grouped based on the general nature of the dynamics of the interaction between participants and components of the simulation. Typically labeling a simulation as a "business simulation" or "nursing simulation" fails to reveal the underlying components of the simulation. When simulations are classified in such a manner, surface features are responsible for the labels (Vanments, 1984).

Gredler (1991) charges that simulations should be "examined in terms of their fundamental defining features or deep structure" (p. 16). Using this criterion, two main families of simulations based on the types of tasks being addressed exist: (a) social-process simulations and (b) tactical-decision simulations. With each classification, participants focus on different goals and engage in different experiences.

Social-Process Simulations

Social-process simulations focus on various human interactions involving with some group or individuals engaged in a degree of personal interaction. Examples include members of a village, a group of nurses encountering downsizing of staff, and children with attention-deficit disorder entering mainstream education.

The range of strategies used with social-process, computer-based simulation includes interviewing, writing, questioning, editing, and negotiating (Gredler, 1992). Three distinct types of social-process simulations are social system, language skills/communication and empathy/insight simulations. They differ in the types of interaction required and outcome desired.
**Tactical-Decision Simulations**

Tactical-decision simulations foster interactions with complex problems in which participants execute their own roles, make decisions, use their own skills to interpret and organize data, and manage a situation to solve a problem. There are three types of tactical-decision simulations. They are diagnostic, crisis-management, and data-management simulations. Each represents a particular type of data interpretation and management. The types also differ in terms of basic context in which these skills must be executed (e.g., solving complex, ever-changing problems, addressing an impending crisis, or participating in the management of a medical case history). This study examined a computer-based diagnostic simulation program as a teaching and evaluation tool for undergraduate novices enrolled in a cardiopulmonary physiology and intermediates enrolled in an advanced respiratory care course.

**Diagnostic Simulations**

Diagnostic simulations enable the participant to assume a particular role, such as a medical care-giver, airline pilot, teacher, patient, or archaeologist. Beginning with limited information, the participant is offered an initial situation or problem and then assumes the specified role. For example, in medicine, information provided may include patient symptoms and past medical history. As the computer simulation progresses, the participant must request additional data to solve the problem set. Once the data are collected, a decision is made.

According to Gredler (1991), the most common discipline where diagnostic simulations are used in teaching is the health sciences. Other uses for diagnostic
simulations include identifying problems causing airline accidents (Rolfe & Taylor, 1984), arguing court cases, and solving problems in the social sciences. Diagnostic simulations have several identifiable characteristics including sequential decision-making. Once data and other information are collected, interpreted, and summarized, the participants continue with the simulation. The sequence of steps taken by any participant depends upon prior responses. In other words, progress through the simulation depends upon the individual's response to data provided by the simulation, the changing events, and the evolving problem. If the participant fails to gather appropriate data, solving the identified problem may be delayed or thwarted. The learner's progression through the simulation depends upon his/her sequence of response (Gredler, 1992).

Diagnostic simulations allow a variety of participants to achieve similar outcomes using somewhat different management and data collection strategies. Selected solutions to a problem may vary from participant to participant. In addition, available options will vary in effectiveness, thus both the novice and expert will still find attractive responses as will the expert. However, successful performance is dependent upon the existence of domain-specific information and experience (Bruer, 1993).

The context, framework, setting, and events to take place influence the participant's response and reaction to various components of the simulation. These variables differ based on whether the simulation is a closed or open-structured computer-type simulation.
According to Gredler (1992), a closed-structured simulation format includes, "simulations that are pre-packaged exercises. All information, options for data interpretation and management and reactions to participant decisions are developed in advance and organized into multiple branching exercises" (p. 64). A closed-structured simulation presents a problem, identifies a setting or context, provides options to begin data gathering or making a response, options for observing the response to actions taken, and a means to terminate the simulation. The scope of the problem, options available to the participant, and responses to the interaction between the participant and problem are responsible for the reality of the simulation.

Open-structured simulations are used when the goal is to gather, interpret, and analyze data. Following an introduction reviewing the participant's role, several options are provided from a set of choices in a chosen category (e.g., physical examination data). Feedback on the chosen options is provided and the participant interprets the information and makes a subsequent choice from the same or different category. This process continues until either successful or unsuccessful completion of the simulation occurs. Most closed-structured simulations allow for minor errors and offer a means of correcting them. However, serious or irretrievable errors will lead to an undesirable conclusion and the participant is "exited" from the program.

The closed-structure simulation relies upon the depth of the problem, possible courses of actions, and the results of choices made by the participant to establish a sense of realism. A limitation of this type of simulation is the limited branching that must occur, because in reality there often are limited options or choices for successful solving
of a problem. In addition, the choices and options afforded the participant must be plausible and credible. In other words, the sequence of moving through options and solutions to solve the problem must be based on current scientific reasoning or social theory (Gredler, 1992).

Open-structured simulations are used when the goal includes data collection or the problem requires a group of participants. This type of simulation provides participants with the problem and team roles. This format is described as an open-ended exercise that allows participants to solve a problem by choosing from a variety of options. Typically, the types of problems chosen are derived from actual experiences of the simulation creators or from a field setting in which the learners may be currently experiencing difficulty. An example of an open-structured simulation is an airline accident investigation simulation performed to assist new investigators in encountering problems that may have contributed to the cause of the accident (Rolfe and Taylor, 1984).

In summary, diagnostic simulations are an interactive, versatile format that provides creation of exercises in a variety of subject areas. Diagnostic exercises allow participants to have a real-world experience without the risk of actually having to solve the problem there. This type of simulation allows practice with solving problems at relative low risk and possibly cost.

Literature Review for Use of Simulations

Effective thinking is not just a product of motivation and general cognitive strategies, but a function of well-organized content-based, conceptual knowledge.
Neither is the accumulation of facts or declarative knowledge sufficient for problem-solving. Effective thinking requires the learner to conceptualize the "what," "why," and "how" that accompany scientific phenomenon. Once concepts are understood, applied, and valued as relevant, the learner will be more apt to problem solve and to engage in self-directed learning.

To encourage learners to become independent thinkers and problem solve, appropriate activities or learning strategies must be employed to promote this desired outcome. The premise of providing the learner with an opportunity to engage in the various activities that encourage independent thinking is referred to as transfer appropriate processing (Morris, Bransford, & Franks, 1979).

Despite the teacher's awareness and support for transfer appropriate processing, typical instructional strategies violate this premise. Teachers claim they want to aid learners to think critically and deeply about the subject matter, but often lecture with emphasis on an abundant number of relatively unrelated facts to be memorized, leaving little time for learners to explore and interrelate the material. Teachers claim learner understanding is the ultimate outcome of their instruction, but will overburden the learner with noncontextual material or skills that must be mastered long before actual application, or provide technical definitions and formulas, while failing to link this knowledge to the learner's existing understanding. Furthermore, teachers claim they desire a motivated, responsible, and curious learner, but then treat the learners as passive recipients of knowledge, not providing ample opportunity to explore ideas, collaborate with peers, and integrate learned material in an effective manner.
Hasselbring (1994). Hasselbring (1994) claims this discrepancy between what teachers value as outcomes and the actual outcome of their teaching is an argument for "breaking-the-mold rather than a curriculum embellishment approach" (p.40). Focusing instruction around meaningful issues using problem-rich environments, such as media-based programs or computer-based simulations is an example of providing effective instruction.

Effectiveness of computer-based technologies has been examined from a variety of theoretical viewpoints, including Bloom's taxonomy of knowledge, (i.e., cognitive, affective, and psychomotor domains). Computer-based instruction can be effectively employed within the cognitive and affective knowledge domains. Wang and Sleeman (1994) describe the structure of the computer environment as a mental-like process for organizing and interpreting information similar to how the mind works during effective problem solving.

In the cognitive domain, Wang and Sleeman (1994) describe several strategies of computer-based instruction that can be effective in promoting learning and problem solving. These strategies include drill-and-practice, tutorials, and simulations. In the affective domain, computers offer a self-directed, bias-free interface, allowing learners to examine their values, feelings, and personal concepts. Such an environment motivates and encourages learners to be creative. Affective domain-type strategies include problem solving, teacher-generated problem-sets, and information databases for learner inquiry. Wang and Sleeman (1994) claim that computer-based formats, such as simulations, can encourage maximum learning using the information-processing model.
of cognition that values better encoding, retrieval, and conceptualization of information, thus improving overall problem solving.

Research values on the effects of computer-based simulations have focused on cognitive learning and have tended to ignore the affective and psychomotor areas of learning. Recent literature calls for research to examine effects of simulations on affective and psychomotor learning (Butler, Markkulis, & Strang, 1988). These authors call for additional qualitative studies using simulation as an instructional strategy.

Simulations have been advocated to assess the cognitive, affective, and psychomotor knowledge domains during the clinical education of health science students. Assessing the student nurse’s clinical competencies includes evaluating her or his ability to problem solve, perform technical skills, and demonstrate a professional attitude. Throughout nursing education, there is an overlapping of all three of these learning domains. Evaluation is complex and there is substantial difficulty in separating behaviors by domain, since many domain-specific behaviors occur simultaneously. Most nursing evaluation instruments assess only cognitive and psychomotor skills—leaving affective skills unassessed (Kolb & Shugart, 1984).

Kolb and Shugart (1984) describe several simulation formats that are capable of addressing all three knowledge domains. They advocate the use of role-playing, dramatic representations, simulated patients, and written or computer-based simulations as potentially effective means for preparing learners to gain competence and confidence as they move from modified reality to the real world. These authors support the use of simulations to teach information gathering skills, technical procedures, and
physical assessment skills in nursing education. Kolb and Shugart (1984) point out several advantages to simulations. These include: (a) the teacher can control which variables are to be engaged, allowing controlled testing, (b) there is greater realism than in pencil-paper tests (if used for testing), (c) the faculty members must focus on defined critical elements of behavior and provide a means of evaluating such behavior, (d) allow preclinical instruction with simulated experiences prior to encountering real patients, and (e) they aid in identifying the learner's weaknesses and learning difficulties, and correcting them prior to the time with learner enters the clinical area. In addition, these authors claim simulations offer effective feedback, high fidelity, and a degree of realism unmatched in traditional education.

Simulations have been used in assessing nurses who are practicing in the clinical setting. The National Council of State Boards began a three-year feasibility study of developing, administering, and scoring computerized clinical simulation tests for competencies in clinical decision making. This study of simulations was a part of a $1.9 million grant from the W. K. Kellogg Foundation to assess effectiveness of using computer simulations for determining clinical competence and resulted in development of the Computerized Clinical Simulation Testing (CST) program.

The CST is an uncued, interactive, dynamic test that permits examinees to realistically demonstrate their clinical decision-making skills when providing nursing care. Examinees are not cued as to the patient's problems, the diagnosis, or any actions to take. Instead, after a brief introduction, the examinee seeks the appropriate nurse response using a "free-text" entry via the computer keyboard. The CST is different
from standard interactive, computer-based simulations which provide the user with a list of decision options at various points in the simulation. The CST was designed to offer high fidelity, uncued interaction, time-based management of the patient, and real-life patient encounters (Bersky & Yocom, 1994).

A study performed by Bersky and Yocom (1994) revealed the CST can mimic real-life situations more effectively (in terms of interaction and effectiveness of assessment) than to paper-and-pencil simulation. Pilot study results indicated that computer simulations could be an effective tool in assessing the clinical competencies of graduate nurses seeking nurse licensure. The CST has the potential for assisting nursing state boards in making valid assessments about graduates as to their competence to practice nursing. Furthermore, the study that revealed computer simulations were effective in assessing the nurse’s critical thinking abilities, identifying topics on which the nurse need remediation, and as a continuing competency test for currently licensed nurses. In summary, these authors anticipate computer simulations will have a significant impact on nursing education curricula and the evaluation processes, resulting in an improvement in the overall quality of care provided by future nurses.

A study comparing students' perceptions of the use of paper-and-pencil versus computer-based simulations in nursing education was performed by Schleuterman and associates (1983). Using 12 graduate students in nursing, both formats were compared. Simulations dealt with physical assessment, diagnosis, and treatment of both acute and chronic pneumonia. In addition to comparing the two simulation formats, the researchers wanted to evaluate the efficacy of using simulations as an ongoing creative
strategy to augment clinical education. Results of this study yielded no significant
difference with regard to students' preferences for a particular format. Both formats
provided immediate feedback, an attribute cited as very positive by the student.
However, the students also perceived the computer simulation as being a more effective
study tool, which aided their understanding of the patient case study. In addition, the
study found the simulation to be an effective teaching tool during clinical education of
the student nurse (Schleutermann, Holzemer, & Farrand, 1983).

Use of video-based simulation as a tool to promote and test critical thinking
skills in nursing students was studied by Johannsson and Wertenberger (1996). Nine
medical and surgical videotaped vignettes were selected from the critical thinking
component of the Performance Based Development System (PBDS)—a simulation to
test critical thinking ability in the areas of clinical decision making, priority setting and
revising, problem solving, and care planning. The researchers employed expert nurses to
establish content-related validity, relevance of problems, quantitative validity, and
reliability of the simulations. The study involved is 18 students enrolled in an associate
degree nursing program. Each student was evaluated with six 4-minute simulations that
varied from easy to difficult and covered a variety of patient conditions. The role of the
examinee was to determine a management strategy for a particular patient situation. A
written posttest was administered following the simulation exercise.

At the completion of the study, students were debriefed and the scores from each
of the simulations were discussed. Debriefing was necessary in order for the students to
understand their own performance achievements in the simulation. Results of this study
were positive for assessing the students ability to think critically and her/his nursing competency. The authors suggested that simulations may be an effective learning exercise administered prior to clinical experiences. In addition, the students suggested that simulations could be also used for self-assessment.

Makar Joos (1984) has promoted use of simulations and games as strategies to motivate learners and foster critical thinking. That author cited research supporting the use of simulations and games to increase learning, interest, attitude, and strengthen psychomotor skills. In addition, Joos argues that simulation and game formats can aid in factual knowledge acquisition, improve retention, provide the experience of "how it feels," and assist the learner in synthesizing skills. That paper also provides guidelines to help teachers use simulations effectively in the classroom. These guidelines include effective planning for use, locating the appropriate simulation or game, assessing the learner’s style of learning and willingness to take part in such as novel approach, preparing the simulation for use, and actually running the simulation or game.

In contrast, a study by Holzemer, Resnik, and Slichter (1986) examining nurse practitioner performance by comparing chart audit, direct observation, and clinical simulation found chart audit and clinical observations were highly correlated, however study variables were not significantly correlated with clinical simulation experience. The authors cautioned university faculty about using simulations as evaluation tools until further research can document their effectiveness.

Pickell et al. (1986) studied the use of natural language, free inquiry patient simulations with high fidelity using low cost microcomputers. Their study found that
computer-based simulations may be flexible, portable, and responsive to learner’s needs. That study examined a program called Computerized Clinical Patient Problem (C2P2) which is designed to assist learners in developing the intellectual skills necessary for patient assessment and treatment. The authors reported the use of computer-based patient management simulations may be an effective, partial substitute for clinical experience, especially as actual patients become increasingly limited in number.

The C2P2 is a high fidelity patient simulation modeled after the Problem Based Learning Module produced by Barrows and associates at Southern Illinois University in 1982 (Distehorst & Barrows, 1982). The C2P2 simulation provides actual patient cases and its users are challenged to perform all of the cognitive tasks necessary to evaluate and manage the patient effectively. Users are to obtain historical and physical information, laboratory data, patient weight, age, and other related information in order to develop a working diagnosis. In addition to an appropriate diagnosis, the goal of the simulation is to increase the user's understanding of the pathophysiology of the patient's disease process.

The C2P2 simulation program possesses features the authors cite as desirable with computer-based instructional technology. These include: (a) the capacity for free inquiry, (b) the use of natural language, (c) minimal cuing (such as menus, lists of potential questions, or warnings), (d) rapid response, (e) realism in timing of obtaining data and test results, and (f) a running tally of time and money spent on the care and treatment of the patient. The unique feature of free inquiry is that once the user is
provided an introduction to the patient case, he or she can request a physical
examination, laboratory tests, or other related information in any sequence. Time
eclapses and costs accumulate as the patient is managed by the user. Once the user
develops a management and care plan based on a working diagnosis, the program offers
an acceptable explanation, to which the user can compare his or her care plan.

C2P2 is designed to be used with individuals or small groups. Research with
medical students comparing C2P2 with paper-and-pencil simulations, found the
computer simulation to be as effective as the paper-and-pencil format. The C2P2
program allows medical students to practice clinical reasoning and compare their
evaluations with an actual work-up for a real patient. The authors conclude by noting
high student enthusiasm for the simulation program (Pickell et al.,1986).

A pediatric simulation program which provides simulated patient management
to assist health science learners in the care of the pediatric patient was developed by
faculty at the University of Alberta, in the Division of Pediatric Cardiology. Use of this
program was shown to aid medical student education by reducing faculty teaching load,
and increasing student experiences with pediatric conditions. Each patient case
consisted of five sections that parallel the typical data gathered by physicians in a real
clinical situation: (a) description of the patient’s condition or complaint, (b) collection
of data, such as medical history, physical examination data, (c) patient diagnosis, (d)
management including treatment, follow-up, and discharge advice, (e) and follow-up
review of user performance. Study results found that use of the program over several
years yielded positive results in its teaching effectiveness in medical student education.
In addition, affective user response was positive toward the use of the simulation as a learning tool (Bidwell, Collins-Nakai, Taylor, & William, 1985).

Research at the Western Australian Institute of Technology included a literature review of research studies on the use of simulation as an instructional strategy. This study evaluated 93 empirical studies on the use of simulations. Results of these studies revealed that simulations (as an instructional strategy) were superior to lecture, and often motivated learners to self-direct their learning. Study results also included both improved cognitive development associated with the use of simulations and also improved thinking skills (Dekkers & Donnatti, 1981).

Whitman (1990) claims use of simulations is a more creative way to teach and evaluate medical students and residents. By placing students in a setting that imitates reality, all three knowledge domains may be activated by offering opportunities to practice medical procedures, decision-making, and assessment of patients prior to actual clinical contact with patients. Pencil-and-paper or computer-based simulations providing patient management problems can offer an opportunity to increase clinical problem-solving, either before or in conjunction with clinical education.

The Department of Family and Community Medicine at the University of Toronto has been employing small group sessions and simulating patient conversations for medical residents to help them gain insight into handling patients and addressing related problems during telephone conversations. Following a series of simulated calls (using a speaker phone), group discussions follow with instructor comments. After participating in this simulation, residents reportedly became more adept at handling
patient problem via telephone (Dunn, Norton, & Dunn, 1987). Whitman (1990) recommended providing medical students with an overview of the simulation before using a teaching simulation, and following simulation use with a debriefing to allow discussion concerning the student's experience with the simulation. Whitman claims simulations allow students to anticipate real-life situations, and thus will reinforce learning and allow integration of other related classroom information. An example of this is the use of a life-size simulation mannequin (called “Harvey”) that is capable of simulating a variety of cardiovascular conditions (e.g., heart sounds). Senior students in LSU Medical Center, Department of Cardiopulmonary Science Program utilize this simulation as a part of their education in cardiovascular technology.

A use of a simulation that allows the development of the psychomotor domain is a model developed by a surgery resident, John D. Reid. Reid created a simulated set of subclavian and femoral veins and arteries from autopsy remains. He cannulated and irrigated each vessel with food-dye-colored, sterile, saline solution to simulate venous and arterial blood. The saline bag assembly was compressed to simulate cardiac contractions, or pulse. This allowed medical and surgery residents to practice performing vascular invasive procedures. This cadaver-based simulation was effective in preparing students to learn how to properly access the vascular system with needles, catheters, and other invasive devices. (Swanson, 1984).

A physician, Dr. Richard Robb, Director of Biotechnology Computer Resources at the Mayo Clinic, developed a medical simulation, Analyze, that was nominated as a finalist in the Medicine and Health Care category for the 1990 Computerworld

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Smithsonian Awards. With this program, physicians can practice surgery at a computer workstation, using patient x-ray images before actually performing the surgery on the patient (Harrington, 1990).

Jones and Keith (1983) found simulations to augment learning in the health sciences. These authors studied the effects of using a variety of commercially produced simulations (e.g., PLATO, CASE, and GENESYS). Their review of the literature indicated simulations have a potential role in providing effective instruction in undergraduate, graduate, and continuing education programs in the health sciences. Jones and Keith further promoted multidisciplinary use of simulations as a means to encourage collaboration among various health disciplines. They report the Lincoln Medical Education Foundation is developing simulations for psychiatry, surgery, dentistry, and family medicine by using software authors from each discipline. The foundation reported effective use of simulations as a multidisciplinary and interdisciplinary tool to improve learning about the special needs of patients, the subtleties of different types of problem solving, and decision-making skills applicable to a wide variety of disciplines (Jones and Keith, 1983).

Jones and Keith (1983) reported simulations may be used as complete, stand-alone courses, or as a means to enrich existing course work. Use of simulated patient cases in class offers learners an opportunity to discuss cases in depth, to pursue interesting aspects of the case or subject matter, and to use the case within the context of a broader learning opportunity. Use of simulation-based cases may also prove effective as a prelecture adjunct to aid novice learners in better understanding lecture content.
Others have recognized the value of using simulated patient case studies in health science teaching. Using microcomputers, learners are able to investigate a patient problem via a simulation that provides the history of an illness, physical examination findings, and laboratory results commonly obtained in a hospital setting. A good simulation does not cue the user as to the underlying disease process. Thus, to understand the nature of the disease process or patient problem (i.e., make a diagnosis), the simulation-user must assimilate various records of seemingly unrelated bits of information and integrate them into an understanding of the patient's condition. Learners are able to apply basic medical science knowledge in a practical way, and see how their understanding fits into their role as a health care provider (Krahn & Blanchaer, 1986b).

A study by Blancheaer and Stevens (as cited in Krahn and Blanchaer, 1986) reported that providing an advance organizer at the start of a simulation aided clarification of concepts for a learner having difficulty in understanding an unfamiliar situation presented in a simulated patient case. Using advance organizers before the simulation was shown to create an “ideational scaffolding” (Ausubel, 1978) which facilitates the application of existing knowledge to the new situations that surfaced within the simulated patient case study.

Krahn and Blancheaer further studied the effects of advance organizers prior to simulations with a group of first-year medical students. The experimental group received an advance organizer prior to a simulated case, and the control group received just the simulation experience. The simulated case dealt with a patient with a salicylic
acid overdose and was chosen due to its complexity and depth. The advance organizer was constructed to fulfill the definition and guidelines of Ausubel (1960), Hartley and Davis (1976), and Mayer (1979). Pre- and posttests were administered to both groups. The pretest assured a certain degree of prerequisite knowledge and the posttest assessed the effectiveness of the advance organizer.

Results of this study revealed higher posttest scores by those learners in the experimental group. The researchers concluded that an advance organizer had a positive influence on successful management of the patient in the simulated case study. The authors also concluded, based on this study, that advance organizers used prior to simulated patient case studies could aid in assimilation and integration of new material within the learner's preexisting knowledge based for the patient case topic, thus helping the learner answer more complex questions regarding patient management. The advance organizer may afford the learner with key ideas or anchors which promote meaningful learning and better problem solving.

In a similar study, advance organizers were used prior to a HyperCard simulation with fifth-, sixth-, and seventh-graders. HyperCard simulation, using sound, animation, and graphics, had users responding in the role of being lost and alone in the wilderness. The teacher-generated simulation required participants to make a variety of decisions in order to survive. Poor decisions resulted in death. A posttest was administered to assess achievement gains. Analysis of data and a summary of results indicate that receiving an advance organizer was effective in promoting learning in the group that received an advance organizer prior to the simulation experience (Kang, 1996). Lavoie and Good
(1988) examined the additional science process skill of prediction using qualitative research, and reported positive results of using a computer-based, biological simulation to facilitate the user's development of manipulation of variables, observation skills, motivation, and in general, higher thinking skills. These authors advocated the use of simulations as a means for identifying alternative conceptions and improving the learner's conceptualization of biological phenomena. Lavoie and Good suggested ways for learners to address their own alternative conceptions. Suggestions included having learners discuss their own misconceptions, being exposed to contrasting ideas or events, and providing instruction which places emphasis on concept development, rather than just on factual knowledge. A computer-based simulation may assist in reaching these desired outcomes.

Brant, Hooper, and Sugrue (1991) addressed the use of simulations as pre- and postinstructional learning tools. They claim simulations can play two instructional roles: (a) set the stage for future learning, and (b) provide an opportunity to apply and integrate new knowledge with existing knowledge. These authors evaluated the relative effectiveness of a computer-based genetics simulation, before and after formal instruction. Two evaluation studies were conducted to determine the value of simulation for learning genetics principles, and to determine appropriate timing of the simulation within the sequence of instructional events. Brant, Hooper, and Sugrue claim that while postinstructional use of simulations is widely accepted, research has demonstrated their effectiveness prior to instruction. These authors state that use of preinstructional simulations as teaching tools may result in: (a) motivating students to
learn, (b) revealing alternative conceptions that inhibit learning, (c) act as advance
group for connecting new information with existing knowledge, and (d) serve as
concrete examples of complex, abstract concepts. This study, in part, looked at the role
simulation played prelecture and supports many of the findings Brant et al. found in
their work.

Using a computer-based simulation called FARMER, college-level students
enrolled in an animal science course assumed the role of an animal breeder to apply
genetic principles to solve various breeding problems (from simple to complex).
FARMER was originally designed to be used after lecture to encourage integration and
application of previously learned principles. Over 100 students were involved in two
studies over several semesters. The studies compared the use of simulation before and
after instruction to a control group that did not receive any simulation-based instruction.

Results of this study revealed that effectiveness of computer-based simulations
is dependent upon the sequence of presentation of the instructional activity. The
experimental group who received the simulation prior to formal instruction performed
better on a genetics posttest than did the post-instructional experimental group or the
control group. The group that completed the genetics simulation as postinstruction
performed only slightly better than the control group.

These authors concluded that preinstructional use of simulations can prime
learners before formal instruction and thus aid understanding of new, theoretical
information. Learners exposed to computer-based simulations arrive at the lecture hall
with an incomplete (but receptive) cognitive structure via the simulation topic, which

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allows the formal lecture to augment, alter, or enhance that understanding. Furthermore, use of pre-instructional simulation may reduce cognitive demand for memory of complex concepts, allow for better connections between intralecture concepts and ideas, and allow users to receive valuable initial feedback through trial- and-error.

The authors suggest further study to evaluate the sequencing of simulation-based teaching. A major focus of this research was to continue the work of Brant, Hooper, and Surgue and examine the effects of cardiopulmonary physiology simulation software prior to and following formal instruction in a university health science classroom. This study differed from the study performed by Brant, Hooper, and Surgue in the methods used to evaluate simulation effectiveness. An ideographic design was used for this study, rather than the nomothetic design used by Brant and associates.

Researcher's Motivation For Conducting This Research

The motivation for this researcher to pursue doctoral work in science education, was in part, a desire to promote learning in health sciences that results in learners developing a systems view of cardiopulmonary physiology. By promoting a systems view of cardiopulmonary physiology, it was hypothesized that learners could better understand interrelated concepts and principles as they apply to the gas transport system of the human body. Having a systems view of lung and heart function should provide the new clinician with a better understanding of how pathologic conditions alter oxygen transport and utilization, and facilitate decision making at the bedside when providing care to the patient with cardiopulmonary disease. It has been this researcher's experience that most learners fail to integrate variables that affect total body oxygenation and, as a
result, fail to see the total effects of therapy they administer to patients that may be suffering from cardiopulmonary disease.

Traditional education encourages the learner to see cause and effect as closely related in terms of time and space. Often, learners attempt to find close relationships between events and their causes, misunderstanding the actual behavior of a complex system like the heart-lung system. In realistic complex systems, causes of events may be far removed from what appears as obvious causes. Factors influencing system behavior may come from entirely different parts of the system than previously thought. In addition, actions or reactions may reverberate throughout the entire system, leading to unpredictable effects. Often, these effects may be inversely related to the intended effects (Wilson, 1984). An example of this phenomenon can be seen with cardiopulmonary science students attempting to interpret arterial and venous blood gases. While arterial oxygenation may be obvious and altered values are easily understood by most students, interpretation of venous oxygenation is much more elusive. In this study students often failed to conceptualize the cause of a reduced venous oxygen level, and the relationship of blood flow to the tissues and to venous oxygenation. Reduced venous oxygenation is a result of either increased oxygen consumption by the tissues or reduced blood supply to the tissue. Students failed to integrate these concepts and focus on reduced arterial oxygen status as the cause of decreased venous oxygenation. It is not intuitive for students to think that, as cardiac output decreases, the tissues extract more oxygen, leaving less oxygen in venous blood. A systems view of these physiologic variables may assist the student to better
conceptualize these relationships, and to understand overall oxygen transport and utilization in humans.

Systems theory embraces at least four principles that govern how people see phenomena or biological systems. These principles represent cognitive skills necessary for a person to think about systems and their function. These principles are guides for effective teaching to promote systems knowledge and problem solving skills.

The first systems view is referred to as the “system as cause.” This perspective places a boundary around a set of elements and interrelationships, allowing the viewer to capture the behavior under study within the defined boundaries. The phenomenon within the system is a result of contained elements, and is not influenced by outside forces. The second systems view is referred to as the “closed-loop perspective.” This view answers the question, “What inside the system is causing the dynamics of the system to occur?” With this view, causal relationships within the system are reciprocal.

Various relationships between elements within the system shift or change over time. As the system evolves, relationships between elements change. The third systems view is referred to as the “operational perspective.” This view asks the question, “How does this system work?” This level of questioning requires a deeper understanding of how the system works in order to make the system work better. The final systems view is referred to as the “dynamic perspective.” This perspective involves observing how patterns of behavior develop over time and the interrelatedness of elements within and outside the system that influence the entire system (Richardson, 1994). Learners vary as to their understanding of these views of systems and instructional strategies should be
planned to promote their development. An effective strategy to promote these four views may be realized with computer-based cardiopulmonary simulation software.

Using simulation to promote systems thinking may result in learners having a better understanding of how the heart and lungs integrate their function to oxygenate humans who are in various states of health. Simulation allows users to make judgements, evaluate outcomes of complex behavior such as physiologic processes, patient responses to therapy, and other health management strategies. Simulation may afford the learner an improved understanding of how physiologic variables work, and how they are interrelated. In addition, simulation allows users to predict behavior and test self-generated concepts or ideas, thus correcting or modifying erroneous beliefs or poorly differentiated concepts. A trial-and-error approach to understanding how a system works (i.e., cardiopulmonary system) may facilitate the development of the four views discussed with emphasis on developing a dynamic perspective, which ultimately should lead to better problem solving.

Clinical reasoning about physiologic principles and processes is paramount for the bedside cardiopulmonary practitioner. Without understanding the detailed interactions of the heart and lungs, the practitioner has limited capability to manage a patient with cardiopulmonary disease intelligently. Typical health science instruction excludes teaching organ systems in an interrelated, conceptual framework manner. Even if learners initially master an integrated view of heart and lung function, by the time they reach their clinical experiences, the principles learned prior to clinical work may seem difficult to apply.
It was the goal of this research to optimize instructional strategies so that cardiopulmonary science students develop a conceptual whole or systems view of cardiopulmonary function. Furthermore, once a basic systems view has been developed, transfer of knowledge and associated skills are more likely to occur in the clinical situation, where the student has a better sense of what is occurring and can direct treatment accordingly.

As students move from the artificial environment of the classroom to the analytic environment of the clinical setting, clinical reasoning and problem solving become expectations. Learning becomes less structured, more personal, more interactive, and real. At this point, students struggle to bridge what they were taught in the classroom to what is occurring with the patient (clinically). This bridging is often weak and seldom a focus of instruction by clinical faculty.

Problem solving with computer-based simulation software may help to close the gap between what occurs in the health science classroom and what occurs in the clinical setting. Simulation software may also provide the cardiopulmonary science student an opportunity for detailed and advanced experiential learning prior to entering the clinic, and once at the bedside, to develop a systems view of the patient's condition.
METHODS

This study consisted of the evaluation of the use of computer-based cardiopulmonary simulation software as a learning and teaching tool to augment conceptual development and identify alternative conceptions in undergraduate cardiopulmonary science students. Emphasis was placed on the effects of sequencing the use of simulation software on novice and intermediate learners, and the diagnostic effectiveness of simulation to identify critical junctures in a course in cardiopulmonary physiology, with an emphasis on oxygen transport and utilization.

It was anticipated that the use of simulation as an instructional tool would result in more meaningful learning, better retention of concepts, and improved clinical problem solving.

Main Research Question

1. Can cardiopulmonary simulation software enhance the learning of propositional knowledge and/or help diagnose alternative conceptions in novices and intermediates?

Secondary Questions for This Study Were:

2. What are the effects of the use of cardiopulmonary simulation software prior to classroom instruction on motivation to learn and initial concept development?

3. Can postinstructional use of cardiopulmonary simulation software aid in self-assessing conceptual development and identifying alternative conceptions?
4. Can cardiopulmonary simulation software be used by the instructor and student (novice and intermediate) to identify critical junctures in understanding for concepts associated with oxygen transport and utilization?

Research Center

Louisiana State Medical Center (LSUMC) includes dual campuses located in Shreveport and New Orleans, Louisiana. The Medical Center offers a variety of undergraduate and graduate programs within the Schools of Medicine, Dentistry, Graduate Studies, and Allied Health Professions. The School of Graduate Studies offers graduate work in the basic sciences, such as biochemistry, physiology, cellular biology and anatomy, and microbiology. The School of Allied Health Professions offers undergraduate degrees in Cardiopulmonary Science, Clinical Laboratory Science, Rehabilitative Counseling, Occupational Therapy, and Physician Assistant. Graduate degrees are offered in Communication Disorders and Physical Therapy. Students enrolled in the undergraduate programs may choose to pursue a Master of Health Science Degree in Cardiopulmonary Science, Clinical Laboratory Science, Occupational Therapy, or Rehabilitative Counseling.

The Medical Center maintains clinical affiliation with local hospitals to provide clinical instruction for its various professional programs. In addition, each campus is associated with research foundations offering opportunities for research in the health sciences. This research was limited to examining students enrolled in the Cardiopulmonary Science Program at the Shreveport campus of LSUMC.
The Cardiopulmonary Science Program

Students accepted in the Cardiopulmonary Science Program enter at the junior level of a four-year baccalaureate degree program. The Cardiopulmonary Science Program provides professional education in two allied health subspecialties: respiratory care and cardiovascular technology. At the completion of the junior year, students are eligible to become licensed respiratory care practitioners and begin the credentialing process to become a Registered Respiratory Therapist. Meanwhile, students continue through the senior year to complete professional education in invasive and noninvasive cardiac diagnostics and cardiopulmonary home care and rehabilitation. Following successful completion of the senior year, students earn a baccalaureate degree and become credentialled in cardiovascular technology. Graduates enjoy a wide variety of employment opportunities including critical care, cardiopulmonary diagnostics, rehabilitation, and home care. In addition, graduates often obtain a leadership position in both respiratory care and cardiovascular technology. Most individuals upon graduation, choose to work in neonatal, pediatric, or adult critical care units to obtain clinical experience.

Prior to entering the program, students complete a minimum of sixty hours of freshman and sophomore course work that includes, in part, courses in chemistry, physics, biology, human anatomy, and microbiology.

Once the previously mentioned prerequisites are completed and application to the program is made, the student faces a competitive admissions process. If selected, the student enters the Summer Semester as a junior Cardiopulmonary Science student.
Students enroll in two summer courses: Human Anatomy (with complete dissection of human cadavers) and Human Physiology. Following successful completion of the first semester, junior students enter the second semester of the program (Fall Semester) and take: Respiratory Therapy Fundamentals (weeks 1-8), Cardiopulmonary Physiology (weeks 1-16), General Pharmacology (weeks 1-16), Advanced Techniques I (weeks 9-16), and participate in clinical education (weeks 9-16).

The novice student-participants enrolled in research entered this project at the beginning of the 1997 Fall Semester (August 1997). The senior intermediate student-participants entered the project at the same time. The intermediate student-participants completed the aforementioned course work and the following additional courses during the latter half of their junior year (Spring 1997): Advanced Techniques II (weeks 1-5), Pulmonary Pathophysiology (weeks 1-16), and Pulmonary Diagnostics (weeks 1-16), Neonatal and Pediatric Respiratory Care (weeks 1-16), Clinical Applications and Procedures II (20 weeks), Advanced Cardiac Care Concepts (10 weeks), and EKG Interpretation (10 weeks).

While participating in this research study, the three intermediate student-participants were enrolled in the following courses during Fall 1997 and Spring 1998: Principles of Allied Health Education (weeks 1-16), Noninvasive Cardiac Diagnostics I & II (weeks 1-16 for Fall and Spring), Cardiac Pathophysiology (weeks 1-16), Invasive Cardiac Diagnostics, plus participation in Clinical Application and Procedures I & II (20 weeks).
The Student-Participants

Participants enrolled in this research study were junior and senior students enrolled in the LSU Medical Center's School of Allied Health Professions', Cardiopulmonary Science Program. Student-participants entered the LSU Medical Center's Cardiopulmonary Science Program via competitive admissions to pursue a career in health care. It was assumed by the researcher that each student-participant had an innate desire to work with people and help humanity in some manner.

Novice student-participants consisted of nine students (six males and two females) ranging from 21 to 31 years of age for the 1997 Fall Semester and 8 students for the Spring 1998 Semester. One African-American female dropped from the program as a result of unsatisfactory grades in two Fall 1997 courses. Data collected from this student were not used in this research. Novice Group GPAs varied at the beginning of the study from 2.50 to 3.13 (on a four-point scale). The Intermediate Group consisted of two females and one male volunteers ranging between 28 and 30 years of age with GPAs at the beginning of the study varying between 2.50-3.50. Table 1 lists student-participants background information for novice and intermediate students. In addition, earned grades for the 1997 Fall Cardiopulmonary Physiology and Advanced Techniques courses are provided. Grades were complied from scores derived from tests, worksheets, in class exercises, and an instructor-designated 5% assessment of affective performance. The researcher felt the demographics of the student-participants represented a good mix of female and male and a sample of typical ages enrolled in Cardiopulmonary Science.
The Cardiopulmonary Physiology Course

The Cardiopulmonary Physiology course is designed to be a foundational course for students enrolled in Cardiopulmonary Science. This course and Respiratory Therapy Fundamentals are considered foundational courses on which the curriculum pivots, and both are necessary for subsequent, advanced courses. Students are not permitted to continue in the program if they are unsuccessful in either of these core courses.
Cardiopulmonary Physiology is a three-credit-hour course taught in 3 hour segments once a week for the entire 16 week semester. The course emphasizes pulmonary physiology, followed by cardiovascular physiology. This researcher has been the lead instructor for this course for 14 years.

The course content is divided into eight modules that include: (a) pulmonary anatomy and mechanics of ventilation (including pulmonary function and neurocontrol of ventilation), (b) gas exchange—oxygen, (c) gas exchange—carbon dioxide, (d) peripheral gas exchange (b and c include ventilation to perfusion relationships, diffusion, and pulmonary blood flow physiology), (e) systemic and pulmonary hemodynamics, (f) cardiac function, (g) control of cardiac output, and (h) autonomic circulatory control.

**Advanced Techniques II**

Students in the junior year enter their third semester by taking Advanced Techniques II. This five-week course prepares the student to administer critical care to neonatal, pediatric, and adult patients. Emphasis is placed on providing life support for patients suffering with cardiopulmonary disease, and assessing and monitoring their cardiopulmonary function. Specific modules contained in this course include: (a) managing airways, (b) providing mechanical ventilation, (c) maintaining and monitoring patients cardiopulmonary function while on life support, and (d) discontinuing critical care. Lectures were used for assessment and monitoring of cardiopulmonary function with emphasis on oxygenation.
Most of the instructor-provided concepts related to oxygen transport and utilization were given in the Cardiopulmonary Physiology and Advanced Techniques II courses. Both courses use a standard cardiopulmonary physiology and critical care textbook, traditional examinations, and a typical classroom format. Students have access to the instructor's electronic grade book for self-monitoring of achievement in either course and to see how the final grade is determined. Guest speakers are utilized as needed.

**The Cardiopulmonary Simulation Software Program**

The cardiopulmonary simulation software selected for this study places emphasis on cardiopulmonary physiology. The researcher's scientific career research interest includes cardiovascular effects of mechanical ventilation and assessment of bedside cardiopulmonary variables. Furthermore, the heart and lungs represent a complex system that will lend itself to a study of systems.

The heart and lungs compose the fundamental organs of the body's gas exchange system. The integration of these organs into a functional unit links the metabolizing tissues with the atmosphere. Tissue gas exchange is accomplished as a result of the anatomic arrangement and mechanical interplay between the heart and lungs, with a complex neurohumoral control mechanism. This complex system can be viewed as an integrated system of a pump (heart) within a pump (lungs) or viewed as two separate systems, the pulmonary and systemic circulations, with a common gas reservoir, the lungs.
The cardiopulmonary system lends itself well as a model for examining the undergraduate student's understanding of physiologic principles when confronted with healthy and disease states. A disease process involving any component of the unit will reduce the overall functional status of the system, and compromise the patient's oxygenation and tissue function (Weber, Janicki, Shroff, & Likoff, 1983).

After a nationwide search for simulation software, several related simulation programs were evaluated prior to selecting the SimBioSys™ Simulation Program (Samsel, 1994). Anesoft's Critical Care Simulator (Issaquah, WA) was evaluated and found to be limited in the degree of free inquiry, graphical interface, diagnostic options, and options for manipulation of pulmonary function. Emphasis with this simulation is the medical emergencies associated with hemodynamic dysfunction often seen in the emergency department or intensive care setting. This researcher felt this program did not include all the physiological components needed to illustrate cardiopulmonary physiology. Another program, the O₂/C0₂ Transport Model, developed by the Department of Physiology and Biophysics at LSU Medical Center in Shreveport, Louisiana was evaluated. This program simulated oxygen transport with a single graphical output device to illustrate change between two variables manipulated by the user. This program does not offer the user advanced concepts nor diagnostic or patient management options, and thus would not have served the purposes of this research.

Prior to evaluating simulation software, this researcher participated in extensive training to become familiar with the use of the Stella II (1996) modeling software program. Purpose of this training, in part, was for this researcher to develop
foundational theory and experience with systems thinking and to examine the possible role of the use of dynamic modeling software in the Cardiopulmonary Science Program. Following completion of this study, the use of Stella II as an adjunct to simulation will be pursued.

**SimBioSys™ Version 2 – A Simulator of Biological Systems**

SimBioSys™ (SBS) is an educational software package that simulates the physiologic functions of the human body (Samsel, 1994). This computer-based simulation software is produced by Critical Concepts, Incorporated, 225 N. Michigan Ave, Suite 2522, Chicago, IL. A website describing the program may be found at http://www.laketech.com. The SBS program is composed of two parts: SBS Clinics and SBS Physiology Labs.

The SBS program is an advanced tool for physiology education. By simulating experimental cardiopulmonary data in real time, the learner can test his or her understanding of physiology against a state-of-the-art, integrated mathematical model of the cardiopulmonary, renal, and vascular systems. This real-time simulation program both simplifies and mirrors what occurs in real-patient conditions.

Responding like the human body, SBS allows changes in pressure, flow, volumes, and nutrient concentration, determined by one system communicating with all the other body systems and influencing their function. This automatic integration of subunits of larger systems allows the user to see effects of various interventions and therapies on a simulated patient case.
The essence of SBS is simulated realism. SBS is designed to be as realistic as possible, while being a user-friendly, high fidelity simulation program. Systems modeled include the heart (right and left atria and ventricles) coupled with the pericardium and pleural cavity, vasculature of the pulmonary and systemic circulations, lungs, peripheral tissue metabolism, and renal function, fluid, and electrolyte distribution.

Each physiologic component is modeled as a set of differential equations. Cardiac chambers are modeled using time-varying elastance and resistance concepts, while pulmonary and systemic arteries and veins are represented by one- or two-compartment models. Pulmonary mechanics are computed from a nonlinear description-of-lung-and-chest-wall-behavior model. Lung gas exchange is calculated from a 50-compartment ventilation-to-perfusion distribution of ratios. Blood acid-base chemistry is determined by ion and carbon dioxide concentration. Peripheral gas exchange is determined by conventional oxygen uptake-delivery relationships. Fluid and solute exchange is governed by a 15-compartment model. Transport relationships incorporate permeability, and oncotic and hydrostatic pressures. Renal fluid exchange predicts glomerular filtration rate from glomerular pressure, which, in turns, depends on aggregate resistance in the afferent and efferent arterioles (Samsel, 1994).

SBS is capable of modeling the following:

1. pressure and volume in any cardiac chamber;
2. arterial, pulmonary arterial, and central venous pressures;
3. cardiac output, aortic blood flow, blood volume;
4. end-diastolic and end-systolic pressures and volumes;
5. arterial and mixed venous oxygen measurements;
6. systemic oxygen delivery and uptake;
7. pleural and pericardial pressures;
8. alveolar pressure, volume, and flow;
9. auto-positive-end expiratory pressure, and ventilator waveforms; and
10. urine production, or solute concentration.

Overview of SBS Physiology Labs

SBS Physiology Labs is an open-ended simulation that allows users to explore human physiology independently and easily. Instructor-designed laboratory exercises or standard exercises found within the program can be used. Hundreds of values are calculated in real time and can be viewed as waveforms or digital data. Physiologic parameters can be adjusted from normal values and responses observed. Instructors can preconfigure variables to control various cardiopulmonary responses for the user to observe.

SBS can control a variety of parameters via a tool bar. Those variables which can be adjusted by the user include:

1. systemic and pulmonary arterial and venous compliance;
2. systemic and pulmonary vascular resistances;
3. diastolic compliances of atria and ventricles;
4. contractility of atria and ventricles;
5. ventilatory parameters, such as tidal volume, mode and so forth;
6. pericardial fluid volume;
7. lung volumes and capacities;
8. chest and lung compliances;
9. shunt fraction, deadspace ratios, and V/Q ratios;
10. peripheral circulation gas exchange properties; and
11. infusion of drugs (e.g., dosages, rates, and frequencies).

Not all parameters can be changed. If a parameter is selected that is under normal physiologic control, the user will be unable to change it. This may occur when the user selects a variable that is an output of the simulation (e.g., cardiac output). However, for experimental reasons, the program allows parameters under control of the body, for instance, autonomic control, to be temporarily disconnected; and the user is free to investigate cause-and-effect relationships in greater depth.

**Overview of SBS Clinics**

SBS Clinics allows the user to explore human physiology in a clinical setting. SBS simulates an intensive care unit where the central tool is the patient monitor. Using a tabbed interface, the patient's status can be examined with various diagnostic and treatment options. Once a patient case is chosen (the user can choose from a variety of patients suffering from pulmonary or cardiovascular disease), the user is virtually at the bedside with all the resources a typical intensive care unit provides. Users have the option to perform a complete physical exam, obtain EKGs or echocardiograms, examine chest x-rays, administer fluids, place arterial catheters, and obtain hemodynamic measurements. Tube thoracostomy or pericardiocentesis can also be
performed. The patient can be intubated and placed on mechanical ventilation. As drugs and fluids are given, or other interventions performed, effects can be observed in real-time with actual parameter outputs (e.g., waveforms or digital readings). This sample of options illustrates the appropriateness of this simulation program for cardiopulmonary science students. Examples of the monitor output and physiologic exercises are illustrated in Appendix B.

In summary, the SBS program allows the learner to observe, realistically, in real time, the physiological parameters of the cardiopulmonary system. By using surrogate patients for medical study, user intervention can be displayed by a variety of monitors and displays. Via the user control interface, effects of drugs and interventions, or effects of alteration of model parameters can be observed with a variety of patients.

Methods Used for Addressing Research Questions

Rationale for Qualitative Research Design

The rationale underlying qualitative research is to better understand phenomena by using exploratory and explanatory strategies. Qualitative investigators view research as an interactive process embedded in an ever-changing world wherein rich descriptors are required, along with purposeful sampling and processing of data as it is collected (Gilchrist & Engel, 1995).

Traditional medical researchers seek cause and effect, using positivist approaches with elements of randomization, control, and manipulation. The quantitative researcher, however, views what is being studied as external and independent of the researcher, and seeks objectivity.
A positivist model, or quantitative orientation extracts simple relationships from complex, real-world phenomena and examines them independent of time and context. For example, a person's affect or personhood may be studied to find out if it is stable, rather than ever changing (Rubin & Rubin, 1995). According to Rubin and Rubin (1995), "The idea that there may be several different realities, that is different constructions of events by the participants, an idea that underlies much of qualitative interviewing, is unacceptable in quantitative positivism" (p. 33).

Qualitative researchers view themselves as a part of what is being studied. An investigator will construct a personal mental model of experiences that attempt to characterize and understand the observed behavior. The essence of qualitative research is observation and interpretation (Gilchrist & Engel, 1995).

Qualitative research is completed in a natural setting where study participants are found. Qualitative research respects the influence of both the researcher and the participant's perspective of the event or behavior being studied.

The purpose of qualitative research is to contextualize, interpret, and understand the perspective of the study participants. In contrast, quantitative research seeks to make generalizations, predictions, and explain cause and effect. Where qualitative research is inductive, quantitative research is deductive.

Outcomes of qualitative research include, in part, the generation of hypotheses, seeking or identifying patterns, and an attempt to understand the meaning the study's participants place on events or behavior being studied (Glesne & Peshkin, 1992).
A key aspect of qualitative research is recognizing that results vary according to the context of the setting or the participant. Effective clinical interviewing of a patient is, in essence, a form of qualitative research. The clinician observes and talks with the patient and generalizes a working diagnosis, often prior to collecting objective data. Because science encompasses approaches to "know" something based on systematic inquiry, hypothesis testing, and theory generalization, one can be just as scientific categorizing observations and behaviors, as when evaluating objective laboratory data (Gilchrist & Engel, 1995). As the interview unfolds, the clinician may alter his or her diagnosis, just as a qualitative researcher may alter a hypothesis as information becomes available.

Just as medicine is a human science defined by making meaning-meaning of events, experiences, symbols, utterances, and behavior (McWhinney, 1989), learning is a process that creates new meanings (Ausubel, 1978). Since there are no objective tests for meaning, qualitative research answers questions that quantitative research cannot. Those questions include asking what motivates a person to do what he or she does, what are a person's perceptions or expectations, and what meaning do individuals place on experience?

Teaching and learning are personal experiences that vary from person to person. The value a learner places on a particular teaching experience will influence what is attended to and what is learned (Tobin et al., 1994). With such concepts in mind, the researcher is motivated to examine what occurs cognitively with students while they attempt to make meaning of what is being presented in the classroom, how the more
powerful ideas develop in the context of learning, and what motivates learners to want to learn new material.

Qualitative research methods such as the clinical interview (Novak & Gowin, 1984), Socratic questioning (Paul, 1995), protocol analysis (Ericsson & Simon, 1991), verbal analysis (Chi, 1997), and qualitative interviewing (Rubin & Rubin, 1995) can be used to identify the learner's understanding, conceptual development, and meaning. Furthermore, with these strategies, what motivates learners to learn and what aspects of learning are valued can be discerned.

Clinical interviewing, protocol analysis, and verbal analysis will be described briefly. This research utilized clinical interviewing and verbal analysis, in part, for data collection.

**Clinical Interview**

Novak and Gowin (1984) build upon the tradition of Jean Piaget and his colleagues who perfected the interview as a tool for assessing cognitive function. With interview techniques adapted from Piaget (Novak & Gowin, 1984), Novak and Gowin developed a meaning-based, qualitative research strategy known as the clinical interview. The clinical overview is widely used to: (a) expose a learner's cognitive framework, (b) understand what is being observed by the learner, and (c) explore the self-reported reasons for human behavior.

Verbal data from interviews can help form explanations and theories that are grounded in the details, evidence, and examples of the interviews. Derived in part from this type of data can be theory and a understanding of cognition (Rubin & Rubin, 1995).
Novak and Gowin's (1984) interview techniques can vary from highly flexible (since questions vary from learner to learner) to highly standardized (e.g., preestablished questions and questioning patterns). Questions may vary in scope from narrow and focused to broad and expansive.

According to Novak and Gowin (1984) there are several reasons why the questioning format should remain flexible. These authors state:

* We are trying to look into the student's cognitive structure and ascertain not only what concepts and propositions are there, but also how those concepts are structured and how they can be evoked for problem solving. A narrow spectrum of tasks and/or questions may heretofore fail to reveal knowledge or abilities that are highly relevant to a broader assessment of abilities (pp. 121-122).

The interview topic should focus on the area of interest being pursued by the researcher. Although the affective domain can be assessed via interviews, the focus of the clinical interviews for this study was to determine the learner's conceptual development and alternative conceptions.

Novak and Gowin (1984) advocate the use of the clinical interview prior to formal instruction for determining "what the learner knows," and then instructional strategies should be planned accordingly (Ausubel, 1978). Knowing what the learner knows about a topic allows the teacher to select and organize concepts and examples to enhance the effectiveness of instruction.

To plan the interview the researcher may create a "master" concept map of the topic being examined. Various concepts and propositions can guide the interviewer in generating questions and selecting props to use with the interview. Novak and Gowin
(1984) suggest identifying key concepts for the topic and having a sample of learners add to them and create individual concept maps. From the collected learner's concept maps, the researcher can identify valid propositions and the presence of alternative conceptions. These authors suggest evaluating and revising interview questions several times before using learner-generated concept maps. In other words, using the learners' concept maps as a starting point, faulty propositions can be identified and interview questions constructed that further probe the learner's understanding to ascertain whether or not additional alternative conceptions exist. A list can be generated from the initial concept maps and recorded for triangulating with other data.

The collection of concept maps and listing of faulty propositions can serve as a guide for choosing interview props, puzzling activities, and other evocative devices to be used during the interview process. These interview aids may be used to expand upon a topic being questioned or as probes for further questioning.

Using questions generated from a collected set of concept maps is an efficient way to begin the interview. Opened-end, general questions should be used first to secure cooperation and create a non-threatening atmosphere. Questions should move from more to less familiar, and from broad to detailed.

Guidelines for conducting a clinical interview include:

1. select the topic (interviewer must be a content expert);
2. prepare a concept map of the topic to use as a guide for questions;
3. structure questions with the concept map—keep the focus narrow;
4. select props to augment the interview questions;

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5. begin with open-ended, factual questions;
6. record the interview for later transcript analysis;
7. demonstrate patience and good listening skill;
8. avoid irrelevant discussions;
9. rephrase the interviewee's questions using his or her own language; and
10. avoid teaching and imposing your own logic on the interviewee.

Novak and Gowin (1984) mention other issues worth noting. These include avoiding Socratic teaching during an interview. The intention of the interview is to ascertain what the learner knows and how that knowledge is used. Socratic questions may steer the learner toward a different understanding or a peripheral topic to discuss. The interviewer should use neutral language prompts such as, “Tell me more about that,” or, “Anything else you can tell me about this?” Other considerations include having the interviewer be a competent expert, having patience with the process, and noting behavioral and affective comments— if relevant to the topic.

**Data Analysis from Interviews**

Novak and Gowin (1984) describe a process called concept propositional analysis (CPA) as a method for analyzing interview data. The technique includes editing transcripts from completed interviews to extract a set of propositions that learners hold as a part of their understanding. Appropriate segmentation and selection of grain size of the verbal data will yield the desired patterns and information. These factors are determined based on the working hypothesis the researcher has, and his or her theoretical orientation (Chi, 1997). The task of CPA may be accomplished using
powerful qualitative research analysis programs called NUD*IST™ (Richard, 1996) and Q-Notes™ (Brackett, 1997) data bases.

An alternative strategy may be to construct a table showing propositions identified prior to instruction, key propositions or concepts included during the instruction by the teacher, and a list of propositions given by the learner following instruction. Several researchers have created conceptual inventories from interview data (Erickson, 1979; Songer & Mintzes, 1994). Analysis of interview date can be used to create a list of student-generated propositions which then can be classified under categories that represent the knowledge domain of the topic under consideration.

Interpreting Data Derived from an Interview

Once the data are collected and recorded, knowledge categories or codes are developed to categorize similar concepts and propositions obtained from the interview. Multiple interviews are required (with identified concepts, propositions, and alternative conceptions) to create appropriate codes or categories. A typical 30-minute interview can yield four to seven categories (Novak and Gowin, 1984). As with other qualitative data processing techniques, verbal data from the interviewee may be coded and processed using a qualitative research computer program designed for analysis of qualitative data. Data can thus be processed to determine similarities and links between data pieces in order to form a hypothesis about the interviewee's or groups of interviewees' cognition.
**Concept Mapping Evaluation**

Concept maps may be graded or evaluated using a variety of techniques described in the literature (Novak & Gowin, 1984; Wandersee, 1990). Wandersee suggests the use of The Standard Concept Map checklist (see Appendix C). This checklist evaluates the map for components such as seed concepts, appropriate links between concepts, use of examples, scientific quality, and number of elements. A score can be generated to provide quantitative analysis. This research used this checklist to assess student-participant-generated concept maps.

This study employed the interview technique, concept mapping, and verbal analysis to ascertain what the student-participants knew about oxygen transport and utilization both before and after experiencing the cardiopulmonary simulation software. Data collection was conducted across a 27-week period to capture and record concept development over time.

**Protocol Analysis**

Ericsson and Simon (1993) developed a qualitative strategy to analyze the verbal data generated while a subject is solving a problem. Distrusting behaviorism's use of verbal data, these researchers relied upon observable or verbalizations as mirrors to information processing. To assess thinking, they developed a strategy known as protocol analysis. Protocol analysis consists of three substrategies known as talk-aloud protocol, think-aloud protocol (known as concurrent verbalization), and retrospective verbal reports. Talk-aloud protocols analyze verbal data from subjects saying out loud whatever they are silently saying to themselves, while think-aloud protocols ask the
subject to literally think aloud while solving a problem. Think-aloud protocols help to illuminate the subject's understanding of concepts and the presence of alternative conceptions (Grabinger, 1996). Retrospective verbal reports are verbal data given by the subject immediately following the completion of a task or solving a problem. This form of verbalization uses information in short-term memory and long-term memory, and thus requires additional mental processing. Because think-aloud protocols parallel the method used for data collection for this research (verbal analysis) (Chi, 1997), a brief description of think-aloud protocols will be provided.

Protocol analysis is based on several premises or assumptions: (a) verbalized cognition or thinking can be described as stating what corresponds to the contents of short-term memory (i.e., information that is being attended to), (b) the information vocalized is a verbal encoding of the information in the short term memory, (c) the verbalization processes begin as thoughts become conscious, and (d) the verbalization is a direct encoding of the heeded thought and will reflect latent cognitive structure.

Ericsson and Simon (1993) describe thoughts as a “sequence of states, each state containing the end products of cognitive processes, such as information retrieved from long-term memory, information perceived and recognized, and information generated by inference” (p.xiii). Information, according to these authors, is stable and can be verbalized and reported as verbal data. Although information can be reported, the retrieval and recognition process that takes place within the person's cognitive structure cannot be reported.

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The standard methods for obtaining verbal data or having persons verbalize their thoughts is to instruct them to “think aloud.” While thinking aloud and verbalizing the steps to solve a problem, subjects are discouraged from explaining why or describing why they chose to perform a particular step.

Chi (1997) describes think-aloud protocols as having the subject state or verbalize sequentially how a problem is getting solved. Simple verbalization will not affect the outcome of problem solving.

Think-aloud protocols focus on the process in which the subject engages to solve a problem or make a decision. The researcher analyzes the sequence that the subject uses to arrive at a solution and compares this to an ideal “template” or a task analysis of the problem-solution set. Containing the problem and analyzing the details of verbalization is the defining feature of protocol analysis. Data collected with this method can be processed similar to CPA, with the use of a qualitative research computer-based analysis programs.

Limitations of think-aloud protocols include not asking how the problem or task was generated or why a particular strategy was adopted by the subject. Instructions to the subject must be precise and the researcher must be able to assure a relationship between requested information and the actual sequence of heeded information (Ericsson & Simon, 1991).

Ericsson and Simon (1991) conclude by stating that verbal data can be seen as one of several categories of data about cognitive processes and models. Methods of accounting for verbal data should not be any different than for any other source of data.
Furthermore, verbal data should be integrated with other data collected within an educational research study.

**Verbal Analysis**

Much of the data collected during qualitative research is "soft" data or what Chi (1997) calls "messy" data. These data may be obtained from interviews, verbal explanations, observations, gestures, and media forms such as pictures, videotapes, and films. A focus of qualitative research is to gather data in the context that it is occurring. For example, a study by Chi, Hashem, Ludvigsen, Shalin, and Bertram (cited in Chi, 1997) used videotaped conversations among attending physicians, interns, and residents while making rounds on hospitalized patients. These verbal data collected in a natural, field setting yielded rich, descriptive data (as a result of collecting it within context of the hospital).

Attempts to combine qualitative and quantitative methods to account for the deficiencies inherent in each method has been advocated (Savenye & Robinson, 1996). Though there are various ways to combine the two research paradigms, this discussion will focus on how verbal analysis can provide both quantitative and qualitative evaluations of verbal data.

There are several ways to integrate qualitative and quantitative analysis. Chi (1997) recommends using qualitative data to help interpret quantitative research findings. A second method is to combine a quantitative measurement with a qualitative measurement. For example, this study combined test scores, number of propositional knowledge statements from verbal analysis to form a hypothesis and knowledge claims.
A third way to combine the two research methods is to use a qualitative approach to
generate a hypothesis and then pursue quantitative methods to gather data to accept or
reject that hypothesis. “Qualitative data is [sic] examined for impressions and trends,
methods of coding are developed to capture those impressions, and the coding can then
be analyzed quantitatively” (Chi, 1997, p. 281). For example, with this method the
number of inferences a student-participant makes within a coding category can be
quantitatively processed. Verbal analysis was a primary data collection method used in
this study.

Verbal analysis is a method for quantifying the subjective verbalization of a
subject. As Chi (1997) describes, with “verbal analysis, one tabulates, counts and draws
relations between the occurrences of different kinds of utterances to reduce the
subjectiveness of qualitative coding” (p. 273). This study quantitated propositional
knowledge statements—which are unique verbal phrases containing a linked concept--
and alternative conceptions. The researcher’s intention with verbal analysis was to
understand how subjects think and learn. A goal of verbal analysis is to determine what
the subject knows by analyzing what the subject says, does, or exhibits to indicate
knowing (e.g., gestures, body language).

Analyzing verbal data in attempts to capture the cognitive structure or
understanding that underlies the verbalization includes quantifying results. This may be
accomplished by analyzing the content found in verbal data, organizing the content
(coding), and assessing the relationships of propositions, concepts, or ideas that
emerged from the verbal data (Chi, 1997). Chi refers to these relationships of content as
structure. Chi supports the use of verbal analysis to analyze think-aloud protocol data. Unlike protocol analysis, where the intent is to capture the process in which the subject engages to solve a problem, verbal analysis attempts to capture the subject's representation of the knowledge. Instead of using an ideal template to see if the subject's problem-solving process fits, verbal analysis attempts to establish that mental model or mental template from which the subject is working.

Protocol analysis compares the researcher’s ideal template for the process to follow in solving a problem to the subject's verbalization of his or her process. The degree of match validates the verbal analysis (Chi, 1997). With verbal analysis, the quantification of qualitative coding is performed to see if results support the researcher’s working hypothesis.

**Technique for Verbal Analysis**

Once verbalizations are collected and transcribed (e.g., from interview or think-aloud protocols), the researcher performs several steps to analyze the verbal data as outlined from Chi (1997):

1. Using qualitative research methods, analyze transcripts and develop codes for classifying data (Denzin & Lincoln, 1994). To reduce the amount of data collected the researcher can use random sampling of verbal data.

2. Establish the size of the segment of the verbal data. This means determining the grain size of the data to be analyzed, such as a proposition, a sentence, an idea, a reasoning chain, a paragraph, a
specific activity (event). Segmentation can be done from a narrow piece of data to a more complete data set, referred to as coarse grain size. (Coding at several grain sizes can increase the reliability of collected data and the resulting conclusions.) Use of coarse segmentation will aid in the capture of the semantics of inferences and concepts, or the presence of alternative conceptions. Segmenting several sentences to capture the subject's reasoning may aid in identifying a more complete thinking process. With this study, the actual grain size was determined after data collection occurred.

3. Develop a coding scheme for the data collected.

4. Using qualitative data analysis software (e.g., NU*DIST and Q-Notes), propositional knowledge statements can be coded.

5. Once the data are coded, analyze via qualitative data analysis to seek patterns and aid in interpreting the data—ultimately reaching a tenable hypothesis.

This project attempted to draw upon data generated by clinical interview, concept mapping, and verbal analysis to triangulate the data collected. Data gathered from concept maps, field notes, interviews, and tests were processed using the QSR NU*DIST Version 3.0 9 (Richard, 1996) and Q-Notes™ 1.1 software packages (Brackett, 1997). NU*DIST stands for Non-numerical Unstructured Data Indexing Searching and Theorizing and represents a computer-based program to aid users in handling non-numerical and unstructured data for qualitative analysis. The heart of the
NU*DIST program is the ability to index, search, and theorize about data that have been collected and stored within the program.

The NUD*IST program (Richard, 1996) creates an environment to store and explore data and ideas, to minimize clerical routine and maximize flexibility while discovering patterns, trends, and new ideas. Specifically, NU*DIST assists the qualitative researcher to:

1. manage, explore, and search text and documents;
2. manage and explore ideas about data;
3. link ideas and help theorize about data;
4. test theories about the data; and
5. generate reports including statistical summaries.

NU*DIST (Richard, 1996) is designed to handle a variety of data sources including text (e.g., interview transcripts, reports, minutes), historical or literary documents, personnel records, field notes, newspaper clippings, and abstracts. Non-textual data can also be stored—such as musical scores, photographs, tape recordings, films, and maps.

Each research project entered into the NU*DIST environment has its own database which stores the records of textual and non-textual data (Richard, 1996). Data can be maintained both on-line and off-line. The project data base allows the storage, editing, and retrieval of data (e.g., text), recording factual information about each data source, writing and editing of memos and ideas about collected and coded data, and the searching for and finding of key words or phrases in the data source via indexing.
In addition to the initially described database, each project has an indexed database that allows the user to create, record, store, and explore categories for thinking about the project, code or index data, and manage coding categories and subcategories in index "trees". NU*DIST allows modification of the index or codes at anytime. Users can search the index system to locate links between coding categories and data, write and edit memos about the indexing scheme, and create new categories for future analysis.

NU*DIST is designed around two interdependent subsystems; (a) the document system contains information about each document, whether on- or-off line and any memos attached, and (b) the index system contains index categories created by the user, in addition to all the information about the categories (e.g., title and definition of nodes, which document the node indexes, and any attached memos) (Richard, 1996). NU*DIST creates a sophisticated indexing system that allows the user to locate documents and other data, allows any part of the document or data collected to be indexed at any number of topics, while allowing for search and retrieval of single or combined topics.

NU*DIST indexes data by placing them in virtually unlimited categories and subcategories. Relationships between categories and subcategories are illustrated by a tree-shaped graphic (Richard, 1996). The tree begins at the root containing the most general category (at the top) followed with multiple branching to subtrees to show how the subject is divided. An example of indexing for this project includes oxygen transport divided into blood and plasma, then blood flow, tissue oxygenation, and so forth.

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The tree-like structure for representing data in NU*DUST contains nodes that are found at each branching of the tree (Richard, 1996). Once the index system has been developed for a particular project, the complete, tree-like graphic can be viewed, or any portion of the tree can be selected and observed in detail. The user can access particular topics to see what data is stored there, just by clicking on the desired node. The user can record notes on any node. NU*DUST assigns each node a numerical address and a title for easy access.

The index tree becomes a map of the research project and is modified and expanded as the project unfolds. The tree map shows the ideas being researched, categories or codes being developed, facts being stored, and subjects being explored.

NU*DUST is unique in its approach to data analysis. It is one of only two programs that will handle complex data beyond just cataloging, searching, and retrieval of data (Richard, 1996). NU*DUST will assist in shaping one's understanding of the data collected, and thus help shape and form theory.

For this research, NU*DUST was used for storage of data gathered by the various methods for selected collecting data (Richard, 1996). These data included concepts, propositional knowledge statements, alternative conceptions, and field notes. Each of these data were defined and edited, labeled as to how data are related to other data documents by index references, and linked in a flexible, tree-like graphic index system of categories and subcategories that provides a data picture for theory development.
Q-Notes™ produced by the Q-Corporation in Brookline, Maine is an electronic note-card system that runs alongside other computer programs, such as a word processing program (Brackett, 1997). Q-Notes™ offers an easy method to organize, store, and print notes, transcript data, and other typed information into electronic files. Taking any data placed on the computer’s clipboard, the qualitative researcher can create unlimited number file topics. Each entry to the clip board can be placed in a predefined coding category with bibliography information, optional notes, and printing option. Each topic and file series can be placed in a tree-like graphic so the user can see how information is organized. Q-Notes™ was used in this study for the second and third coding processes.

This project tracked conceptual development and identified propositional knowledge statements and alternative conceptions held by Cardiopulmonary Science students enrolled in a cardiopulmonary physiology and advanced respiratory care course. As data were collected, the researcher developed ideas about the data, explored links between data, described possible causes for the data, and interpreted the data to identify emerging theories or hypotheses. To accomplish this, NU*DIST™ (Richard, 1996) and Q-Notes™ (Brackett, 1997) software programs were employed for data analysis.

**Overview of Research Phases**

This research proceeded in three distinct phases: (a) Novice Group A exposed to simulation software prior to formal lecture, (b) Novice Group B exposed to simulation software following formal lecture, and (c) use of simulation with an Intermediate Group
for patient case-management. Flow diagrams (Figures 1 & 2) are included to illustrate
the above phases this research addressed:

![Flow Diagram of Research with Intermediate Group](image)

**Figure 1**
Flow Diagram of Research with Intermediate Group

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The researcher conducted a pilot study during the 1997 Summer Semester involving three student-participants. The purpose of the pilot study was to explore the use of three processes: concept mapping, clinical interview, and cardiopulmonary simulation software with Cardiopulmonary Science students.

Pilot study results provided the researcher with further experience with clinical interviewing, instructing how to construct concept maps, and to assess time requirements for orientating student-participants to the simulation program. For
example, results of the pilot allowed the researcher to adjust interview technique to be more of an effective data gathering technique. These data along with simulation data provided the researcher an opportunity to experience verbal analysis and to code data following guidelines established by Chi (1997). Verbal protocols obtained from the pilot using the simulation program revealed that this method may be effective in answering the research questions established for this study.

In summary, the results suggested these research tools were effective for assessing the presence of propositional knowledge, alternative conceptions, and gaps in conceptual understanding of oxygen transport and utilization. Appendix D provides a summary of the pilot study design and results.

**Institutional Review Board Approval**

On August 12, 1997 the Louisiana State University Medical Center Institutional Review Board (IRB) for Human Research met and approved this research protocol. The IRB assigned this project with an approval number (#97-536) and made the following recommendation: (a) approved by exemption (b) provide written documentation for assurance of student-participant confidentiality with study results. The Initial Review of Protocol Report of Committee Action form was signed by A. Oliver Sartor, M.D., Chairman of the IRB Committee on the above date (see Appendix E).

**Student-Participant Orientation**

At the beginning of the Fall Semester (August 1997), the researcher met with the student-participants (both novice and intermediates) and provided an overview of the research plan, an opportunity for questions, and sought participants on a volunteer
basis. All student-participants that chose to participate read and signed a permission form (see Appendix F). All signed forms are on file in each of the participant’s departmental file. Novice student-participants were not reimbursed for their efforts, However, to assure participation by intermediate student-participants, a stipend of $50.00 was paid to each at the completion of the study. The researcher felt payment was necessary due to the intermediate student-participants’ demanding school and employment schedules. The stipend was also offered to encourage appointment keeping and to improve the quality of data reporting.

During the first week of the 1997 Semester, the researcher divided student-participants (N=11) into the following groups:

1. Novice student-participants (n=3) who experienced the SBS program prior to formal instruction. This group was Novice Group A.

2. Novice student-participants (n=5) who experienced the SBS Program post formal instruction. This group was Novice Group B.

3. Intermediate student-participants (n=3).

Novice student-participants were randomly assigned to each of the two groups.

Pretest

Both novice groups were given a pretest composed of 30 questions (see Appendix G). Scores from this pretest along with the participant's GPAs were used to rank each student-participant. The researcher made the assumption that, based on previous biology-related course work (e.g., human physiology), the novice groups had an elementary understanding of concepts related to oxygen transport and utilization.
Test scores, GPAs, and any field notes taken during pretest session were placed into a NU*DIST™ (Richard, 1996) and a Q-Note™ database (Brackett, 1997).

**Eight Content Modules and Simulations**

Prior to the beginning of the semester, the researcher generated a list of eight modules that represented key content areas of the two courses with which the study was associated with. These content areas were related to oxygen supply and utilization. From this list, eight simulations were created using the cardiopulmonary simulation program (see Table 2). Related pre-existing simulations were identified from the operator’s manual of the SimBioSys™ Physiology Labs program (Samsel, 1994). Each simulation exercise was modified to reflect content of the two courses. The modifications were based on the textbook content, national standards for respiratory care education, and the experience of the researcher.

<table>
<thead>
<tr>
<th>Table 2 Eight Content Modules for Simulation Studies</th>
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<tbody>
<tr>
<td>1. Mechanics of Ventilation</td>
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<td>2. Ventilation-to-Perfusion Ratio</td>
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<tr>
<td>3. Oxygen Transport I</td>
</tr>
<tr>
<td>4. Control of Cardiac Output</td>
</tr>
<tr>
<td>5. Oxygen Transport II</td>
</tr>
<tr>
<td>6-7. Preload, Afterload, and Contractility</td>
</tr>
<tr>
<td>8. Oxygen Dependency</td>
</tr>
</tbody>
</table>

**Precourse Interview**

A precourse clinical interview was conducted with each novice student-participant (See questions in Appendix H). The precourse interview and all subsequent
interviews were audiotaped, transcribed, and coded for analysis. The combination of pretest scores and interview data provided the researcher with an understanding of the novice group's entry-level knowledge of concepts related to oxygen transport and utilization.

**Concept Mapping**

The researcher demonstrated and instructed the novice groups on how to create a concept map using guidelines established in the literature by Gowin, Novak, and Wandersee (Gowin, 1981; Novak & Gowin, 1984; Wandersee & Abrams, 1994). Each student-participant generated a macro map using a researcher-generated list of seed concepts following each lecture-series that corresponded to the eight content modules (see Table 2). A total of 48 concept maps were generated during the course of this study. Each map was scored and evaluated using the Standard Concept Map Checklist (see Appendix C) and evaluated for propositional knowledge statements and alternative conceptions. The overall novice student-participant group average score for these maps was 38 (maximum score was set at 50 points). Concept maps were created by the student-participants from August of 1997 through March of 1998. These data were transferred to the NU*DIST™ (Richard, 1996) and Q-Note™ (Brackett, 1997) database.

**Prefecture Simulations**

During the first week of the Fall 1997 semester and prior to the first formal lecture in the cardiopulmonary physiology class, Novice Group A completed the first simulation modules using SimBioSys™ Physiology Labs (this simulation was on the
mechanics of ventilation—see Appendix I for sample simulation guide) (Samsel, 1994). Each student-participant was instructed to think-aloud throughout the completion of the simulation. All verbalizations were audiotaped. Novice Group A completed each of the eight simulations module using SimBioSys™ Physiology Labs prior to each corresponding lecture series. As with the first simulation, all verbalizations of the remaining simulations were audiotaped, transcribed, coded, and analyzed.

Postcourse Simulations

During December of 1997 and February of 1998 following each study course (Cardiopulmonary Physiology and Advanced Techniques II), Novice Group B completed simulation exercises using SimBioSys™ Physiology Labs (Samsel, 1994). Simulations 1-4 were completed in December of 1997 and simulations 5-8 were completed in February of 1998. Each student-participant was instructed to think-aloud throughout the completion of the simulation. All verbalizations were audiotaped. Novice Group B completed each of the eight simulations module using SimBioSys™ Physiology Labs following each of modules corresponding lecture series. All simulation verbalizations were audiotaped, transcribed, coded, and analyzed.

Critical Junctures

The researcher generated a preliminary list of critical junctures and subjunctures that dealt with main concepts associated with oxygen transport and utilization (See Table 4). These junctures were chosen based on the teaching and clinical experience of the researcher. The junctures paralleled key macro concepts found in most cardiopulmonary physiology textbooks. The preliminary list was submitted for
modification and approval to a panel of three content specialists which included a scientist/physician and two respiratory care science educators (see Appendix J). The validated list of critical junctures helped frame questions asked in subsequent clinical interviews. The preliminary list of critical junctures was modified (via expert panel and researcher) in January and July of 1998 to reflect the validated critical junctures. These modifications were in part, a result from on-going data analysis during this study.

The researcher recorded related field notes that applied to this project. Notes were coded, stored, and analyzed via the NU*DIST™ (Richard, 1996) and Q-Notes™ (Brackett, 1997) programs as needed. Lecture content was derived from the researcher’s instructional file containing previous written lesson plans, overhead transparencies, slides, and so forth.

**Following Each Lecture Series**

Both novice groups received the same formal instruction (lecture series related to the eight topics of content modules). The first four content modules (see Table 2) were completed during the Fall 1997 Semester (within the Cardiopulmonary Physiology course) and the remaining four modules were completed during the Spring 1998 Semester (within the Advanced Techniques II course). Following each completed module, all student-participants completed a macro concept map on the module topic using a list of researcher-generated seed concepts. Maps were collected, analyzed, and data stored in the NU*DIST™ (Richard, 1996) and Q-Notes™ (Brackett, 1997) databases. Field notes were maintained, coded, stored, and analyzed.
Postlecture Interview and Exam

Following each lecture series that represented the content of each of the eight content modules, a clinical interview was conducted with each novice participant from both groups. Questions were based on key concepts the researcher considered were important to the content module, postinstruction concept maps, and critical junctures. Data were audiotaped and analyzed as described previously.

Regular course exams were given to both novice groups at selected times during the course, independent of this study, for student grade determination. Exam item responses related to the eight content modules and critical junctures were recorded and coded.

At the conclusion of this study, novice group student-participants were given a post-test. The post-test consisted of the same 30 questions that were on the pretest that was administered in August of 1997. Comparing tests for internal consistency and to assess degree of student-participant, improvement scores were analyzed using the Cronbach alpha formula.

Both novice groups completed the standard departmental course evaluation and these data were added to a NU*DIST™ (Richard, 1996) and a Q-Note™ (Brackett, 1997) database. Evaluations are on file in the Department of Cardiopulmonary Science.

Remediation of Novice Groups

Any resistant alternative conceptions demonstrated by novice student-participants following Advanced Techniques II (as a result of initial analysis of collected data) was addressed by researcher-generated lecture and simulation problem
using the SimBioSys™ Physiology Labs. With a portable computer, LCD panel, and overhead projector, the researcher projected simulated patient problem sets onto a screen for the entire participant group view and illustrated oxygen transport and utilization variables while treating a simulated patient in cardiopulmonary failure. The researcher made the assumption that using a real-life patient simulation to place oxygen transport and utilization variables in a clinical context may be effective in modifying alternative conceptions. Following a demonstration of the simulation and group discussion, a final macro concept map was created by each student-participant.

**Intermediate Student-Participant Self-Assessment**

Following orientation to this research, intermediate student-participants completed a self-assessment of their understanding of oxygen transport and utilization using the National Board for Respiratory Care (NBRC) Written Registry Examination Content Outline. This matrix contains content that is tested with respiratory care credentialing exams. Graduates from Cardiopulmonary Science are eligible to take credentialing exams to become recognized as Registered Respiratory Therapists. The researcher judged that this content outline represented concepts that a competent bedside clinician should possess. In addition, once the students reach their senior year in Cardiopulmonary Science they are, by definition, intermediates. This self-assessment provided the researcher with information on what each student-participants thought they understood about oxygen transport and utilization. Results of this assessment are provided in the Results chapter.
**Intermediate Participants' Use of Simulation**

The three paid volunteer intermediate student-participants completed a medical-related simulation dealing with real-time management of two patients with cardiopulmonary disease (pneumonia and hemothorax). Two simulation cases were chosen: Penny and Hallie.

Each student-participant medically managed the selected simulated patient in by treating signs and symptoms, and attempting to correct the underlying disease process to optimize oxygen transport and utilization. Student-participants were expected to use physical examination data (e.g., auscultation, percussion, palpation, etc.), pharmacologic intervention (e.g., inotropic drugs), cardiopulmonary diagnostics (e.g., chest x-ray, pulmonary function), physiologic measurements (e.g., hemodynamic measurements), and supportive treatment (e.g., mechanical ventilation, chest tubes) to manage the patient. Each intermediate student-participant was videotaped and audiotaped while completing the simulations and producing think-aloud protocols.

The first of two simulations were completed in October of 1997. The second simulation was completed in March of 1998. Following the second simulation exercise, each student-participant took part in a clinical interview and constructed a concept map. All data were analyzed using the NU*DIST™ (Richard, 1996) and Q-Notes™ (Brackett, 1997) Programs, and appropriate quantitative measurement were made. Interview questions focused on alternative questions that were identified from collected data.
Verbal analysis of transcript data gathered during completion of the simulation exercise by intermediate student-participants were performed. Simulation data were evaluated to assess the quality of clinical decision making, propositional knowledge statements, and conceptions—valid or alternative.

Remediation of the Intermediate Learners

Remediation of the intermediate learners was identical to the remediation of the novice group participants. All intermediate student-participants were debriefed using the results of this study. Emphasis was placed on identified alternative conceptions and how the student-participants developed them, and, on the importance of self-monitoring learning to minimize such occurrences. Debriefing occurred in March of 1998 during Spring Semester, following initial data analysis. Comments about the simulation program as a learning tool were favorable from all participants.
RESULTS OF THE STUDY WITH NOVICE GROUPS

Introduction

This study explored the use of cardiopulmonary simulation software in two courses focusing on cardiopulmonary physiology and advanced respiratory care. The focus of the study was the conceptual change student-participants underwent during the period of August of 1997 through March of 1998. Moreover, the identification of alternative conceptions (and their tenacity, in despite formal instruction) was also explored. Data were gathered from multiple sources, triangulated, and analyzed. Results provided the researcher with key propositional knowledge statements that developed over time along with alternative conceptions.

Study Subjects

This qualitative study analyzed the performance of a group of junior students enrolled in Cardiopulmonary Science at LSU Medical Center, School of Allied Health, Shreveport, Louisiana. Junior students were considered, by definition, novice students. The novice group contained eight student-participants. Descriptive data about the student-participants has been previously provided (see Table 1).

Data Analysis

Data analysis were performed on multiple sources of data across both novice groups. These sources included: precourse interviews, transcripts of simulation performance, postlecture interviews, pre- and posttests, examination results from two courses, postcourse interviews, concept maps, and field notes. To assist the reader, Figures 1 and 2 are concept maps illustrating an overview of all the data collection.
methods for both novice and intermediate groups. These multiple sources of data resulted in a large database which required a unique organization. Tables are grouped by simulation topic (one through eight). Data sources for each topic are tabled. A large percentage of the data were collected during the 1997 Fall Semester with emphasis on analysis placed on two key informants (Tables 3, and 7-56). Tables 57 through 70 reflect the remaining data collected on the informants during 1998 Spring Semester.

The reader may elect to just scan the data tables and focus on discussion that follows.

FIGURE 1
CONCEPT MAP OF NOVICE GROUP RESULTS SECTION
A brief explanation of how data were collected and analyzed using each source is provided below. Each of these sources were used for all eight simulation topics. Due to their brevity, modules six and seven were combined and data collected accordingly.

Precourse Interview

Each novice student-participant underwent a precourse interview. This interview contained 20 opened-ended questions (see Appendix H). The content of the precourse interview was a sample of main concepts found in a cardiopulmonary physiology course, with emphasis on content found within the preliminary six critical junctures.
developed by the researcher. Responses from interview questions were audiotaped, coded on three occasions, and results placed in tables. Actual propositional knowledge statements and alternative conceptions from the interviews were counted and listed.

Pretest

Each novice student-participant was administered a thirty multiple choice question pretest (see Appendix G) representing sample content across an entire cardiopulmonary physiology course with emphasis on the initial six critical junctures uncovered by the researcher. Item analysis was performed, and then tabulated see Table 3 below). Maximum score for this exam was 30 points.

Cardiopulmonary Simulation

Each novice student-participant completed eight simulation exercises. Using think-aloud format, sessions were audiotaped and field notes taken. Data were coded on three occasions, and results placed on tables. Actual propositional knowledge statements and alternative conceptions were counted and listed. In addition, each student-participant’s predictions of simulation response and incorrect predictions were counted and placed in tables. Emphasis was placed on data from two key informants selected from the Novice Student-Participant Group A (Novice Group A student Participant One and Two). A focused analysis was performed on Oxygen Transport I and Oxygen Transport II Simulation Exercises. The researcher decided that these two simulation exercises represented a good internal sample of data that were collected from simulation transcripts.
Each student-participant completed a postlecture interview dealing with concepts presented in the lecture series. There were eight separate lecture series—each corresponding to the eight simulation modules (see Table 2). Interviews were audiotaped and data coded on three occasions and placed in tables. Actual propositional knowledge statements and alternative conceptions were counted and listed.

Concept Maps

Concept maps were completed by student-participants at the end of each lecture series and at the end of the study. Maps were scored using the Standard Concept Map Checklist (see Appendix C) and analyzed for propositional knowledge statements and alternative concepts. These data were coded on three occasions and placed in tables.

Postcourse Interview

Each novice student-participant underwent a postcourse interview (following the Cardiopulmonary Physiology and Advanced Techniques II courses). This interview contained the same twenty opened-ended questions found in the precourse interview (see Appendix H). Each student-participant was asked a subset of questions from the question set. Content of the postcourse interview was a sample of main concepts found in a cardiopulmonary physiology course with emphasis on content found within the preliminary six critical junctures developed by the researcher. Responses from interview questions were audiotaped, coded on three occasions, and results were placed in tables. Actual propositional knowledge statements and alternative conceptions from the interviews were counted and listed.

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Final Interview

Student-participants underwent a final interview that focused questions on assessing oxygen transport and types of hypoxia. Interview data were coded on three occasions and placed in tables. Actual propositional knowledge statements and alternative concepts were counted and listed.

Posttest

Each student-participant completed a poststudy test in February of 1998 that consisted of the same questions found in the pretest (see Appendix G). Item analysis was performed along with statistical analysis comparing the pre- and posttest scores. Internal consistency was evaluated using a variation of the Kuder-Richardson index of homogeneity, the Cronbach alpha statistic. The Cronbach alpha statistic was used as an index of internal consistency between the pre and posttest. If the test items are heterogeneous—that is, they measure more than one trait (e.g., concept) or attribute—the reliability index as computed using the Cronbach alpha statistic will be lower.

Examination Data

Data that included scores, propositional knowledge statements, and alternative conceptions were identified from examinations given throughout the study. These examinations were part of the Cardiopulmonary Physiology and Advanced Techniques II courses, and were given for grade determination. Data were coded on three occasions, counted, and listed in tables.

Collected data were sorted and coded in March, July, and August of 1998 while undergoing continuous analysis as outlined by Bogdan and Bilken (1992). Based on the
comparison of Novice Student-Participant Group A to Novice Student-Participant Group B's macro conceptual inventories were generated. The researcher chose to focus analysis and discussion on two key informants from Novice Student-Participant Group A to illustrate research findings (novice student-participants one and two—see Table 1). Key informants are participants that are generally more willing to talk to provide a richer description of thinking, feeling, or other emotions (Bogdan, 1992). The two novice student-participants were selected by the researcher because they were judged to be key informants.

**Data Tables**

Statistical comparison data for pre- and posttests are listed in Table 3. As stated previously, the maximum score for this test was 30 points. As expected, an increase in the test scores occurred from pre- to posttest.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Pre- and Posttest Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Pretest</td>
<td>11.5</td>
</tr>
<tr>
<td>Posttest</td>
<td>23.0</td>
</tr>
</tbody>
</table>

**Critical Junctures**

During and following this study a list of six critical junctures were created and modified as data analysis occurred (See Table 4) An expert panel (see Appendix J) played a key role in frequent evaluation and respecification of these junctures. So
throughout the study these critical junctures were evaluated and revised to assure their appropriateness as key concepts associated with oxygen transport and utilization. Table 4 lists these junctures along with subjunctures.

| Table 4 |
|-----------------|-----------------|-----------------|
| **Critical Junctures for Understanding** | **Oxygen Transport and Utilization in Humans** | (Created by Researcher and Expert Panel) |
| **A. Mechanics of ventilation** | **D. Arterial oxygen transport** | **1. Arterial oxygenation** |
| 1. Lung and thoracic relationships | 1. Arterial oxygenation | **2. Oxygen delivery** |
| 2. Pressure-volume relationships | **E. Tissue oxygenation** | **1. Tissue oxygen uptake** |
| 3. Pressure-flow relationships | 2. Tissue oxygen utilization | **F. Venous blood gas transport** |
| **B. Alveolar and blood gas exchange** | **1. Venous oxygen transport** | **2. Carbon dioxide transport** |
| 1. Gas pressures | **C. Blood flow** | **1. Pulmonary circulation** |
| 2. Alveolar ventilation | 2. Systemic circulation | **2. Cardiac pressure and flow** |
| 3. Ventilation-to-perfusion relationships | | **4. Diffusion** |
| 4. Diffusion | **D. Arterial oxygen transport** | **1. Arterial oxygenation** |
| **C. Blood flow** | **2. Oxygen delivery** | **E. Tissue oxygenation** |
| 1. Pulmonary circulation | **1. Tissue oxygen uptake** | **2. Tissue oxygen utilization** |
| 2. Systemic circulation | **F. Venous blood gas transport** | **1. Venous oxygen transport** |
| 3. Cardiac pressure and flow | **2. Carbon dioxide transport** | |

Data from all sources (interviews, concept mapping, simulation verbal protocols, test data, and field notes) for all members of the Novice Student-Participant Group A were coded and analyzed to create a similar macro conceptual inventory (see Table 5). Likewise, a similar macro conceptual inventory was created for all members of the Novice Student-Participant Group B (see Table 6). These inventories contain macro concepts identified by data analysis that were held in common by all student-participants. Concepts were classified under each of the six critical junctures and subjunctures.
Table 5  
Conceptual Inventory  
Macro Concepts  
Novice Group A

<table>
<thead>
<tr>
<th>A. Mechanics of Ventilation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Lung and thoracic relationship</td>
<td></td>
</tr>
<tr>
<td>1.0.1 Lung and thoracic relationships establishes FRC</td>
<td></td>
</tr>
<tr>
<td>1.0.2 FRC influences lung compliance</td>
<td></td>
</tr>
<tr>
<td>1.0.3 FRC is a gas reservoir</td>
<td></td>
</tr>
<tr>
<td>1.2 Volume-pressure relationships</td>
<td></td>
</tr>
<tr>
<td>1.2.1 Compliance is the willingness to expand</td>
<td></td>
</tr>
<tr>
<td>1.2.2 Compliance is the reciprocal of elastance</td>
<td></td>
</tr>
<tr>
<td>1.3 Pressure-flow relationships</td>
<td></td>
</tr>
<tr>
<td>1.3.1 Airway resistance is effected by airway diameter and length</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Alveolar and Blood Gas Exchange</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 Gas pressures</td>
<td></td>
</tr>
<tr>
<td>2.0.1 Increased P_{\text{O}<em>2} increases P</em>{\text{A}<em>2} and P</em>{\text{A}_2}</td>
<td></td>
</tr>
<tr>
<td>2.1 Alveolar ventilation</td>
<td></td>
</tr>
<tr>
<td>2.1.1 Increase in ventilation reduces P_{\text{A}_2}</td>
<td></td>
</tr>
<tr>
<td>2.1.2 Increase in deadspace can increase P_{\text{A}_2}</td>
<td></td>
</tr>
<tr>
<td>2.2 Ventilation-to-perfusion relationships</td>
<td></td>
</tr>
<tr>
<td>2.2.1 Gas exchange requires matching of ventilation and perfusion</td>
<td></td>
</tr>
<tr>
<td>2.2.2 Altered ventilation-to-perfusion relationships can decrease P_{\text{A}<em>2} and increase P</em>{\text{A}_2}</td>
<td></td>
</tr>
<tr>
<td>2.3 Diffusion</td>
<td></td>
</tr>
<tr>
<td>2.3.1 Oxygen and carbon dioxide exchange occurs due to pressure gradients</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. Blood Flow</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 Pulmonary circulation</td>
<td></td>
</tr>
<tr>
<td>3.0.1 Pulmonary circulation is under low pressure</td>
<td></td>
</tr>
<tr>
<td>3.0.2 Pulmonary circulation carries reduced oxygenated blood</td>
<td></td>
</tr>
<tr>
<td>3.1 Systemic circulation</td>
<td></td>
</tr>
<tr>
<td>3.1.1 Systemic circulation is under high pressure</td>
<td></td>
</tr>
<tr>
<td>3.1.2 Systemic circulation carries oxygen to tissues</td>
<td></td>
</tr>
</tbody>
</table>

(table continued)
3.2 Cardiac pressure and flow relationships
3.2.1 Four determinants of cardiac output include preload, afterload, contractility, and heart rate
   3.2.2 Decrease in blood volume decreases blood pressure
   3.2.3 Increase in preload can increase cardiac output

D. Blood Gas Transport
4.0 Arterial oxygen transport
   4.0.1 Arterial oxygen is carried by hemoglobin and plasma
   4.0.2 Arterial oxygen transport requires blood flow

E. Tissue Oxygenation
5.1 Tissue utilization
   5.1.1 Normal oxygen consumption is 250 mL/min

F. Venous Oxygenation
6.1 Venous oxygen transport is \( \text{CvO}_2 \)
   6.1.1 Venous oxygen reflects tissue oxygenation
   6.1.2 Reduced venous oxygen may reflect reduced cardiac output
   6.1.3 Venous oxygen is a reservoir
   6.2 Carbon dioxide is transported in venous blood back to the lung

Table 6
Conceptual Inventory
Macro Concepts
Novice Group B

A. Mechanics of Ventilation
1.0 Lung and thoracic relationships
   1.0.1 Lung recoils out and chestwall recoils in
   1.0.2 The FRC is a gas reservoir
1.1 Volume-pressure relationships
   1.2.1 Compliance is the willingness to expand
   1.2.2 Compliance is the reciprocal of elastance
1.2 Pressure-flow relationships
   1.3.1 Airway resistance is effected by airway diameter

(table continued)
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. Alveolar and Blood Gas Exchange</td>
<td></td>
</tr>
<tr>
<td>2.0 Gas pressures</td>
<td></td>
</tr>
<tr>
<td>2.0.1 Increased PI0₂ increases PA0₂ and Pa0₂</td>
<td></td>
</tr>
<tr>
<td>2.1 Alveolar ventilation</td>
<td></td>
</tr>
<tr>
<td>2.1.1 Increase in ventilation reduces PAC0₂</td>
<td></td>
</tr>
<tr>
<td>2.1.2 Increase in deadspace can increase PaC0₂</td>
<td></td>
</tr>
<tr>
<td>2.2 Ventilation-to-perfusion relationships</td>
<td></td>
</tr>
<tr>
<td>2.2.1 Gas exchange requires matching of ventilation and perfusion</td>
<td></td>
</tr>
<tr>
<td>2.3 Diffusion</td>
<td></td>
</tr>
<tr>
<td>2.3.1 Oxygen and carbon dioxide exchange occurs due to pressure gradients</td>
<td></td>
</tr>
<tr>
<td>C. Blood Flow</td>
<td></td>
</tr>
<tr>
<td>3.0 Pulmonary circulation</td>
<td></td>
</tr>
<tr>
<td>3.0.1 Pulmonary circulation is under low pressure</td>
<td></td>
</tr>
<tr>
<td>3.1 Systemic circulation</td>
<td></td>
</tr>
<tr>
<td>3.1.1 Systemic circulation is under high pressure</td>
<td></td>
</tr>
<tr>
<td>3.1.2 Systemic circulation carries oxygen to the tissues</td>
<td></td>
</tr>
<tr>
<td>3.2 Cardiac pressure and flow relationships</td>
<td></td>
</tr>
<tr>
<td>3.2.1 Preload and afterload contribute to producing cardiac output</td>
<td></td>
</tr>
<tr>
<td>3.2.2 Decrease in blood volume decreases blood pressure</td>
<td></td>
</tr>
<tr>
<td>D. Blood Gas Transport</td>
<td></td>
</tr>
<tr>
<td>4.0 Arterial oxygen transport</td>
<td></td>
</tr>
<tr>
<td>4.0.1 Arterial oxygen is carried attached to hemoglobin and plasma</td>
<td></td>
</tr>
<tr>
<td>4.0.2 Arterial oxygen transport requires blood flow</td>
<td></td>
</tr>
<tr>
<td>E. Tissue Oxygenation</td>
<td></td>
</tr>
<tr>
<td>5.0 Tissue uptake</td>
<td></td>
</tr>
<tr>
<td>5.1 Tissue utilization</td>
<td></td>
</tr>
<tr>
<td>5.1.1 Normal oxygen consumption is 250 mL/min</td>
<td></td>
</tr>
<tr>
<td>F. Venous Oxygenation</td>
<td></td>
</tr>
<tr>
<td>6.0 Venous oxygen transport</td>
<td></td>
</tr>
<tr>
<td>6.0.1 Venous oxygenation reflects tissue oxygenation</td>
<td></td>
</tr>
<tr>
<td>6.0.2 Reduced cardiac output decreases venous oxygenation</td>
<td></td>
</tr>
<tr>
<td>6.1 Carbon dioxide transport</td>
<td></td>
</tr>
<tr>
<td>6.1.1 Venous blood has a PaC0₂ of 46 torr</td>
<td></td>
</tr>
</tbody>
</table>
Table 7
Module One
Mechanics of Ventilation
Precourse Interview with Novice Student-Participant One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Compliance is the willingness to expand</td>
<td></td>
</tr>
<tr>
<td>2. Lung mechanics create pressure gradients</td>
<td></td>
</tr>
<tr>
<td>3. Resistance is a force against</td>
<td>1. Increase time for nitrogen washout with inhaling 100% oxygen is due to tumor</td>
</tr>
<tr>
<td></td>
<td>2. Abdominal muscles force air out with normal breathing</td>
</tr>
</tbody>
</table>

Total | 3 | 2 |

Table 8
Module One
Mechanics of Ventilation
Precourse Interview Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Compliance is how pliable the lungs are</td>
<td>1 Airway resistance is how much air goes in and out of the lungs</td>
</tr>
<tr>
<td></td>
<td>2. Muscles push air to with breathing</td>
</tr>
</tbody>
</table>

Total | 1 | 2 |
### Table 9
Module Two
Ventilation-to-Perfusion Ratios
Precourse Interview Novice Student-Participant One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Oxygen flows from alveoli to blood 2. Carbon dioxide flows from blood to alveoli</td>
<td>1. Hyperventilation is too much oxygen in the lungs 2. Increased deadspace will not increase carbon dioxide</td>
</tr>
</tbody>
</table>

| Total | 2 | 2 |

### Table 10
Module Two
Ventilation-to-Perfusion Ratios
Precourse Interview Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increased deadspace will increase carbon dioxide</td>
<td>1. PI02 is greater than PA02 because of large lung volumes 2. Hyperventilation is breathing too fast</td>
</tr>
</tbody>
</table>

<p>| Total | 1 | 2 |</p>
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Hemoglobin carries oxygen</td>
<td>1. First response to low oxygen in the blood is increased respiratory rate</td>
</tr>
<tr>
<td>2. Assess a patient’s oxygenation</td>
<td>2. Pulmonary circulation pressure equals systemic circulation pressure</td>
</tr>
<tr>
<td>3. Pulmonary blood flow is to take up oxygen</td>
<td></td>
</tr>
<tr>
<td>4. Arterial blood carries oxygen</td>
<td></td>
</tr>
</tbody>
</table>

Total 4  2

---

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To assess how well a person is oxygenated is to get a blood gas</td>
<td>1. Carrier molecules carry blood</td>
</tr>
<tr>
<td></td>
<td>2. Pulmonary circulation pressure equals systemic circulation pressure</td>
</tr>
</tbody>
</table>

Total 1  2
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Left heart failure can decrease oxygen delivery  
2. Preload is ventricular filling  
3. Cardiac output is blood from heart  
4. Afterload is obstruction to blood flow  
5. Blood carries oxygen  
6. Decrease in blood flow reduces oxygen delivery  
7. What the heart receives is | 1. If arterioles constrict, blood from the heart can increase |

**Total** 8 1

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Preload is ventricular filling of blood  
2. What the heart gets is what is pumped out  
3. Blood carries oxygen | 1. Heart rate determines how much is pumped out of the heart  
2. Afterload is the amount of blood pumped |

**Total** 3 2

184
<table>
<thead>
<tr>
<th>Number of Predictions Correct</th>
<th>Number of Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

**Actual Predictions**

1. Increase elastance decreases compliance
2. Decrease elastance increases FRC
3. Decrease elastance has no effects on chest wall compliance
4. Increase elastance flattens volume-pressure curve
5. Increased elastance decreases compliance
6. Decrease surfactant decreases compliance

**Incorrect Predictions**

1. Increase elastance, increase end-expiratory pressure
2. Increase elastance, decreases mean airway pressure
3. Increase elastance, increases airway conductance
4. Decrease surfactant, increases end-expiratory volume and pressure

**Propositional Knowledge Statements**

1. As elastance increases, compliances decreases
2. As surfactant decreases, surface tension increases and compliance decreases
3. As compliance decreases, RR increases
4. Decrease in compliance increases WOB
5. Increase in FRC increase lung compliance

**Alternative Conceptions**

1. If chest wall compliance changes, there is a change in elastance
2. FRC will not change with a change in surfactant
3. Decrease in surfactant will decrease chest wall compliance

**Total**

6

3
### Table 16
Module Two
Mechanics of Ventilation
Prelecture Simulation
Verbal Analysis of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Actual Predictions</th>
<th>Actual Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase elastance decrease compliance</td>
<td>1. Not sure what happens to PAWP with decrease in elastance</td>
</tr>
<tr>
<td>2. Decrease elastance increase compliance</td>
<td>2. Decrease elastance decreases FRC</td>
</tr>
<tr>
<td>3. Decrease compliance flattens volume-pressure curve</td>
<td>3. Not sure what happens to end-expiratory volume/pressure with decrease in elastance</td>
</tr>
<tr>
<td>4. Decrease surfactant decreases compliance</td>
<td>4. Not sure what happens to PAWP with increase in elastance</td>
</tr>
<tr>
<td>5. As surfactant decreases there is no change in chest wall compliance</td>
<td>5. Not sure what happens to airway conductance with an increase in elastance</td>
</tr>
<tr>
<td>6. Change in elastance does not change chest wall compliance</td>
<td></td>
</tr>
<tr>
<td>7. Decrease in FRC decreases</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Decrease compliance flattens volume-pressure curve</td>
<td>1. As surface tension decreases, chest wall compliance decrease</td>
</tr>
<tr>
<td>2. When elastance increases compliance decreases</td>
<td>2. As elastance decreases, FRC decreases</td>
</tr>
<tr>
<td>3. Steep part of the volume-pressure curve represents an increased compliance</td>
<td>3. As AWR increases, RR increases</td>
</tr>
<tr>
<td>4. As compliance decreases, RR</td>
<td>4. As elastance increases, FRC increases</td>
</tr>
</tbody>
</table>

<p>| Total | 4                                             | 4                                             |</p>
<table>
<thead>
<tr>
<th>Actual Predictions</th>
<th>Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Decrease PaO2 increases RR</td>
<td>1. Increased deadspace decreases PaO2 and PaCO2 remains unchanged</td>
</tr>
<tr>
<td>2. Increase deadspace increases CO2</td>
<td></td>
</tr>
<tr>
<td>3. Increase deadspace decreases PaO2</td>
<td></td>
</tr>
<tr>
<td>4. Decrease deadspace decreases CO2</td>
<td></td>
</tr>
<tr>
<td>5. Hypoventilation leads to an increase in CO2</td>
<td></td>
</tr>
<tr>
<td>6. Double the minute ventilation increases oxygen level and decreases CO2.</td>
<td></td>
</tr>
<tr>
<td>Propositional Knowledge Statements</td>
<td>Alternative Conceptions</td>
</tr>
<tr>
<td>1. As CO2 increases, pH decreases</td>
<td>1. Increase deadspace will effect oxygen more than carbon dioxide</td>
</tr>
<tr>
<td>2. Hypoventilation increases PaCO2</td>
<td>2. Oxygen level will decrease as the same rate carbon dioxide decreases</td>
</tr>
<tr>
<td>3. Decrease deadspace will decrease CO2 if minute volume does not change</td>
<td>3. As deadspace increases oxygen cannot get in to diffuse</td>
</tr>
<tr>
<td>4. Increase RR leads to an increase in minute volume</td>
<td>4. If oxygen cannot get in carbon dioxide cannot get out</td>
</tr>
<tr>
<td>5. As shunt increases, A-aD02</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Total 7</td>
</tr>
<tr>
<td></td>
<td>Total 6</td>
</tr>
</tbody>
</table>
Table 18
Module Two
Ventilation-to-Perfusion Ratios
Prelecture Simulation
Verbal Analysis of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Number of Predictions Correct</th>
<th>Number of Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Actual Predictions</th>
<th>Actual Incorrect Predictions</th>
</tr>
</thead>
</table>
| 1. Increase in deadspace decreases PaO2  
  2. Increase deadspace decrease RR increase PaCO2  
  3. Double minute ventilation decreases CO2  
  4. Increase carbon dioxide decrease pH | 1. Increase deadspace will decrease PaCO2 |

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Increase deadspace increases PaCO2 if minute ventilation does not change  
  2. Increase deadspace decreases PaO2  
  3. Increase CO2 decreases pH  
  4. Increase minute ventilation decreases CO2  
  5. Increase shunt will require | 1. Increase in deadspace decreases diffusion  
  2. Increase blood flow will decrease carbon dioxide if deadspace decreases |

| Total | 6 | 2 |
Table 19
Module Three
Oxygen Transport I
Prelecture Simulation
Verbal Analysis of Novice Student-Participant One

<table>
<thead>
<tr>
<th>Number of Predictions Correct</th>
<th>Number of Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Actual Predictions</th>
<th>Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase in FI02 will increase: P102, PA02, Pa02, Sa02, Pv02, Ca02</td>
<td>1. Increase in FI02 results in change in Sv02</td>
</tr>
<tr>
<td>2. Increase FI02 will have no change in PaC02, hemoglobin, cardiac output, and RR</td>
<td>2. Increase in FI02 will not change A-aD02</td>
</tr>
<tr>
<td>3. Increase in Qs/Qt will result in a decreased PA02, Pa02, Sv02, Ca02, and no change in P102</td>
<td>3. Increase FI02 with increase Qs/Qt will have no change in Ca02</td>
</tr>
<tr>
<td>4. Increase Qs/Qt will result in an increase in A-aD02</td>
<td>4. Increase FI02 with increase Qs/Qt will have no change in A-aD02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ca02 is oxygen content in blood</td>
<td>1. PA02 remains unchanged with increase Qs/Qt</td>
</tr>
<tr>
<td>2. Increase FI02 will increase P102, PA02, Pa02, and Sa02</td>
<td>2. Decrease in cardiac output will decrease oxygen delivery (no comment about heart rate compensation)</td>
</tr>
<tr>
<td>3. Sv02 is oxygen saturation of the venous blood</td>
<td>3. Decrease in deaspace and no change in PaC02</td>
</tr>
<tr>
<td>4. Increase FI02 will increase Ca02</td>
<td>4. Increase RR is the only way to increase minute volume</td>
</tr>
<tr>
<td>5. Increase in Sa02 will increase Ca02</td>
<td>5. Decrease tidal volume by one-</td>
</tr>
<tr>
<td>6. P102 does not change with</td>
<td></td>
</tr>
<tr>
<td>Number of Predictions Correct</td>
<td>Number of Incorrect Predictions</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>19</td>
<td>4</td>
</tr>
</tbody>
</table>

**Actual Predictions**
1. Increase in $\text{FiO2}$ will:
   - Increase $\text{PiO2}$, $\text{PAO2}$, $\text{PaO2}$, $\text{SaO2}$, $\text{SvO2}$, and $\text{CaO2}$
2. With 15% $\text{Qs}/\text{Qt}$ the following will decrease $\text{PaO2}$, $\text{SaO2}$, $\text{PvO2}$
3. With 15% $\text{Qs}/\text{Qt}$ and increase $\text{FiO2}$ the following will increase:
   - $\text{PiO2}$, $\text{PAO2}$, $\text{PaO2}$, $\text{SaO2}$, $\text{CaO2}$

**Propositional Knowledge Statements**
1. Increase $\text{FiO2}$ increase $\text{PiO2}$,
2. $\text{PaO2}$ mirrors $\text{PAO2}$
3. Increase $\text{PaO2}$ increases $\text{SaO2}$
4. Decrease tidal volume increase $\text{PaCO2}$
5. Decrease tidal volume decreases $\text{PaO2}$ and $\text{SaO2}$
6. Increase $\text{Qs}/\text{Qt}$ will decrease $\text{PaO2}$
7. Increased $\text{Qs}/\text{Qt}$ increases $\text{A-aDO2}$
8. Decrease $\text{PiO2}$ decreases $\text{PAO2}$, and $\text{CaO2}$
9. Decrease in tidal volume will not change $\text{PiO2}$

**Alternative Conceptions**
1. Increased $\text{FiO2}$ will not increase $\text{Qs}/\text{Qt}$, $\text{CaO2}$, $\text{PvO2}$, or $\text{SvO2}$
2. Decrease cardiac output will decrease $\text{PaO2}$
3. Normal $\text{SvO2}$ is 90%

**Total**
12
3
Table 21
Module Four
Control of Cardiac Output
Prelecture Simulation
Verbal Analysis of Novice Student-Participant One

<table>
<thead>
<tr>
<th>Number of Predictions Correct</th>
<th>Number of Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Actual Predictions</th>
<th>Actual Incorrect Predictions</th>
</tr>
</thead>
</table>
| 1. Remove 1000 mL blood with CNS off will decrease MAP, CO, PMS  
2. Remove 1000 mL with CNS on will decrease MAP, however CO can be maintained due to increased heart rate  
3. Remove 1000 mL with CNS on and vasoconstriction results  
5. Remove an additional 500 mL with CNS off CO and MAP decreases | 1. PCWP and RAP may increase or decrease with loss of 1000 mL with CNS turned off  
2. PCWP and RAP may increase or decrease with loss of 1000 mL with CNS turned on |

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Decrease CO and heart rate will increase to maintain CO  
2. If RAP increases, venous return will decrease  
3. Increase contractility increases CO | 1. Hemorrhage is a bruise or damaged blood vessel  
2. Vasodilation will increase venous return and decrease CO  
3. Not sure of effects of change in hemodynamics in PMS |

| Total | 5 | 3 |
## Table 22

### Module Four

**Control of Cardiac Output**

**Prelecture Simulation**

**Verbal Analysis of Novice Student-Participant Two**

<table>
<thead>
<tr>
<th>Number of Predictions</th>
<th>Number of Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>6</td>
</tr>
</tbody>
</table>

### Actual Predictions

1. Remove 1000 mL with the CNS off will decrease MAP, CO, SV, PCWP
2. Remove 1000 mL with CNS on may maintain MAP and CO if HR increases
3. Decrease contractility will decrease CO, MAP, and SV
4. Vasodilation will increase CO and SV
5. Vasodilation will decrease

### Incorrect Predictions

1. Not sure what occurs if 1000 mL are removed with CNS off with PCWP and LVEF
2. Not sure what occurs to PCWP and LV ejection fraction if 1000 mL are removed with CNS on
3. Not sure what occurs to PCWP and LV ejection fraction with a decrease in contractility

### Propositional Knowledge Statements

1. As volume decreases, blood pressure decreases
2. As volume decreases, CO decreases
3. If volume decreases, heart rate will increase
4. If volume decreases, PCWP decreases

### Alternative Conceptions

1. Vasodilation increases venous return
2. Vasodilation can increase MAP

<table>
<thead>
<tr>
<th>Total</th>
<th>6</th>
<th>2</th>
</tr>
</thead>
</table>

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Table 23
Module One
Mechanics of Ventilation
Prelecture Simulation
Post-Lecture Interview with Novice Student-Participant One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase elasticity decreases compliance</td>
<td>1. Increase FRC decreases compliance</td>
</tr>
<tr>
<td>2. Decrease airway diameter increases AWR</td>
<td>2. Elastic fibers maintain FRC</td>
</tr>
<tr>
<td>3. Decrease compliance increases MAWP</td>
<td></td>
</tr>
<tr>
<td>4. Decrease surfactant decreases compliance</td>
<td></td>
</tr>
<tr>
<td>5. Decrease compliance flattens volume-pressure curve</td>
<td></td>
</tr>
<tr>
<td>6. Increase in pressure gradient will increase flow through airway</td>
<td></td>
</tr>
<tr>
<td>7. Compliance is willingness to expand</td>
<td></td>
</tr>
<tr>
<td>8. FRC is end-expiratory volume</td>
<td></td>
</tr>
</tbody>
</table>

Total 10 2
### Table 24
**Module One**
**Mechanics of Ventilation**
**Postlecture Interview Novice Student-Participant Two**

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase elastance decreases compliance</td>
<td>1. Increase surfactant increases elasticity</td>
</tr>
<tr>
<td>2. Decrease surfactant decreases compliance</td>
<td>2. Air enters lung and creates FRC</td>
</tr>
<tr>
<td>3. Lung recoil out and chest wall recoils in which results in the lung remaining partially inflated</td>
<td>3. Airway compliance is one of three compliances</td>
</tr>
<tr>
<td>4. Lung recoil and chest wall recoil results in FRC</td>
<td>4. Alveolar pressures becomes positive during inspiration</td>
</tr>
<tr>
<td>5. Compliance is the willingness to expand</td>
<td>5. Alveolar pressure becomes negative during expiration</td>
</tr>
<tr>
<td>6. Decrease compliance flattens volume-pressure curve</td>
<td></td>
</tr>
<tr>
<td>7. Decrease airway diameter</td>
<td></td>
</tr>
</tbody>
</table>

**Total** 6 5
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Alveolar collapse increases shunting</td>
<td></td>
</tr>
<tr>
<td>2. Alveolar collapse decreases surface area and PaO₂ drops</td>
<td></td>
</tr>
<tr>
<td>3. Shunting effects PaO₂</td>
<td></td>
</tr>
<tr>
<td>4. Deadspace is ventilation without perfusion</td>
<td></td>
</tr>
<tr>
<td>5. Shunt is blood flow without ventilation</td>
<td></td>
</tr>
<tr>
<td>6. Three types of deadspace: anatomic, alveolar, physiologic</td>
<td></td>
</tr>
<tr>
<td>1. Increase deadspace decreases PaO₂ because blood does not get oxygen</td>
<td></td>
</tr>
<tr>
<td>2. Increase deadspace patient must hyperventilate</td>
<td></td>
</tr>
<tr>
<td>3. As shunting increases FRC increases and there is less oxygen in the lung</td>
<td></td>
</tr>
</tbody>
</table>

<p>| Total | 8 | 3 |</p>
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Shunt is blood flow without ventilation</td>
<td>1. As shunt increases, PaC02 increases because you can’t blow off C02</td>
</tr>
<tr>
<td>2. Deadspace is ventilation without blood flow</td>
<td>2. Shunting primarily effects Pa02</td>
</tr>
<tr>
<td>3. If deadspace increases, PaC02 will increase</td>
<td>3. As FRC decreases, you move the same tidal volume but take in less oxygen</td>
</tr>
<tr>
<td>4. If deadspace increases, RR must increase to maintain PaC02</td>
<td></td>
</tr>
<tr>
<td>5. As FRC decreases, shunting increases</td>
<td></td>
</tr>
<tr>
<td>6. Three types of deadspace: anatomic, alveolar, physiologic</td>
<td></td>
</tr>
<tr>
<td>7. Normal V/Q is 0.8</td>
<td></td>
</tr>
<tr>
<td>8. High V/Q is deadspace</td>
<td></td>
</tr>
<tr>
<td>9. Low V/Q is shunt</td>
<td></td>
</tr>
</tbody>
</table>

| Total | 9 | 3 |
Table 27  
Module Three  
Oxygen Transport I  
Postlecture Interview of Novice Student-Participant One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. PA02 is 100 torr</td>
<td>1. Decrease in Sv02 means change in hemoglobin’s affinity for oxygen</td>
</tr>
<tr>
<td>2. Sa02 is 97%</td>
<td>2. Decrease hemoglobin will change affinity for oxygen</td>
</tr>
<tr>
<td>3. Hemoglobin oxygen saturation has corresponding Pa02</td>
<td>3. Sv02 is 98%</td>
</tr>
<tr>
<td>4. Flat part of ODC has little change in Sa02 for any change in Pa02</td>
<td>4. Ca02 = Pa02 x 1.34</td>
</tr>
<tr>
<td>5. Steep portion of ODC has large change for small changes in Pa02</td>
<td>5. Ca02 = 250 mL/dL</td>
</tr>
<tr>
<td>6. Right shift in ODC increases hemoglobin unloading of oxygen</td>
<td></td>
</tr>
<tr>
<td>7. Left shift ODC decreases hemoglobin unloading of oxygen</td>
<td></td>
</tr>
<tr>
<td>8. Hemoglobin is a protein with</td>
<td></td>
</tr>
</tbody>
</table>

<p>| Total | 12 | 5 |</p>
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Oxygen is transported by hemoglobin and plasma</td>
<td></td>
</tr>
<tr>
<td>2. CaO₂ = Hb x SaO₂ x 1.34 + PaO₂ x .003</td>
<td></td>
</tr>
<tr>
<td>3. Oxygen consumption is 250 mL/min</td>
<td></td>
</tr>
<tr>
<td>4. Decrease SvO₂ reflects tissues using more oxygen</td>
<td></td>
</tr>
<tr>
<td>5. ODC shows relationship between PaO₂ and SaO₂</td>
<td></td>
</tr>
<tr>
<td>6. Left shift of ODC increases Hb affinity</td>
<td></td>
</tr>
<tr>
<td>7. Right shift of ODC decreases Hb affinity</td>
<td></td>
</tr>
<tr>
<td>1. Normal CaO₂ is 95-100%</td>
<td></td>
</tr>
<tr>
<td>2. Normal PaO₂ is 80-100 torr</td>
<td></td>
</tr>
<tr>
<td>3. ODC flattens at a PaO₂ 50 torr</td>
<td></td>
</tr>
<tr>
<td>4. Oxygen transport is 250 mL/min</td>
<td></td>
</tr>
<tr>
<td>5. Not sure what benefit of flat portion of ODC</td>
<td></td>
</tr>
<tr>
<td>6. Not sure what hemoglobin is made of</td>
<td></td>
</tr>
<tr>
<td>7. Not sure what causes hemoglobin to alter affinity</td>
<td></td>
</tr>
<tr>
<td>8. SvO₂ = 50%</td>
<td></td>
</tr>
<tr>
<td>9. Oxygen delivery = CO x SaO₂</td>
<td></td>
</tr>
</tbody>
</table>

| Total | 8 | 9 |
### Table 29
Module Four
Control of Cardiac Output
Postlecture Interview Novice Student-participant One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Afterload is resistance to blood flow</td>
<td></td>
</tr>
<tr>
<td>2. Preload is ventricular filling during diastole</td>
<td></td>
</tr>
<tr>
<td>3. CO is the amount of blood pumped per minute</td>
<td></td>
</tr>
<tr>
<td>4. Contractility is muscular contraction</td>
<td></td>
</tr>
<tr>
<td>5. Decrease blood flow decreases oxygen delivery</td>
<td></td>
</tr>
</tbody>
</table>

Total: 6

### Table 30
Module Four
Control of Cardiac Output
Postlecture Interview of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Afterload is resistance to blood flow</td>
<td></td>
</tr>
<tr>
<td>2. Preload is ventricular filling during diastole</td>
<td></td>
</tr>
<tr>
<td>3. CO is what the heart pumps per minute</td>
<td></td>
</tr>
<tr>
<td>4. As blood flow decreases, so does oxygen delivery</td>
<td></td>
</tr>
<tr>
<td>5. What the heart receives is</td>
<td></td>
</tr>
</tbody>
</table>

Total: 5

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Table 31
Module One
Mechanics of Ventilation
Concept Map Analysis of Novice Student-Participant One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Decrease surfactant increases ST</td>
<td></td>
</tr>
<tr>
<td>2. Surfactant will decrease ST</td>
<td></td>
</tr>
<tr>
<td>3. Increase ST decreases compliance</td>
<td></td>
</tr>
<tr>
<td>4. Chest wall recoils out and lung recoils in</td>
<td></td>
</tr>
<tr>
<td>5. Negative alveolar pressure allows air to enter lung</td>
<td></td>
</tr>
<tr>
<td>6. Increase compliance decreases elastance</td>
<td></td>
</tr>
<tr>
<td>7. Decrease compliance</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total</th>
<th>9</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Map Score</td>
<td>29/50</td>
<td></td>
</tr>
</tbody>
</table>
### Table 32

**Module One**  
**Mechanics of Ventilation**  
**Concept Map Analysis of Novice Student-Participant Two**

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Gas flows into lung due to a pressure gradients  
2. Increase ST decreases compliance  
3. Increase surfactant decreases ST  
4. Increase ST decrease tidal volume | 1. Gas moves into lung as a result of lung recoil  
2. Gas moves into lung as a result of chestwall recoil |

<table>
<thead>
<tr>
<th>Total</th>
<th>7</th>
<th>2</th>
</tr>
</thead>
</table>

**Concept Map Score**  
35/50

---

### Table 33

**Module Two**  
**Ventilation-to-Perfusion Ratios**  
**Concept Map Analysis of Novice Student-Participant One**

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Hypoxemia increases WOB  
2. High V/Q is deadspace  
3. Low V/Q is shunt  
4. Deadspace is ventilation with blood flow  
5. Shunt is perfusion without ventilation | 1. Ventilation can cause high V/Q  
2. Ventilation determines hypoxemia |

<table>
<thead>
<tr>
<th>Total</th>
<th>6</th>
<th>2</th>
</tr>
</thead>
</table>

**Concept Map Score**  
35/50

---

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Table 34
Module Two
Ventilation-to-Ventilation Ratios
Concept Map Analysis of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Shunt is low V/Q</td>
<td></td>
</tr>
<tr>
<td>2. Deadspace is high V/Q</td>
<td></td>
</tr>
<tr>
<td>3. Shunt is perfusion without ventilation</td>
<td></td>
</tr>
<tr>
<td>4. Deadspace is ventilation without perfusion</td>
<td></td>
</tr>
<tr>
<td>5. Shunt lowers Pa02</td>
<td></td>
</tr>
<tr>
<td>6. V/Q relationship determines</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8</strong></td>
</tr>
<tr>
<td><strong>Concept Map Score</strong></td>
<td><strong>36/50</strong></td>
</tr>
<tr>
<td>Propositional Knowledge Statements</td>
<td>Alternative Conceptions</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>1. PA02 determines Pa02</td>
<td>1. PA02 indicates Ca02</td>
</tr>
<tr>
<td>2. Oxygen is transported by</td>
<td>2. Oxygen transport is measured</td>
</tr>
<tr>
<td>hemoglobin and plasma</td>
<td>by Sa02</td>
</tr>
<tr>
<td>3. Increase Pa02 increases Sa02</td>
<td>3. Oxygen delivery is how much</td>
</tr>
<tr>
<td>4. Venous blood also carries</td>
<td>oxygen is released to tissues</td>
</tr>
<tr>
<td>oxygen</td>
<td></td>
</tr>
<tr>
<td>5. Sv02 reflects venous</td>
<td></td>
</tr>
<tr>
<td>saturation</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total</th>
<th>6</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Map Score</td>
<td>35/50</td>
<td></td>
</tr>
</tbody>
</table>
Table 36
Module Three
Oxygen Transport I
Concept Map Analysis of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Oxygen leaves alveoli and enters blood  
2. Carbon dioxide leaves blood and enters alveoli  
3. Oxygen is transported attached to hemoglobin and plasma  
4. Oxygen is transported to tissues  
5. Deadspace is ventilation | 1. Oxygen transport ends with expiration |
<p>| Total | 7 | 1 |
| Concept Map Score | 31/50 |</p>
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CO is blood flow through heart</td>
<td>1. Mean arterial blood pressure is left ventricular afterload</td>
</tr>
<tr>
<td>2. What enters heart is preload</td>
<td>2. Mean pulmonary arterial blood pressure is right ventricular afterload</td>
</tr>
<tr>
<td>3. Decrease preload decreases CO</td>
<td></td>
</tr>
<tr>
<td>4. As CO decreases heart rate</td>
<td></td>
</tr>
<tr>
<td>increases</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
</tr>
<tr>
<td>Concept Map Score</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>39/50</td>
</tr>
</tbody>
</table>
### Table 38

**Module Four**  
Control of Cardiac Output  
Concept Map Analysis of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CO is blood leaving the heart</td>
<td>1. As CO decreases, heart rate remains unchanged</td>
</tr>
<tr>
<td>2. Preload is ventricular filling</td>
<td>2. Right atrial pressure is afterload</td>
</tr>
<tr>
<td>3. Afterload is resistance to blood flow</td>
<td>3. Left ventricular pressure is afterload</td>
</tr>
<tr>
<td>4. Decrease CO, decreases mean blood pressure</td>
<td>4. Mean arterial blood pressure is preload of left ventricle</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Map Score</td>
<td>32/50</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Compliance is willingness to expand</td>
<td>1. FRC is 200 mL</td>
</tr>
<tr>
<td>2. Airway resistance is friction to air flow</td>
<td>2. Not sure what creates the FRC</td>
</tr>
<tr>
<td>3. There are three compliances: lung, chest wall and total</td>
<td></td>
</tr>
<tr>
<td>4. FRC effects Pa02</td>
<td></td>
</tr>
<tr>
<td>5. Decreases FRC decreases compliance</td>
<td></td>
</tr>
<tr>
<td>6. Decrease compliance increases RR</td>
<td></td>
</tr>
<tr>
<td>7. As FRC increases it takes more time for change in Pa02 with increase in F102</td>
<td></td>
</tr>
<tr>
<td>8. Decrease FRC increases WOB</td>
<td></td>
</tr>
<tr>
<td>9. Increase ST decreases compliance</td>
<td></td>
</tr>
<tr>
<td>10. Volume-pressure curve shows compliance</td>
<td></td>
</tr>
<tr>
<td>11. Decrease surfactant decreases compliance</td>
<td></td>
</tr>
<tr>
<td>12. Surfactant decreases ST</td>
<td></td>
</tr>
<tr>
<td>13. Lung compliance: 200</td>
<td></td>
</tr>
</tbody>
</table>

| Total | 17 | 2 |

**Exam Score 41/48**
## Table 40
Module Two
Mechanics of Ventilation
Exam Analysis of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Compliance is the willingness to expand</td>
<td>1. Normal FRC 200mL</td>
</tr>
<tr>
<td>2. Increase elastance decreases compliance</td>
<td>2. Increase FRC will take less time to change Pa02 with changes in FI02</td>
</tr>
<tr>
<td>3. FRC effects Pa02</td>
<td>3. Not sure what FRC is</td>
</tr>
<tr>
<td>4. Decrease FRC decreases compliance</td>
<td>5. Not sure what is responsible for FRC</td>
</tr>
<tr>
<td>5. Decrease FRC increases WOB</td>
<td>6. As FRC decreases the ability to take in a tidal volume decreases</td>
</tr>
<tr>
<td>6. Volume-pressure curve reflects compliance</td>
<td>7. As ST decreases compliance decreases</td>
</tr>
<tr>
<td>7. As compliance decreases volume-pressure curve flattens</td>
<td>8. Not sure why ST increases with larger volume</td>
</tr>
<tr>
<td>8. FRC is a gas reservoir</td>
<td></td>
</tr>
</tbody>
</table>

| Total | 9 | 7 |

Exam Score 28/48
Table 41
Module Two
Ventilation-to-Perfusion Ratios
Exam Analysis of Novice Student-Participant One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Normal PI02 is 158 torr</td>
<td>1. Pa02 is 94 torr</td>
</tr>
<tr>
<td>2. Normal PA02 is 100 torr</td>
<td>2. Fe02 is 3%</td>
</tr>
<tr>
<td>3. Normal FI02 is 21%</td>
<td>3. FeC02 is 16%</td>
</tr>
<tr>
<td>4. Low V/Q is shunt</td>
<td>4. If PA02 is 53 torr, Pa02 will be 30 torr</td>
</tr>
<tr>
<td>5. Shunt is perfusion without</td>
<td>5. Not sure what end-capillary oxygen content is</td>
</tr>
<tr>
<td>ventilation</td>
<td></td>
</tr>
<tr>
<td>6. High V/Q is deadspace</td>
<td>6. Not sure what right-to-left shunt is</td>
</tr>
<tr>
<td>7. Deadspace is ventilation</td>
<td></td>
</tr>
<tr>
<td>without perfusion</td>
<td></td>
</tr>
<tr>
<td>8. Hypoventilation is PaC02 &gt;</td>
<td></td>
</tr>
<tr>
<td>45 torr</td>
<td></td>
</tr>
<tr>
<td>9. Hyperventilation is PaC02 &lt;</td>
<td></td>
</tr>
<tr>
<td>35 torr</td>
<td></td>
</tr>
<tr>
<td>10. Increased A-aD02 indicates</td>
<td></td>
</tr>
<tr>
<td>shunting</td>
<td></td>
</tr>
<tr>
<td>11. As V/Q mismatch occurs,</td>
<td></td>
</tr>
<tr>
<td>FI02 will need to be increased</td>
<td></td>
</tr>
<tr>
<td>12. Left lower lobe collapse is</td>
<td></td>
</tr>
<tr>
<td>an example of shunt</td>
<td></td>
</tr>
</tbody>
</table>

Total | 13 | 6

Exam Score 30/36
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Normal FI02 is 21%</td>
<td>1. Normal Pa02 is 95 torr</td>
</tr>
<tr>
<td>2. Normal Pb is 760 torr</td>
<td>2. Normal PaC02 is 5 torr</td>
</tr>
<tr>
<td>3. Normal PvC02 is 46 torr</td>
<td>3. Normal PI02 is 760 torr</td>
</tr>
<tr>
<td>4. Normal PA02 is 100 torr</td>
<td>4. Normal Pv02 is 15 torr</td>
</tr>
<tr>
<td>5. Normal PAC02 is 40 torr</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5</strong></td>
</tr>
<tr>
<td></td>
<td><strong>4</strong></td>
</tr>
</tbody>
</table>

Exam Score 5/12
## Table 43

**Module Two**

**Ventilation-to-Perfusion Ratios**

**Exam Analysis for Novice Student-Participant Two**

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. PI02 is 150 torr</td>
<td>1. TLC is the amount of air we breathe in with each breath</td>
</tr>
<tr>
<td>2. PA02 is 100 torr</td>
<td>2. ERC is the maximum amount of air we breathe in</td>
</tr>
<tr>
<td>3. Pa02 is 80-100 torr</td>
<td>3. IRV is maximum air in lungs</td>
</tr>
<tr>
<td>4. FI02 is 21%</td>
<td>5. Not sure how to estimate Pa02 from PA02</td>
</tr>
<tr>
<td>5. FE02% is 16%</td>
<td>6. 75% of the tidal volume is deadspace</td>
</tr>
<tr>
<td>6. FEC02 is 5%</td>
<td>7. Not sure of normal values of lung volumes and capacities</td>
</tr>
<tr>
<td>7. FRC is gas in lung at end-expiration</td>
<td>8. Not sure what occurs with A-aD02 with hypoventilation</td>
</tr>
<tr>
<td>8. PAJ2 is 150 torr (when given variable to calculate)</td>
<td></td>
</tr>
<tr>
<td>9. Deadspace-to-tidal volume is 25%</td>
<td></td>
</tr>
<tr>
<td>10. Can calculate deadspace ratio</td>
<td></td>
</tr>
<tr>
<td>11. Can calculate minute ventilation</td>
<td></td>
</tr>
<tr>
<td>12. Hypoventilation is PaC02&gt;</td>
<td></td>
</tr>
</tbody>
</table>

| Total | 17 | 8 |

**Exam Score 28/36**
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Norma PI02 is 158 torr</td>
<td>1. Not sure of normal values for PIC02, PaC02, Pv02, PvC02, Pa02, Sv02, Sa02, FE02</td>
</tr>
<tr>
<td>2. Normal FI02 is 21%</td>
<td></td>
</tr>
<tr>
<td>3. Normal FIC02 is .03%</td>
<td></td>
</tr>
<tr>
<td>4. Normal PaC02 is 40 torr</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8</strong></td>
</tr>
</tbody>
</table>

**Exam Score 4/12**
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Knows normal values for Pi02, PA02, Pvo2, Sa02, FE02, FEC02</td>
<td>1. Normal Pa02 is 90-100 torr</td>
</tr>
<tr>
<td>2. Normal oxygen consumption is 250 mL/min</td>
<td>2. Normal Sv02 is 40%</td>
</tr>
<tr>
<td>3. Normal carbon dioxide production 200 mL/min</td>
<td>3. Increase A-aD02 reflects deadspace</td>
</tr>
<tr>
<td>4. calculate PA02 AT 150 torr (when given variables to calculate)</td>
<td>4. Ca02 is found by multiplying Pa02 1.3</td>
</tr>
<tr>
<td>5. Estimates Pa02 when given PA02</td>
<td>5. Fetal Hb can not carry has much oxygen as adult Hb</td>
</tr>
<tr>
<td>7. If PAC02 increases, PA02 decreases</td>
<td></td>
</tr>
<tr>
<td>8. Oxygen is carried by hemoglobin and plasma</td>
<td></td>
</tr>
<tr>
<td>9. Calculates Ca02</td>
<td></td>
</tr>
<tr>
<td>10. Calculates oxygen delivery</td>
<td></td>
</tr>
<tr>
<td>11. ODC shifts due to ligands</td>
<td></td>
</tr>
<tr>
<td>12. Sa02 of 90% has Pa02 60 torr</td>
<td></td>
</tr>
<tr>
<td>13. Sa02 of 50% has Pa02 27 torr</td>
<td></td>
</tr>
</tbody>
</table>

| Total | 18 | 6 |

**Exam Score 99/109**
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Knows normals for PI02, PA02, Pvo2, Sa02, FE02, FEC02</td>
<td>1. As CO decreases Ca02-Cv02 decreases</td>
</tr>
<tr>
<td>2. Normal oxygen consumption is 250 mL/min</td>
<td>2. Not sure how calculate dissolved oxygen</td>
</tr>
<tr>
<td>3. Normal carbon dioxide production is 200 mL/min</td>
<td>3. Not sure of what the flat part of the ODC is all about</td>
</tr>
<tr>
<td>4. Calculate PA02 (when given variables)</td>
<td>4. Pa02 and Sa02 has a linear relationship</td>
</tr>
<tr>
<td>5. Estimates Pa02 when given PA02</td>
<td></td>
</tr>
<tr>
<td>6. Fick’s Law governs diffusion</td>
<td></td>
</tr>
<tr>
<td>7. If PAC02 increases, PA02 decreases</td>
<td></td>
</tr>
<tr>
<td>8. Oxygen is carried by hemoglobin and plasma</td>
<td></td>
</tr>
<tr>
<td>9. Calculate Ca02 (when given variables)</td>
<td></td>
</tr>
<tr>
<td>10. Calculate oxygen delivery (when given variables)</td>
<td></td>
</tr>
<tr>
<td>11. ODC shifts due to ligands</td>
<td></td>
</tr>
<tr>
<td>12. Sa02 of 90% has Pa02 60 torr</td>
<td></td>
</tr>
<tr>
<td>13. Sa02 of 50% has Pa02 27 torr</td>
<td></td>
</tr>
<tr>
<td>14. As CO increases, Ca02-</td>
<td></td>
</tr>
</tbody>
</table>

Total 18 4

Exam Score 99/109

Table 46
Module Three
Oxygen Transport I
Exam Analysis of Novice Student-Participant Two
Table 47
Module Four
Control of Cardiac Output
Exam Analysis of Novice Student-Participant One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CO is determined by preload, afterload, contractility, heart rate</td>
<td></td>
</tr>
<tr>
<td>2. Preload is blood in ventricle during diastole</td>
<td></td>
</tr>
<tr>
<td>3. Afterload is resistance to blood flow</td>
<td></td>
</tr>
<tr>
<td>4. Contractility is force of contraction</td>
<td></td>
</tr>
<tr>
<td>5. Increase left heart failure increase lung fluid</td>
<td></td>
</tr>
<tr>
<td>6. Increase RAP decrease venous return</td>
<td></td>
</tr>
<tr>
<td>7. Increase preload increases CO</td>
<td></td>
</tr>
<tr>
<td>8. Increase venous return from vasoconstriction or increase fluids</td>
<td></td>
</tr>
<tr>
<td>9. Afterload is assessed by SVR and PVR</td>
<td></td>
</tr>
<tr>
<td>10. Preload is assessed by left and right atrial pressures</td>
<td></td>
</tr>
<tr>
<td>11. Ventricular volume-pressure</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13</strong></td>
</tr>
</tbody>
</table>

**Exam Score 40/40**
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Four determinants of CO are afterload, preload, HR, and contractility  
2. Preload is blood in ventricle during diastole  
3. Afterload is resistance to blood flow  
4. Increase left heart failure can increase lung fluid  
5. Increase PCWP can increase stroke volume  
6. Vasoconstriction can increase venous return | 1. No sure what is contractility  
2. Increase RAP increases venous return  
3. Not sure how to increase PCWP  
4. Not sure how to assess afterload  
5. Not sure why venous return will increase with a low RAP |
| **Total** | **7** | **5** |

**Exam Score 30/40**
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase surfactant decreases ST</td>
<td>1. Increase surfactant increases elasticity</td>
</tr>
<tr>
<td>2. Increase ST decreases compliance</td>
<td>2. Compliance is responsible for FRC</td>
</tr>
<tr>
<td>3. Increase AWR is due to decrease diameter or increase length</td>
<td>3. Elasticity helps maintain the lung open</td>
</tr>
<tr>
<td>4. Three types of compliances include thoracic, lung, and total</td>
<td>4. As FRC increases, lung compliance decreases</td>
</tr>
<tr>
<td>5. Relationship between chest wall and lung includes lungs recoiling out and chest wall</td>
<td>5. Not sure what end-expiratory volume or pressure is</td>
</tr>
<tr>
<td>Total</td>
<td>6. Not sure what airway conductance is</td>
</tr>
</tbody>
</table>

| Total | 7 | 6 |
### Table 50
**Module One**
**Mechanics of Ventilation**
**Verbal Analysis of Postcourse Interview of Novice Student-Participant Two**

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lungs want to recoil in and chest wall recoils out</td>
<td>1. As FRC increases and nitrogen washout time increases, there is less perfusion</td>
</tr>
<tr>
<td>2. AWR will increase with decrease in diameter or increase length</td>
<td>2. Not sure what effects change in elasticity has on FRC</td>
</tr>
<tr>
<td>3. Increase AWR requires a greater driving pressure</td>
<td>3. Not sure normal value of FRC</td>
</tr>
<tr>
<td>4. Lung expands due to pressure gradient</td>
<td>4. Not sure what airway conductance is</td>
</tr>
<tr>
<td>5. When alveolar pressure equal atmospheric, flow stops</td>
<td>5. Not sure what end-expiratory volume or pressure is</td>
</tr>
<tr>
<td>6. Not sure what the relationship between compliance and FRC is</td>
<td></td>
</tr>
</tbody>
</table>

**Total** | 5 | 6 |

### Table 51
**Module Two**
**Ventilation-to-Perfusion Ratios**
**Verbal Analysis of Postcourse Interview of Student-Participant One**

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Humidity and CO₂ can dilute PAO₂</td>
<td>1. If minute ventilation is doubled, the PCO₂ may decrease, but not sure by how much</td>
</tr>
<tr>
<td>2. PAO₂ &gt; PaO₂</td>
<td></td>
</tr>
<tr>
<td>3. PI02 &gt; PA02</td>
<td></td>
</tr>
<tr>
<td>4. Hyperventilation blows off CO₂</td>
<td></td>
</tr>
<tr>
<td>5. Shunt is blood flow without ventilation</td>
<td></td>
</tr>
</tbody>
</table>

**Total** | 10 | 1 |

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### Table S2

**Module Two**

**Ventilation-to-Perfusion Ratios**

**Verbal Analysis of Post Course Interview of Novice Student-Participant Two**

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase deadspace increases PaC02</td>
<td></td>
</tr>
<tr>
<td>2. Need to increase RR if deadspace increases to preserve CO2</td>
<td></td>
</tr>
<tr>
<td>3. Oxygen diffuses due to pressure gradient</td>
<td></td>
</tr>
<tr>
<td>4. Carbon dioxide diffuses due to pressure gradient</td>
<td></td>
</tr>
<tr>
<td>5. Oxygen consumption of 250 mL/min</td>
<td></td>
</tr>
<tr>
<td>6. Carbon dioxide production 200 mL/min</td>
<td></td>
</tr>
<tr>
<td>7. Shunt is blood flow without</td>
<td></td>
</tr>
</tbody>
</table>

| Total | 11 | 2 |

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<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Oxygen is transported by hemoglobin and plasma</td>
<td>1. Not sure normal SvO2</td>
</tr>
<tr>
<td>2. SaO2 influences CaO2</td>
<td>2. Not sure what PvO2</td>
</tr>
<tr>
<td>3. There is a relationship between PaO2 and SaO2</td>
<td>3. Not sure normal CaO2</td>
</tr>
<tr>
<td>4. Increase PaO2 will increase SaO2</td>
<td>4. Can not calculate PAO2 (when given variables)</td>
</tr>
<tr>
<td>5. Blood carries oxygen</td>
<td>5. Not sure what happens to A-aD02 with increase FiO2</td>
</tr>
<tr>
<td>6. Decrease blood flow will decrease oxygen transport</td>
<td>6. Not sure what the equation for oxygen delivery is</td>
</tr>
<tr>
<td>7. Increase FiO2 increases PAO2</td>
<td></td>
</tr>
<tr>
<td>8. Decrease tidal volume decreases oxygen levels and increases CO2</td>
<td></td>
</tr>
<tr>
<td>9. Low venous oxygenation</td>
<td></td>
</tr>
</tbody>
</table>

**Table 53**  
Module Three  
Oxygen Transport I  
Verbal Analysis of Postcourse Interview of Novice Student-Participant One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total 10</td>
<td>6</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Oxygen is carried by hemoglobin and plasma</td>
<td>1. Not sure of Ca02 equation</td>
</tr>
<tr>
<td>2. Normal Ca02 is 20 mL/dL</td>
<td>2. Not sure of oxygen delivery equation</td>
</tr>
<tr>
<td>3. Sa02 90-100%</td>
<td>3. Not sure normal Cv02</td>
</tr>
<tr>
<td>4. Increase PI02 increases PA02 and Pa02</td>
<td>4. Not sure if A-aD02 increases what occurs with Ca02-Cv02</td>
</tr>
<tr>
<td>5. There is a relationship between Sa02 and Pa02</td>
<td>5. Not sure a/A and Pa02,FI02 means</td>
</tr>
<tr>
<td>6. A decrease in tidal volume will increase CO2 and decrease</td>
<td></td>
</tr>
</tbody>
</table>

**Total**

8

6
### Table 55

**Module Four**

**Control of Cardiac Output**

**Verbal Analysis of Postcourse Interview of Novice Student-Participant One**

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Preload is blood in ventricle during diastole</td>
<td>1. Not sure of preload of right heart</td>
</tr>
<tr>
<td>2. Afterload is resistance to blood flow</td>
<td>2. MAP is afterload of left heart</td>
</tr>
<tr>
<td>3. Increase preload increases CO</td>
<td>3. MPAP is afterload of right heart</td>
</tr>
<tr>
<td>4. Increase afterload decreases stroke volume</td>
<td>4. As ventricular pressures increases, CO increases in a linear manner</td>
</tr>
<tr>
<td>5. Decrease stroke volume decreases CO</td>
<td></td>
</tr>
<tr>
<td>6. PCWP indicates left heart preload</td>
<td></td>
</tr>
<tr>
<td>7. Normal MPAP is 25.10 torr</td>
<td></td>
</tr>
<tr>
<td>8. Normal RAP is 0-6 torr</td>
<td></td>
</tr>
</tbody>
</table>

| Total | 10 | 4 |
Table 56
Module Four
Control of Cardiac Output
Verbal Analysis of Post Course Interview of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions (AC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Preload is blood in ventricle during diastole</td>
<td></td>
</tr>
<tr>
<td>2. Afterload is resistance to blood flow</td>
<td></td>
</tr>
<tr>
<td>3. Increase preload increases CO</td>
<td></td>
</tr>
<tr>
<td>4. Decrease stroke volume decreases CO</td>
<td></td>
</tr>
<tr>
<td>5. Left heart failure will increases lung fluid</td>
<td></td>
</tr>
<tr>
<td>1. Increase RAP increases venous return</td>
<td></td>
</tr>
<tr>
<td>2. Not sure of clinical assessment of afterload and preload</td>
<td></td>
</tr>
<tr>
<td>3. As RAP decreases, PCWP increases</td>
<td></td>
</tr>
</tbody>
</table>

Total | 7 | 3 |
### Table 57
Module five
Oxygen Transport II
Prelecture Simulation Analysis of Novice Student-Participant One

<table>
<thead>
<tr>
<th>Number of Predictions Correct</th>
<th>Number of Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

**Actual Predictions**

1. Increase PA02 increases SaO2
2. SaO2 50% is PA02 27 torr
3. SaO2 90% is PA02 60 torr
4. Increase ventilation decreases C02
5. Increase end-capillary oxygen content, CaO2 & CvO2 remain constant will increase Qs/Qt
6. If end-capillary oxygen decreases, CaO2 and CvO2 decreases
7. Increase PaCO2 increases

**Actual Incorrect Predictions**

1. If CvO2 15 mL/dL, end-capillary oxygen content 15 mL/dL and CaO2 22 mL/dL, shunt will decrease if CaO2 decreases

**Propositional Knowledge Statements**

1. Increase PaO2 increases SaO2
2. PaO2 of 60 has SaO2 90%
3. As you move left to right, CaO2 increases on the oxygen content curve
4. Increase ventilation, decrease C02
5. PaO2 80-100 torr
6. As end-capillary oxygen decreases, CaO2 and CvO2 decreases
7. SvO2 75%

**Alternative Conceptions**

1. Not sure of normal CvO2
2. CaO2 is 100 mL/dL
3. If CaO2 decreases while end-capillary oxygen remains unchanged, not sure what will happen to Qs/Qt

<table>
<thead>
<tr>
<th>Total</th>
<th>8</th>
<th>3</th>
</tr>
</thead>
</table>

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### Table 58
Module Five
Oxygen Transport II
Prelecture Simulation Analysis for Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Number of Predictions</th>
<th>Number of Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>4</td>
</tr>
<tr>
<td>Actual Predictions</td>
<td></td>
</tr>
<tr>
<td>1. Increase Pa02 increases Sa02</td>
<td>1. Not sure Sa02 for Pa02 60 torr</td>
</tr>
<tr>
<td>2. Increase ventilation will decreases C02</td>
<td>2. Not sure Sa02 for Pa02 27 torr</td>
</tr>
<tr>
<td>3. Qs/Qt will increase if Ca02 is decreases while end-capillary oxygen and Cv02 remain unchanged</td>
<td>3. Increase end-capillary oxygen, keeping Ca02 and Cv02 unchanged, Qs/Qt decreases</td>
</tr>
<tr>
<td>4. Decrease end-capillary oxygen will decrease Ca02 and Cv02</td>
<td></td>
</tr>
<tr>
<td>Propositional Knowledge Statements</td>
<td>Alternative Conceptions</td>
</tr>
<tr>
<td>1. Increase Pa02 will increase Sa02</td>
<td>1. Cv02 75%</td>
</tr>
<tr>
<td>2. Increase ventilation decreases</td>
<td>2. Not sure what end-capillary oxygen is</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 59
Module Six & Eight
Preload, Afterload, and Contractility
Prelecture Simulation Analysis of Novice Student-Participant One

<table>
<thead>
<tr>
<th>Number of Predictions Correct</th>
<th>Number of Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>5</td>
</tr>
</tbody>
</table>

Actual Predictions

1. Increase body fluids with 1000 mL whole blood will increase LVEDP, LVEDV, stroke volume, CO, and decrease heart rate
2. Vasodilation will decrease blood pressure
3. Increase in contractility will increase CO
4. Decrease contractility can decrease CO
5. As contractility decreases,

Incorrect Predictions

1. Vasodilation will decrease LVEDV, LVEDP, stroke volume, CO
2. Vasodilation increases heart rate

Propositional Knowledge Statements

1. Increase body fluid will increase stroke volume and CO
2. Increase preload will increase contraction
3. Increase preload will increase CO
4. Vasodilation increases vascular space
5. Decrease resistance will increase stroke volume and CO
6. Increase afterload can decrease CO and decrease oxygen delivery

Alternative Conceptions

1. Not sure how to increase preload other than increase fluids
2. Increase CO will always increase SV
3. Not sure effects of increase preload has on oxygen transport
4. Increase in stroke volume with vasodilation is due to increase venous return
5. Not sure what LVEDV and LVEDP is
6. Increase venous return will

Total

8

6
<table>
<thead>
<tr>
<th>Actual Predictions</th>
<th>Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase body fluids by 1000 mL whole blood will increase: CO, stroke volume, LVEDP, LVEDV</td>
<td></td>
</tr>
<tr>
<td>2. Vasodilation will increase LVEDP, LVEDP, stroke volume, CO</td>
<td></td>
</tr>
<tr>
<td>3. Vasodilation will decrease blood pressure</td>
<td></td>
</tr>
<tr>
<td>4. Increase in body fluids can increase heart rate</td>
<td></td>
</tr>
<tr>
<td>5. Increase contractility will</td>
<td></td>
</tr>
<tr>
<td>Propositional Knowledge Statements</td>
<td>Alternative Conceptions</td>
</tr>
<tr>
<td>1. Increase fluids will increase CO, stroke volume, LVEDP, LVEDV</td>
<td>1. Not sure what LVEDP and LVEDV is</td>
</tr>
<tr>
<td>2. Increase preload can decrease heart rate</td>
<td></td>
</tr>
<tr>
<td>3. Increase preload can increase contractility</td>
<td></td>
</tr>
<tr>
<td>4. Increase contractility increases CO</td>
<td></td>
</tr>
<tr>
<td>5. Vasodilation decreases</td>
<td></td>
</tr>
</tbody>
</table>

<p>| Total | 7 | 1 |</p>
<table>
<thead>
<tr>
<th>Table 61</th>
<th>Module Eight</th>
<th>Oxygen Dependency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prelecture Simulation Analysis of Novice Student-Participant One</td>
<td></td>
</tr>
<tr>
<td>Number of Predictions</td>
<td>Number of Incorrect Predictions</td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Actual Predictions</td>
<td>Incorrect Predictions</td>
<td></td>
</tr>
<tr>
<td>1. As blood volume decreases hemoglobin decreases</td>
<td>1. Decrease CO and 11% FI02 will increase oxygen consumption, decrease carbon dioxide production, increase oxygen extraction</td>
<td></td>
</tr>
<tr>
<td>2. Decrease hemoglobin decreases Ca02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Decrease CO will decrease oxygen delivery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propositional Knowledge Statements</td>
<td>Alternative Conceptions</td>
<td></td>
</tr>
<tr>
<td>1. Decrease blood flow will decrease oxygen transport and delivery</td>
<td>1. Not sure why oxygen consumption decreases with decrease in FI02 and CO</td>
<td></td>
</tr>
<tr>
<td>2. Low FI02 will decrease blood oxygen</td>
<td>2. Not sure why carbon dioxide production decrease with decrease in CO</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

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Table 62
Module Eight
Oxygen Dependency
Prelecture Simulation Analysis of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Number of Predictions Correct</th>
<th>Number of Incorrect Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

**Actual Predictions**

1. As blood volume decreases, hemoglobin decreases
2. Decrease hemoglobin decreases CaO2
3. Decrease CO will decrease oxygen delivery

**Incorrect Predictions**

1. Decrease CO and 11% FI02 will increase oxygen consumption, decreases carbon dioxide production, and increases oxygen extraction

**Propositional Knowledge Statements**

1. Decrease blood flow will decrease oxygen transport and delivery
2. Low FI02 will decrease blood oxygen

**Alternative Conceptions**

1. Not sure why oxygen consumption decreases with decrease in FI02 and CO
2. Not sure why carbon dioxide production decreases with decrease in CO
3. Not sure what occurs with oxygen extraction with a decrease in FI02 or CO

<p>| Total | 2 | 2 |</p>
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Decrease CO decreases Sv02 and Pv02
2. Increase CO increase Sv02 and Pv02
3. To assess how well the lungs are oxygenating look at Pa02, Sa02, Sv02, WOB, skin color, heart rate
4. To assess tissue oxygenation look at Pv02, Sv02, Cv02 | 1. Not sure what other indices of oxygenation to assess
2. First response to hypoxemia is increased RR then heart rate |

<p>| Total | 7 | 2 |</p>
<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To assess how the are oxygenating: Pa02, Pa02, Sv02, V/Q ratio</td>
<td>1. Not sure what other indices are used to assess oxygenation</td>
</tr>
<tr>
<td>2. How well tissues are oxygenated: Sv02 and Pv02</td>
<td>2. Increase blood flow tissues will not have time to extract oxygen so Sv02 will increase</td>
</tr>
<tr>
<td>3. If blood flow decreases tissues increase oxygen extraction</td>
<td>3. Decrease FRC decrease diffusion</td>
</tr>
<tr>
<td>4. Increase tissue extraction decreases venous oxygenation</td>
<td>4. First response to hypoxia is increase RR</td>
</tr>
<tr>
<td>5. Signs of hypoxemia: increase</td>
<td></td>
</tr>
</tbody>
</table>

<p>| Total | 8 | 4 |</p>
<table>
<thead>
<tr>
<th>Propositional Knowledge</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE ONE</td>
<td>CASE ONE</td>
</tr>
<tr>
<td>1. Diagnosis: left heart failure</td>
<td>1. Increase RR due to low PaCO2 in order to get more oxygen in</td>
</tr>
<tr>
<td>2. Decrease CO decreases</td>
<td>CASE TWO</td>
</tr>
<tr>
<td>oxygen delivery</td>
<td>1. Not sure of treatment</td>
</tr>
<tr>
<td>3. Increase afterload to</td>
<td>CASE FOUR</td>
</tr>
<tr>
<td>compensate for low stroke</td>
<td>1. Low SVR decreases CO</td>
</tr>
<tr>
<td>volume</td>
<td>2. Vasoconstriction is present</td>
</tr>
<tr>
<td>CASE TWO</td>
<td>3. Give fluids</td>
</tr>
<tr>
<td>1. Diagnosis: hypovolemia</td>
<td>4. Not sure what else is going on</td>
</tr>
<tr>
<td>2. Increase fluids</td>
<td></td>
</tr>
<tr>
<td>3. All pressures and volumes are increased</td>
<td></td>
</tr>
<tr>
<td>CASE THREE</td>
<td></td>
</tr>
<tr>
<td>1. Diagnosis: hypovolemia</td>
<td></td>
</tr>
<tr>
<td>2. Blood loss decrease volume</td>
<td></td>
</tr>
<tr>
<td>3. Urine output decreases</td>
<td></td>
</tr>
</tbody>
</table>

| Total                           | 11                     |
|                                 | 6                      |

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**Table 66**

Module Six and Seven

Preload, Afterload, and Contractility

Postlecture Interview of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE ONE</td>
<td>CASE ONE</td>
</tr>
<tr>
<td>1. Diagnosis: left heart failure</td>
<td>1. Increase RAP and PCWP due to increase blood volume</td>
</tr>
<tr>
<td>2. Decrease CO decreases oxygen delivery</td>
<td>CASE TWO</td>
</tr>
<tr>
<td>3. Increase afterload to compensate for low stroke volume</td>
<td>1. Not sure of treatment</td>
</tr>
<tr>
<td>4. Increase MAP due to vasoconstriction</td>
<td>2. Increase RAP will increase venous return</td>
</tr>
<tr>
<td>CASE TWO</td>
<td>CASE THREE</td>
</tr>
<tr>
<td>1. Diagnosis: hypervolemia</td>
<td>1. Diagnosis: hypovolemia</td>
</tr>
<tr>
<td>2. Increase fluids</td>
<td>2. Blood loss decrease volume</td>
</tr>
<tr>
<td>3. All pressures and volumes are increased</td>
<td></td>
</tr>
</tbody>
</table>

**Total**    

11                     

4
Table 67
Module Six, Seven, & Eight
Preload, Afterload, Contractility, and Oxygen Dependency
Concept Map Analysis for Novice Student-Participant One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase afterload decreases CO</td>
<td></td>
</tr>
<tr>
<td>2. Vasoconstriction increases afterload</td>
<td></td>
</tr>
<tr>
<td>3. Increase preload increases CO</td>
<td></td>
</tr>
</tbody>
</table>

Total: 5 0

Concept Map Score: 36/50

Table 68
Module Six, Seven, & Eight
Preload, Afterload, Contractility, and Oxygen Dependency
Concept Map Analysis Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase afterload decreases stroke volume</td>
<td></td>
</tr>
<tr>
<td>2. Increase preload increases CO increases oxygen delivery</td>
<td></td>
</tr>
<tr>
<td>1. Vasoconstriction increases MAP</td>
<td></td>
</tr>
</tbody>
</table>

Total: 2 1

Concept Map Score: 34/50

234
**Table 69**
Final Concept Map Analysis of Novice Student One

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Oxygen is transported by hemoglobin and dissolved in plasma  
2. Normal CaO2 is 20 mL/dL  
3. Dissolved oxygen is reflected in PaO2  
4. Venous oxygen indicates what tissues have used | 1. Oxygen transport effects ODC  
2. PaO2 reflects plasma oxygen and hemoglobin |

| Total | 5 | 2 |
| Concept map score | 40/50 |

**Table 70**
Final Concept Map Analysis of Novice Student-Participant Two

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Oxygen is carried by blood attached to hemoglobin and dissolved in plasma  
2. CaO2 influenced by SaO2  
3. PiO2 determines PAO2  
4. PAO2 determines PaO2  
5. Venous oxygenation reflects | 1. Oxygen transport is determined by ODC  
2. Oxygen consumption is determined by ODC |

| Total | 5 | 2 |
| Concept Map Score | 38/50 |

235
<table>
<thead>
<tr>
<th></th>
<th>Number of Correct Response Predictions</th>
<th>Number of Incorrect Response Predictions</th>
<th>Propositional Knowledge Statements</th>
<th>Number of Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mechanics of Ventilation</td>
<td>20/24</td>
<td>19/26</td>
<td>10/18</td>
<td>7/6</td>
</tr>
<tr>
<td>2 Ventilation to Perfusion</td>
<td>11/14</td>
<td>2/14</td>
<td>13/13</td>
<td>8/2</td>
</tr>
<tr>
<td>3 Oxygen Transport I</td>
<td>49/57</td>
<td>8/11</td>
<td>24/18</td>
<td>11/14</td>
</tr>
<tr>
<td>4 Control of Cardiac Output</td>
<td>24/28</td>
<td>13/18</td>
<td>11/16</td>
<td>5/5</td>
</tr>
<tr>
<td>5 Oxygen Transport II</td>
<td>11/9</td>
<td>4/5</td>
<td>11/9</td>
<td>6/8</td>
</tr>
<tr>
<td>6-7 Preload &amp; Afterload</td>
<td>15/11</td>
<td>5/8</td>
<td>15/12</td>
<td>7/12</td>
</tr>
<tr>
<td>8 Oxygen Dependency</td>
<td>4/5</td>
<td>6/4</td>
<td>4/5</td>
<td>4/6</td>
</tr>
<tr>
<td>Total</td>
<td>134/148</td>
<td>57/86</td>
<td>88/91</td>
<td>48/51</td>
</tr>
<tr>
<td>Average</td>
<td>19/21</td>
<td>8.1/12.28</td>
<td>12.57/13</td>
<td>6.8/7.28</td>
</tr>
</tbody>
</table>
Table 72
Resistant-to-Change Alternative Conceptions
that Remained Throughout the Study for all Novice Student-Participants

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>As functional residual capacity increases, time for nitrogen washout while breathing 100% oxygen decreases</td>
</tr>
<tr>
<td>2</td>
<td>A decrease in functional residual capacity will increase compliance</td>
</tr>
<tr>
<td>3</td>
<td>Functional residual capacity is air moved in and out while breathing</td>
</tr>
<tr>
<td>4</td>
<td>Change in deadspace volume will not alter PaCO2</td>
</tr>
<tr>
<td>5</td>
<td>Hyperventilation is fast respiratory rate</td>
</tr>
<tr>
<td>6</td>
<td>The only means of increasing cardiac output is by increasing heart rate</td>
</tr>
<tr>
<td>7</td>
<td>PaO2 and SaO2 are linear</td>
</tr>
<tr>
<td>8</td>
<td>As cardiac output decreases, CaO2-CvO2 decreases</td>
</tr>
<tr>
<td>9</td>
<td>As blood flow rate increases, there is less time for oxygen to be unloaded</td>
</tr>
<tr>
<td>10</td>
<td>Vasodilation will increase venous return</td>
</tr>
<tr>
<td>11</td>
<td>Vasodilation occurs with blood loss</td>
</tr>
<tr>
<td>12</td>
<td>First response to hypoxemia is increase respiratory rate</td>
</tr>
<tr>
<td>13</td>
<td>PaO2 and PaCO2 change in a proportional manner</td>
</tr>
</tbody>
</table>

Table 73
Concepts Related to Oxygen Transport and Utilization
that Remained unknown Throughout the Study

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Indices to assess oxygenation other than: PaO2, SaO2, PvO2, SvO2, CaO2. Unkown indices include: PaO2/FiO2, A-aD02, a/a ratio, oxygen extraction ratio.</td>
</tr>
<tr>
<td>2</td>
<td>Definition of and normal values for functional residual capacity</td>
</tr>
<tr>
<td>3</td>
<td>Concept of deadspace-like ventilation and perfusion-like states</td>
</tr>
<tr>
<td>4</td>
<td>End-expiratory volume and pressures</td>
</tr>
<tr>
<td>5</td>
<td>Clinical assessment of preload and afterload</td>
</tr>
<tr>
<td>6</td>
<td>Significance of a changing CaO2-CvO2 gradient</td>
</tr>
</tbody>
</table>

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1. Assess vital signs
   a. Pulse 74, BP 109/74, T 39°C, RR 22

2. Perform physical exam
   a. General inspection
      1) Alert female
      2) Normal weight
      3) Slight use of accessory muscles
   b. Palpation
      1) Within normal limits (WNL)
   c. Percussion
      1) Dull in left chest
   d. Auscultation
      1) Tubular breath sounds with scattered wheezing

3. Obtain laboratory data
   a. Chest x-ray reveals lower left infiltrate
   b. Arterial blood gas reveals pH 7.31, PaO2 50 torr, and PaCO2 55 torr
   c. Blood count: Hb 14 grams, Hct 42%, and WBC 5500 µL

4. Treat signs and symptoms of pneumonia
   a. Provide oxygen
   b. Monitor for deteriorating cardiopulmonary function
   c. Monitor vital signs
   d. Give fluids and bronchodilators
   e. Give antibiotics
   f. Attempt to reverse hypoxemia and hypercapnea
   g. Intubate and avoid assist/control mode and hyperinflation

(table continued)
Table 78
Medical Management Per Expert Panel for
Simulation Case Two: Hallie

Fifty-five year old female recovering from coronary by-pass surgery. The patient is in the intensive care unit and complaining of acute weakness and dyspnea.

1. Assess vital signs
   a. Pulse 150, BP 60/47, T 37°C, RR 37

2. Perform physical exam
   a. Inspection
      1) Alert obese female will pallor and cyanosis
      2) Diaphoretic
   b. Palpation
      1) WNL
   c. Percussion
      1) Dull in right base
   d. Auscultation
      1) Diminished breath sounds in right base with scattered wheezing
   e. Increased capillary refill time

3. Obtain laboratory data
   a. Chest x-ray reveals right effusion
   b. Arterial blood gases WNL
   c. Blood count: Hb 14 gram, Hct 34%

6. Treat signs and symptoms of hypotension.
   a. R/O hypotension
      1) determine low or high flow state

(table continued)
b. Consider fluid challenge
c. Hypovolemia from hemorrhagic bleeding in pleural cavity
d. Determine if bleeding is present
e. Correct bleeding
f. Drain effusion
g. Preserve oxygen transport
h. Treat pre-existing lung disease
i. Preserve hemodynamics
j. Monitor for sepsis, multiorgan failure and acute respiratory distress syndrome
l. Increase hemoglobin levels

<table>
<thead>
<tr>
<th>Table 79</th>
<th>Intermediate Student-Participant: Transcript of Simulation Response for Case One (Penny)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student-Participant Response</td>
<td>Propositional Knowledge Statements</td>
</tr>
<tr>
<td>Reads Penny case</td>
<td></td>
</tr>
<tr>
<td>Checks (Cks) breath sounds (BS)</td>
<td>Checks breath sound prior to vital sounds</td>
</tr>
<tr>
<td>Cks blood gas “Oh...oh...a low Pa02...need to get this up”</td>
<td>Recognizes need for oxygen</td>
</tr>
<tr>
<td>Increase FI02 100%</td>
<td></td>
</tr>
<tr>
<td>“I need to give Albuterol – will give 1.0 mg every 30 minutes”</td>
<td>Recognizes the need to treat bronchospasm with beta agonist</td>
</tr>
<tr>
<td>Cks vital signs (VS)</td>
<td></td>
</tr>
</tbody>
</table>

240 (table continued)
<table>
<thead>
<tr>
<th>Cks Chest x-ray</th>
<th>No indication for x-ray at this—was unsure what to do next</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cks BS “Still wheezing”</td>
<td>“Not sure what to do”</td>
</tr>
<tr>
<td></td>
<td>“I am not sure what drug to give”</td>
</tr>
<tr>
<td>Cks blood gas “Heart rate, RR, Pa02, and Sa02 are all increased”</td>
<td>Patient is responding to increased oxygen</td>
</tr>
<tr>
<td></td>
<td>Does not note the tachycardia or its cause</td>
</tr>
<tr>
<td>“I’ll check heart sounds”</td>
<td>Seems to want to check heart sounds for the lack of anything else to do. No indication to check heart sounds</td>
</tr>
<tr>
<td>“I’ll get an echo”</td>
<td>Using the wrong diagnostic tool to assess patient</td>
</tr>
<tr>
<td>“I need to give a diuretic--Lasix but I am not sure of dose”</td>
<td>Unsure of dose of Lasix. Gives diuretic without an indication</td>
</tr>
<tr>
<td>Cks blood gas “I need to get the Pa02 up”</td>
<td>Recognizes the need for oxygen</td>
</tr>
<tr>
<td>I need to give an inotrope</td>
<td>Going for a drug when patient needs more oxygen. No arterial line or pulmonary catheter is in place.</td>
</tr>
</tbody>
</table>

(table continued)
<table>
<thead>
<tr>
<th>Cks VS “RR is up”</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>“I think she needs a phlebotomy”</td>
<td>No indication for removing blood volume. Has not assessed hemodynamics</td>
</tr>
<tr>
<td>Cks metabolic panel</td>
<td>Makes no comments—does not note reduced venous oxygenation and increased deadspace</td>
</tr>
<tr>
<td>“I will intubate her since her RR is 48”</td>
<td>Recognizes increase WOB and the possible need for intubation</td>
</tr>
<tr>
<td>“I’ll place her on assist/control, tidal volume 700, rate 12”</td>
<td>Does not assess blood gas, minute ventilation, or other indices of mechanics of ventilation</td>
</tr>
<tr>
<td>“Maybe I’ll sedate her—with morphine”</td>
<td>Wants to control breathing with a mode that will overventilate patient.</td>
</tr>
<tr>
<td>Cks VS</td>
<td>Student not sure of dose</td>
</tr>
</tbody>
</table>

Patient is breathing a rate of 48 while on assist/control. Student fails to assess PaCO2
<table>
<thead>
<tr>
<th>“Maybe I will change her to control mode”</th>
<th>Attempts to reduce rate by placing patient in control mode. This is contraindicated by conventional therapy.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cks chest x-ray</td>
<td>Patients primary problem is respiratory. Student has not distinguished between pulmonary and cardiac disease</td>
</tr>
<tr>
<td>“Her heart is smaller I must have fixed her problem”</td>
<td></td>
</tr>
<tr>
<td>Cks blood gas: PaO2 98, CO2 is still high—with her high RR her CO2 should be lower”</td>
<td>Does not note high deadspace ratio which is the cause of elevated CO2.</td>
</tr>
<tr>
<td>Cks hemodynamics</td>
<td>Assess cardiopulmonary function</td>
</tr>
<tr>
<td>Cks metabolic panel</td>
<td>Uncertain with normal values dealing with lab test to assess oxygen delivery and hemodynamics</td>
</tr>
<tr>
<td>Cks blood gas</td>
<td></td>
</tr>
<tr>
<td>“I have such a problem with normal values”</td>
<td></td>
</tr>
<tr>
<td>“I am not sure what to do”</td>
<td>Uncertain what to do</td>
</tr>
<tr>
<td>Cks venous oxygen</td>
<td>Recognizes need to assess oxygen supply and demand</td>
</tr>
<tr>
<td>“I am unsure what normal values for SvO2 and PvO2 is”</td>
<td>Uncertain of venous blood gas values. Does not note 32L minute volume or increased deadspace ratio</td>
</tr>
<tr>
<td>“I want to get her CO2 down”</td>
<td>Recognizes the lower CO2</td>
</tr>
</tbody>
</table>

(table continued)
| "I will increase her tidal volume to 1000 mL" | Patient is on assist control with a minute volume of 32 L — increasing tidal volume to 1000 mLs will provide excessive ventilation and barotrauma. Student seems unsure of correct mode to choose. |
| "C02 is rising and I don’t know why" | Does not recognize patient has dynamic hyperinflation |
| "I’ll recheck an echo" | No indication for echo—student seems to be guessing at choices. |
| Cks VS | Still has not placed an arterial line. |
| "Maybe I’ll give her a vasodilator" | Student has not assesses hemodynamics to choose vasodilation. |
| "I’ll give nitropresside, but I don’t know dose" | Uncertain of dose of a drug that alters blood flow and oxygen transport. |

(table continued)
<table>
<thead>
<tr>
<th>Cks VS</th>
<th>Student wants to get heart rate down by giving a drug that will increase the heart rate. Student does not know dose.</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Heart rate is 150, lets give epinephrine”</td>
<td></td>
</tr>
<tr>
<td>Cks VS</td>
<td>Fails to see relationship between high CO2, RR, and deadspace.</td>
</tr>
<tr>
<td>“I don’t know why RR is so high”</td>
<td></td>
</tr>
<tr>
<td>“I’ll change her to SIMV”</td>
<td>Recognizes the need to reduce ventilation</td>
</tr>
<tr>
<td>“I’ll change her to SIMV”</td>
<td>Uncertain what motivated the student to change mode. Has not recognize dynamic hyperinflation.</td>
</tr>
<tr>
<td>“No, let me change her to control mode”</td>
<td>Randomly selecting modes. Student wants to control high RR with control mode which is contraindicated at this time.</td>
</tr>
<tr>
<td>Cks VS and blood gas</td>
<td></td>
</tr>
<tr>
<td>“Heart rate is up and CO2 is high”</td>
<td>Student still does not recognize the patient is hyperinflated</td>
</tr>
<tr>
<td>“I can’t get her blood gas inline..I don’t know what to do”</td>
<td></td>
</tr>
<tr>
<td>“I’ll change her to SIMV”</td>
<td>Recognizes need to change mode</td>
</tr>
</tbody>
</table>

(table continued)
"I am lost"

<table>
<thead>
<tr>
<th>Student Response</th>
<th>Propositional Knowledge Statements</th>
<th>Actual or Implied Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reads case history</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Checks (Cks) blood gas “P02 is ok, C02 is high, and hemoglobin is 8 grams”</td>
<td>Obtains blood gas first prior to assessing vital signs (VS) or physical assessment. Does not comment on the low hemoglobin— which decreases oxygen transport</td>
<td></td>
</tr>
</tbody>
</table>

(table continued)

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<table>
<thead>
<tr>
<th>Cks hemodynamics</th>
<th>Seems to be checking blood gas and hemodynamics to assess initial cardiopulmonary function. Notes that heart rate is high, cardiac output and blood pressure is low</th>
<th>Looks at hemodynamics and choose to attempt to lower heart rate. However, heart rate is elevated to compensate for low blood volume. Student fails to connect these three variables to arrive to this conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;I need to the heart rate down&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cks breath sounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Tubular breath sounds in right upper lobe—there is something in there’&quot;</td>
<td></td>
<td>Seems unsure what may be causing abnormal breath sounds.</td>
</tr>
<tr>
<td>Cks VS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Heart rate is 150 and thready”</td>
<td></td>
<td>Fails to see relationship between high heart rate and thready pulse. Patient remains in a low volume state.</td>
</tr>
<tr>
<td>Perform palpation and says &quot;There is tactile fremitus—there is something in there”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Maybe she needs fluids”</td>
<td></td>
<td>Begins to recognize the need to increase blood volume</td>
</tr>
<tr>
<td>Cks PMI “That is ok”</td>
<td></td>
<td>Assesses PMI to determine heart size.</td>
</tr>
<tr>
<td>An incomplete assessment of the cardiac system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(table continued)
"I need to get the heart rate down" | Fails to see the relationship between fast heart rate and low blood volume.

Student looks at vasoactive drug list seems to be considering giving a vasoactive drug to slow heart rate down.

URINE OUTPUT IS LOW Warning panel

"This must be do to the low blood pressure" | Associates low urine output with low blood pressure

"I'll give dopamine" | Considers a drug that is used to increase blood pressure | Not sure of the dose. Does not assess hemodynamics prior to administering a vasoactive drug that alters cardiac function and oxygen delivery.

Cks chest x-ray "Oh oh a pleural effusion..I will need to tap the effusion" | Correct choice in wanting to tap the effusion. Recognizes need to remove pleural fluid. | Seem to be randomly looking at things to do for this patient.

Cks heart rate "It is still high" | | Needed to consider chest tubes at his time.

"I will place chest tubes" | Use of tubes are indicated to remove pleural fluid.

etable continued

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<table>
<thead>
<tr>
<th>Cks heart rate</th>
<th>Seems unsure why heart rate is high. Has not associated blood loss into pleural lining as a source of volume loss.</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Still high”</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>“Maybe I’ll increase Dopamine”</td>
<td>Wants to give a drug that increase blood pressure when the problem is active bleeding in the pleural space.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Is unsure of the dose to give</td>
</tr>
<tr>
<td>Cks VS</td>
<td>Recognizes that blood pressure should be higher with dopamine, however it is not responding.</td>
</tr>
<tr>
<td>“Blood pressure is still low even with the Dopamine”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fails to note hypovolemia</td>
</tr>
<tr>
<td>“I’ll increase the Dopamine and check hemoglobin and hematocrit”</td>
<td>Appropriate to check hemocrit since there is signs and symptoms of low blood volume.</td>
</tr>
<tr>
<td></td>
<td>Additional Dopamine with hypovolemia is contraindicated.</td>
</tr>
<tr>
<td>“She needs blood, I’ll give 333 mL/min”</td>
<td>Recognizes a low hemoglobin and hematocrit and choose blood to give.</td>
</tr>
<tr>
<td></td>
<td>Randomly chooses a blood administration dose. Dose is excessive.</td>
</tr>
<tr>
<td>“Her heart rate is still high”</td>
<td>Still has not put high heart rate with low blood pressure as signs of hypovolemia.</td>
</tr>
</tbody>
</table>

(table continued)
<table>
<thead>
<tr>
<th>Action</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I will give her a beta blocker”</td>
<td>Recognizes that a beta blocker can be used to slow heart rate down.</td>
<td>Beta blocker is contraindicated due to the reason the heart rate is elevated is the low blood volume. This drug will worsen the patient’s condition. Student does not know dose.</td>
</tr>
<tr>
<td>Cks echo</td>
<td></td>
<td>Assesses echo while underlying problem is blood volume and tissue hypoxia (based on venous oxygenation and clinical signs).</td>
</tr>
<tr>
<td>Cks pleural drainage</td>
<td>Needed to ck drainage to see if chest tubes are functioning.</td>
<td></td>
</tr>
<tr>
<td>Cks pleural fluid chemistry</td>
<td></td>
<td>Fails to note elevated glucose in pleural fluid.</td>
</tr>
<tr>
<td>Cks blood gas “Has low pH”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cks breath sounds “Normal”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cks PMI</td>
<td></td>
<td>Checked this previously and is not necessary at this time.</td>
</tr>
<tr>
<td>Cks venous oxygenation</td>
<td>Good assessment of oxygen supply and demand.</td>
<td>Notes Pv02 46 but fails to look at Sv02 46%</td>
</tr>
<tr>
<td>Cks cardiac output</td>
<td>Heart rate is high due to low blood volume. Student does not know drug dose and has chosen an inappropriate drug for patient's condition.</td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
</tbody>
</table>
| "3 L....I'll give her some propranolol to get her heart rate down...114 is too high" | "I'll increase the Dopamine"  
Randomly seems to choosing drugs to give. |
| "I need to give packed red blood cells" | Recognizes the need for blood products for the hypovolemia.  
Cks VS  
"Blood pressure is still low...need to give more Dopamine"  
Still has not connected clinical signs with the hypovolemia.  
Cks blood gas  
"SaO2 97% and hemoglobin is 9 grams"  
"Maybe she is losing blood through her chest tube"  
Makes a possible connection with the hypovolemia and pleural bleeding.  
"Other than her bleeding, I | Stops case |
| URINE OUTPUT IS LOW | Warning |

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<table>
<thead>
<tr>
<th>Table 81</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Alternative Concepts</td>
</tr>
<tr>
<td>Intermediate Student-Participants</td>
</tr>
<tr>
<td>Simulation One/Student Two and Three</td>
</tr>
<tr>
<td>Simulation Two/Student One and Three</td>
</tr>
</tbody>
</table>

1. **Simulation One/Student Two**  
   a. States, "Patient has a high PaCO2, fast respiratory rate, her CO2 should be low"  
   b. Attempts to:  
      1) Decrease blood pressure without assessing hemodynamics  
      2) Gives a vasodilator when the patient is hypotensive  
   c. Chooses theophylline as a means to "open an infiltrate"  
   d. Once vital signs become unstable, acutely stops dopamine  

2. **Simulation One/Student Three**  
   a. Chooses isoproterenol as a steroid  
   b. Administers 1.0 mg albuterol  
   c. States, "Patient has a high CO2 and high minute volume and she should have a lower CO2"  
   d. Gives vasoactive drug without assessing hemodynamics  
   e. Attempts to decrease tidal volume with elevated PaCO2  
   f. Increases tidal volume despite a minute volume of 29L/min  

3. **Simulation Two/Student One**  
   a. Unsure if dopamine is a vasodilator or vasoconstrictor  
   b. Notes patient has high CO2 and respiratory rate and asks why her CO2 is not lower  
   c. Unsure what to do when patient has no urine output, low blood pressure, and a PCWP 3 torr and  
   d. Wants to decrease heart rate with a beta blocker when the blood pressure is low  
   e. Assesses heart rate as high and SvO2 as low and states "Patient is doing better"  

(table continued)
4. Simulation Two/Student Three
   a. Assesses blood gases and blood count (Hb 8 grams) as “fine”
   b. Notes heart rate is high and wants to decrease it without assessing hemodynamics
   c. Chooses to assess blood gases when low Hct warning is viewed
   d. Notes that PCWP is low and administers insufficient fluids
   e. Fails to see the relationship between high heart rate and low blood pressure
   f. Assesses a low Sv02 as “she is doing fine”

Table 82
Data to Support Enhancement of Learning with the Use of Simulation
Intermediate Student Two
Simulation One

<table>
<thead>
<tr>
<th>Student Response</th>
<th>Student Verifies Response</th>
<th>Student Failed to Assess Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gives bronchodilator</td>
<td>Assesses breath sounds</td>
<td></td>
</tr>
<tr>
<td>2. Obtains chest x-ray</td>
<td>Repeats to assess improvement</td>
<td></td>
</tr>
<tr>
<td>3. Inserts arterial line</td>
<td>Assesses blood pressures</td>
<td></td>
</tr>
<tr>
<td>4. Changes modes of ventilation</td>
<td>Assesses blood gases and breath sounds</td>
<td></td>
</tr>
<tr>
<td>5. Administers propranolol</td>
<td>Assess blood pressure</td>
<td></td>
</tr>
<tr>
<td>6. Administers theophylline</td>
<td>Checks theophylline level</td>
<td></td>
</tr>
<tr>
<td>7. Changes mode</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8. Administers lasix</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>9. Administers dopamine</td>
<td>Assesses blood pressure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alters dose as needed</td>
<td></td>
</tr>
</tbody>
</table>

(table continued)
10. Insert PA catheter  Assesses hemodynamics
11. Increase FiO₂  Obtains arterial blood gas
12. Gives albuterol  Assesses breath sounds
13. Administers nitropresside  Assesses blood pressure
                          Adjusts dosage
14. Administers morphine  X
15. Administers PEEP  X
16. Administers dopamine  Assesses and adjusts blood pressure

| Table 83 |
| Data to Support Enhancement of Learning with the Use of Simulation |
| Intermediate Student One |
| Simulation One |
| **Student Response** | **Student Verifies Response** | **Student Failed to Assess Response** |
| 1. Gives bronchodilator | Assesses breath sounds |  |
| 2. Obtains chest x-ray | Repeats to assess improvement |  |
| 3. Changes modes of ventilation | Assesses blood gases and breath sounds |  |
| 4. Changes mode |  | X |
| 5. Administers lasix |  | X |

(table continued)
6. Administers dopamine Assesses blood pressure
7. Increase FiO₂ Obtains arterial blood gas
8. Gives albuterol Assesses breath sounds
9. Administers nitroprusside Assesses blood pressure
   Adjusts dosage X
10. Administers epinephrine X
11. Obtains echocardiogram Gives lasix
12. Intubates the patient X

<table>
<thead>
<tr>
<th>Drug</th>
<th>Effects Oxygen Transport</th>
<th>Knows Correct Dose</th>
<th>Random Dose Given</th>
<th>Default Dose given</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student-Participant One</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Albuterol</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Nitorpresside</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Propranol</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Morphine</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Bicarb</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Theophylline</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Dexamethasone</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Lasix</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Dopamine</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Digoxin</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

Table 84
Intermediate Student-Participants Knowledge of Drug Dosages Used in the Treatment in Simulation One

255 (table continued)
| Student-Participant Two | | | | |
|------------------------|--------|--------|--------|
| Albueterol             | yes    | no     | no     | yes    |
| Isoproternol           | yes    | no     | no     | yes    |
| Nitropresside          | yes    | no     | no     | yes    |
| Morphine               | yes    | no     | no     | yes    |
| Lasix                  | yes    | no     | no     | yes    |

| Student-Participant Three | | | |
|---------------------------|--------|--------|
| Albueterol                | yes    | no     |
| Lasix                     | yes    | no     |
| Morphine                  | yes    | no     |
| Epinephrine               | yes    | no     |
| Nitropresside             | yes    | no     |

Table 85
Intermediate student-Participants Knowledge of Drugs Used in the Treatment in Simulation Two

<table>
<thead>
<tr>
<th>Drug</th>
<th>Effects Oxygen Transport</th>
<th>Knows Correct Dose</th>
<th>Random Dose Given</th>
<th>Gives Default Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student-Participant One</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dopamine</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Whole blood</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Inderol</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

(table continued)

256

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<table>
<thead>
<tr>
<th>Drug</th>
<th>Participant One</th>
<th>Participant Two</th>
<th>Participant Three</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propranolol</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Pack red cells</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>D5W</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Dopamine</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Pack red cells</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Lasix</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Whole blood</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>FFP</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>D5W</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Dopamine</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Nitropresside</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Lasix</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Propositional Knowledge Statements</td>
<td>Alternative Conceptions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Looks at skin color</td>
<td>1. If low perfusion, get arterial blood gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Position they are in</td>
<td>2. Get arterial blood gas and SaO2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Assesses work of breathing</td>
<td>3. Not sure what ot assess with venous oxygenation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Assesses level of awareness/anxiety level</td>
<td>4. Not sure what other bedside measurements of oxygen indices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Listens to breath sounds</td>
<td>5. Not sure of assessing hemodynamics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Obtain SaO2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Check capillary refill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Check for clubbing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Asks how the patient feels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Determine if the patient has</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Total                            | 11                                      | 7                                      |
### Table 87
Intermediate Student-Participant One
Final Interview
Assessing a Patient's Tissue Oxygenation

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
</table>
| 1. Blood needs to carry oxygen to tissues  
2. Blood must have adequate hemoglobin | 1. If heart rate is low enough, oxygen delivery will be decreased and poor perfusion will result in some areas. |

| Total | 2 | 1 |

### Table 88
Intermediate Student-Participant One
Final Interview
Assessing the Role of the Cardiovascular System in Oxygenation

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. “I am not sure of this one”</td>
</tr>
</tbody>
</table>

| Total | 0 | 1 |
### Table 89
**Intermediate Student-Participant Two**
**Final Interview**
**Assessing a Patient’s Level of Oxygenation**

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Assess work of breathing</td>
<td>1. Not sure of three types of hypoxia</td>
</tr>
<tr>
<td>2. Look for the “big picture”</td>
<td></td>
</tr>
<tr>
<td>3. Check for distress</td>
<td></td>
</tr>
<tr>
<td>4. Look for cyanosis</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 90
**Intermediate Student-Participant Two**
**Final Interview**
**Assessing Tissue Oxygenation**

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cardiac output carries oxygen to tissues</td>
<td>1. Venous blood returns to the lung to pick up oxygen</td>
</tr>
<tr>
<td>2. Tissues extract oxygen from blood</td>
<td>2. Less oxygen in the blood there is less oxygen for muscles to</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2</td>
</tr>
</tbody>
</table>
### Table 91
Intermediate Student-Participant Two
Final Interview
Assessing Role of the Cardiovascular System in Oxygenation

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Assess hemoglobin level</td>
<td></td>
</tr>
<tr>
<td>2. As hemoglobin decreases, less oxygen is being delivered to the tissues</td>
<td></td>
</tr>
</tbody>
</table>

Total 2 0

### Table 92
Intermediate Student-Participant Three
Final Interview
Assessing a Patient's Level of Oxygenation

<table>
<thead>
<tr>
<th>Propositional Knowledge (PK)</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Look at the Sp02</td>
<td>1. Not sure of the other three types of hypoxia</td>
</tr>
<tr>
<td>2. Assess for cyanosis</td>
<td>2. Anemic is when the hemoglobin can't carry oxygen</td>
</tr>
<tr>
<td>3. Assess respiratory rate</td>
<td></td>
</tr>
<tr>
<td>4. Assess work of breathing</td>
<td></td>
</tr>
<tr>
<td>5. Get an arterial blood gas</td>
<td></td>
</tr>
</tbody>
</table>

Total 7 2

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### Table 93
Intermediate Student-Participant Three
Final Interview
Assessing the Role of the Cardiovascular System in Oxygenation

<table>
<thead>
<tr>
<th>Propositional Knowledge (PK)</th>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Heart pumps blood to the tissues so there needs to be enough blood 2. Assess hemoglobin level</td>
<td>1. Not sure what venous oxygenation will do if cardiac output decreases</td>
</tr>
</tbody>
</table>

| Total | 3 |

| Table 94
Propositional Knowledge from Simulation Number Two Mapped to Critical Junctures Intermediate Student-Participant Number One |

<table>
<thead>
<tr>
<th>A. Mechanics of Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lung and thoracic relationships</td>
</tr>
<tr>
<td>2. Pressure-volume relationships</td>
</tr>
<tr>
<td>3. Pressure-flow relationships</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Alveolar Ventilation and Blood Gas Exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gas pressures</td>
</tr>
<tr>
<td>&quot;I need to give her more oxygen&quot;</td>
</tr>
<tr>
<td>2. Alveolar ventilation</td>
</tr>
<tr>
<td>&quot;Her C02 is high, need to lower it&quot;</td>
</tr>
<tr>
<td>3. Ventilation-to-perfusion</td>
</tr>
<tr>
<td>4. Diffusion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. Blood Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pulmonary circulation</td>
</tr>
<tr>
<td>2. Systemic circulation</td>
</tr>
<tr>
<td>&quot;Oh... oh pulse is thready&quot;</td>
</tr>
<tr>
<td>3. Cardiac pressures and flow</td>
</tr>
<tr>
<td>&quot;Need to give her blood to get her blood pressure up&quot;</td>
</tr>
<tr>
<td>&quot;She needs more fluid to get blood pressure up&quot;</td>
</tr>
<tr>
<td>&quot;Wedge is 1.8, too low&quot;</td>
</tr>
<tr>
<td>&quot;Must be hypovolemia&quot;</td>
</tr>
<tr>
<td>&quot;Heart rate is 150 and thready...she needs fluids&quot;</td>
</tr>
<tr>
<td>&quot;She has a low RAP... need to give fluid&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>D. Arterial Oxygen Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Arterial oxygen content</td>
</tr>
<tr>
<td>&quot;Her hemoglobin level is low. I need to give her blood&quot;</td>
</tr>
<tr>
<td>2. Oxygen delivery</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>E. Tissue Oxygenation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Tissue uptake</td>
</tr>
<tr>
<td>2. Tissue utilization</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>F. Venous Oxygenation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Venous oxygen transport</td>
</tr>
<tr>
<td>2. Carbon dioxide transport</td>
</tr>
</tbody>
</table>

262
<table>
<thead>
<tr>
<th>A. Mechanics of Ventilation</th>
<th>D. Arterial Oxygen Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lung and thoracic relationships</td>
<td>1. Arterial oxygen content</td>
</tr>
<tr>
<td>2. Pressure-volume relationships</td>
<td>PaO₂ and SaO₂ are up</td>
</tr>
<tr>
<td>3. Pressure-flow relationships</td>
<td>2. Oxygen delivery</td>
</tr>
<tr>
<td>B. Alveolar Ventilation and Blood Gas</td>
<td>E. Tissue Oxygenation</td>
</tr>
<tr>
<td>Exchange</td>
<td>1. Tissue uptake</td>
</tr>
<tr>
<td>1. Gas pressures</td>
<td>2. Tissue utilization</td>
</tr>
<tr>
<td>&quot;I'll place her on some oxygen&quot;</td>
<td>F. Venous Oxygenation</td>
</tr>
<tr>
<td>2. Alveolar ventilation</td>
<td>1. Venous oxygen transport</td>
</tr>
<tr>
<td>&quot;Her CO₂ is too high&quot;</td>
<td>2. Carbon dioxide transport</td>
</tr>
<tr>
<td>&quot;Assess breath sounds&quot;</td>
<td>&quot;Her CO₂ is up&quot;</td>
</tr>
<tr>
<td>&quot;Her CO₂ is up&quot;</td>
<td>3. Ventilation-to-perfusion</td>
</tr>
<tr>
<td>C. Blood Flow</td>
<td></td>
</tr>
<tr>
<td>1. Pulmonary circulation</td>
<td></td>
</tr>
<tr>
<td>2. Systemic circulation</td>
<td>&quot;Pulse is thready&quot;</td>
</tr>
<tr>
<td>&quot;Pulse is thready&quot;</td>
<td></td>
</tr>
<tr>
<td>3. Cardiac pressures and flow</td>
<td>&quot;Urine output is low from the low blood pressure&quot;</td>
</tr>
<tr>
<td>&quot;I will give some fluid to get her blood pressure up&quot;</td>
<td>&quot;Her heart rate is high and blood pressure low&quot;</td>
</tr>
<tr>
<td>&quot;Urine output is low from the low blood pressure&quot;</td>
<td>&quot;Thready pulse means low flow, She needs fluid&quot;</td>
</tr>
</tbody>
</table>

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### Table 96
Propositional Knowledge from Simulation Number Two Mapped to Critical Junctures Intermediate Student-Participant Number Three

<table>
<thead>
<tr>
<th>A. Mechanics of Ventilation</th>
<th>wedge up”</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lung and thoracic relationships</td>
<td>D. Arterial Oxygen Transport</td>
</tr>
<tr>
<td>“She might be air trapping”</td>
<td>1. Arterial oxygen content</td>
</tr>
<tr>
<td>2. Pressure-volume relationships</td>
<td>“Her hemoglobin is low”</td>
</tr>
<tr>
<td>3. Pressure-flow relationships</td>
<td>“Pa02 and Sa02 are better”</td>
</tr>
<tr>
<td>B. Alveolar Ventilation and Blood Gas Exchange</td>
<td>2. Oxygen delivery</td>
</tr>
<tr>
<td>1. Gas pressures</td>
<td>E. Tissue Oxygenation</td>
</tr>
<tr>
<td>“Let give her more oxygen”</td>
<td>1. Tissue uptake</td>
</tr>
<tr>
<td>2. Alveolar ventilation</td>
<td>2. Tissue utilization</td>
</tr>
<tr>
<td>“Inspect the chest for shallow breathing”</td>
<td>“I need to check lactate”</td>
</tr>
<tr>
<td>“Assess breath sounds”</td>
<td>F. Venous Oxygenation</td>
</tr>
<tr>
<td>“Her CO2 is too high, need to get it down”</td>
<td>1. Venous oxygen transport</td>
</tr>
<tr>
<td>3. Ventilation-to-perfusion</td>
<td>“I’ll get a Pv02”</td>
</tr>
<tr>
<td>4. Diffusion</td>
<td>2. Carbon dioxide transport</td>
</tr>
<tr>
<td>C. Blood Flow</td>
<td></td>
</tr>
<tr>
<td>1. Pulmonary circulation</td>
<td></td>
</tr>
<tr>
<td>2. Systemic circulation</td>
<td></td>
</tr>
<tr>
<td>“Pulse is fast and thready”</td>
<td></td>
</tr>
<tr>
<td>3. Cardiac pressures and flow</td>
<td></td>
</tr>
<tr>
<td>“Look at her CO”</td>
<td></td>
</tr>
<tr>
<td>“Let me get a wedge pressure”</td>
<td></td>
</tr>
<tr>
<td>“Blood pressure and Urine output is low. I need to give fluid”</td>
<td></td>
</tr>
<tr>
<td>“I need to give a vasoactive drug”</td>
<td></td>
</tr>
<tr>
<td>“I need to give blood to get her blood pressure up”</td>
<td></td>
</tr>
<tr>
<td>“I need to give fluid to get her</td>
<td></td>
</tr>
</tbody>
</table>

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DISCUSSION

This study investigated the effects of cardiopulmonary simulation software on conceptual development with two groups of allied health students. The groups consisted of novice and intermediate student-participants enrolled in LSU Medical Center’s Department of Cardiopulmonary Science. The focus of this study was to evaluate the effects of a computer simulation environment on student-participant’s conceptual change with the subject of oxygen transport and utilization in humans. The researcher studied how student-participants conceptualize the principles of oxygen transport and utilization in humans. The researcher explored and documented the frequencies of scientifically acceptable propositional knowledge and alternative explanations related to the study topic. Using clinical interviews, concept maps, and simulation software, conceptual development and cognitive difficulties across two semesters with a small group of student-participants were evaluated.

Comparative work can be found in Songer and Mintzes (1994) who studied college-level students' understanding and conceptual difficulties with cellular respiration. Using a similar hypothesis and data collection method which this study used, these researchers reported findings that suggest novices harbor a wide range of conceptual difficulties which constrain understanding of cellular respiration. They reported related conceptual difficulties often persisted after instruction and influenced the formation of new concepts. Often conceptual problems remain resistant to change despite well-planned, repeated instruction at the advanced level.

Another recent study evaluated utilization of computer simulation to enhance conceptual change when learning about the human cardiovascular system (Windschitl
This study investigated the effects of constructivist versus objectivist computer simulation environments on student’s conceptual change within the setting of a college level human physiology course. This study explored the potential interaction between student epistemological belief and type of simulation, with regard to the development of conceptual understanding. Exploratory versus confirmatory simulation models were compared.

The confirmatory group followed verbal instructions to set simulation variables to generate the screen conditions to show a particular type of output for interpretation. This was done in a step-by-step fashion. The confirmatory group was then given a set of specific instructions to follow in manipulating the software. These instructions led the participants to deal with concepts identified as sources of alternative conceptions. Students had few options for exploration. Students were prompted to select and adjust parameters and to select graphical outputs that may have refuted commonly held alternative conceptions.

During an orientation period the exploratory group was prompted to consider how to construct simple hypotheses about the function of the cardiovascular system. These students were shown how to test a sample hypothesis using the simulation program. Students were instructed to test sample hypotheses on their own. Following this, the entire study group discussed results of the exercise. Students were then given a general set of guidelines to follow for exploring their personal understanding of the cardiovascular system. Students were asked to resolve the same problems that the confirmatory group investigated, but without specific instructions. Study results suggested that individuals with well-established sophisticated epistemological beliefs
performed better when allowed to explore, while individuals with less sophisticated beliefs performed poorly when asked to explore. In the confirmatory simulation environment, the reverse was true; individuals with less sophisticated beliefs did well when given explicit directions on how to use the simulation program; individuals with more sophisticated beliefs performed poorly under confirmatory instruction conditions. In sum, the constructivist approach resulted in significantly greater conceptual change than the objectivist approach. Students demonstrating advanced epistemological beliefs performed better (learned more) with an objectivist-type simulation.

The present study used a confirmatory simulation to assess conceptual development and the nature of alternative conceptions. Central to the researcher's approach was conceptual analysis of data. Conceptual analysis of data collected suggested a widespread tendency of cardiopulmonary science students to develop significant gaps in conceptual understanding. These problems included alternative conceptions and maladaptive biases in the thought processes that deal with conceptual complexity. Particularly noteworthy was the researcher's observation that resistant alternative conceptions compounded other alternative conceptions.

Development of alternative conceptions found in this study tended to follow criteria suggested by Feltovich, Spiro, and Coulson (1989). Alternative conceptions may develop from multiple influences that contribute to the acquisition and maintenance of their development. Some of these influences are associated with the learner, some with the teacher, and some with the educational process itself. There is an interdependency of faulty component ideas which in turn, bolsters each other consequently supporting the overall development of alternative conceptions. In
addition, alternative conceptions may arise from oversimplification of complex biomedical concepts.

Thus, what may seem at first to be a simple alternative conception, easily describable in a single sentence, will turn out in fact to have numerous complex, interrelated layers of underlying meaning. As discussed later, these features would likely be undetected without a concentrated analysis of the complexities of individual concepts and other related ideas.

This study focused on a group of college-level students (N=11) while data analysis was performed on two key informants in the novice group and three intermediate student-participants. Chi (1997) advocates intense study of one or two participants when evaluating instructional strategies. This approach allowed the researcher to capture knowledge representation more precisely and make explicit predictions about which underlying conceptual representation enables a specific kind of response. The following discussion focuses on the data from the key informants presented in the Results chapter and is supplemented, at times, with support data from the other student-participants in both novice groups.

Further support for choosing to study only two key informants include the comparison of macro conceptual inventories (Tables 5 and 6) and comparison of simulation performance (Table 7). Analysis of the conceptual inventories revealed little, if any, differences between Novice Group A and Novice Group B. This suggests that all novice student-participants developed similar understandings, at least in terms of macro concepts, alternative conceptions, and propositional knowledge. In addition, comparing pre-lecture to postlecture simulation performance in terms of the number of
correct and incorrect predictions, little difference was found both quantitatively and qualitatively. This finding supported the belief that all student-participants performed similarly. Based on these findings the researcher decided there was support to isolate two key informants and focus on their results. These results perhaps are not typical for all college-level students undergoing similar education, but do represent the student-participants in these particular novice groups.

**Data Validity**

Validity of the data presented and analyzed was assured by coding data on multiple occasions, triangulating the data, and having three student-participants read a sample of typed transcripts to verify accuracy. In addition, a member of the expert panel assisted with coding a sample of data provided by the researcher. Interrater reliability was strengthened by frequent discussion concerning categorization and data coding with faculty colleagues and a member of the expert panel. In addition, coding at two different grain sizes were completed with final coding yielding a more coarser grain size to capture more semantics of explanation or verbal protocol (Chi, 1997). There are instances when finer-grained coding was done to be purposely redundant and capture specific understanding. Fine-to-course coding was done based on the amount and type of information needed.

**A Concentrated Study of Concepts and Alternative Conceptions**

The researcher chose a broad coverage of biomedical concepts in favor of in-depth coverage of smaller sets of complex concepts. In doing so, it was felt the breadth of the data would cover the six critical junctures and subjunctures identified by the expert panel as key concepts for understanding oxygen transport and utilization.
Furthermore, the broad approach was due, in part, to the researcher’s interest in how students develop conceptual knowledge over time and create or maintain alternative conceptions with the topic of oxygen transport and utilization. This study topic contains numerous ideas and concepts that are difficult and complex and the process of studying them must be detailed and comprehensive.

Graduates of Cardiopulmonary Science must understand numerous complex ideas and concepts and apply these to the care of patients with cardiopulmonary disease. To facilitate the application of knowledge of these concepts to the performance of professional skills, the teacher must have a perspective on how students acquire knowledge and utilize cognitive strategies shown to enhance understanding.

**Answering the Research Questions**

Can cardiopulmonary Software Enhance Learning Propositional Knowledge and/or Help Diagnose Alternative Conceptions in Novices?

The role simulation played enhancing propositional knowledge and diagnosing alternative conceptions is evident when exploring data from the tables in the previous chapter. By analyzing data from each of the simulation content modules it was identified that using simulation software can be effective for identifying propositional knowledge statements and alternative conceptions (Tables 15-22, and 57-62). These tables provide the reader with results of coded data gathered from simulation verbal protocols. Although these tables represent key informants, data analysis revealed similar propositional knowledge statements and alternative conceptions from the other student-participants. Alternative conceptions identified in these tables represent
significant statements that may have limited understanding of oxygen transport and utilization by this study group.

By identifying what the learner knows and does not understand, the teacher can plan and implement more effective instruction. This premise is the underpinning of this work and parallels the principles of meaningful learning as outlined by the Ausubel-Novak-Gowin theory for learning. Other researchers have alerted science educators to the importance of first assessing what the learners knows and adjust teaching accordingly (Bruer, 1995; Mintzes et al., 1998; Mintzes et al., 1997; Novak & Gowin, 1984; Wandersee et al., 1994). The researcher was successful in using simulation as a means of assessing student-participants understanding of key concepts related to the study topic. The simulation software was able to identify tenacious alternative conceptions that persisted in both novice groups despite formal education and emphasis placed on some of the emerging alternative conceptions as data was initially analyzed early in the study. The discussion of the analysis below focuses on the two key informants as previously described.

Using the simulation content modules as a framework for analysis, each topic is stated along with its macro concept. Following a brief description of the concept, a discussion of what key informants understood and any alternative conceptions that existed is presented. To aid the reader, the following discussion refers to Novice Group A student-participant one and two as key informant one (KI-1) and two (KI-2) respectfully.
Summary Data for Propositional Knowledge Statements and Alternative Conceptions

Across all data collection methods, KI-1 generated 295 propositional knowledge statements with 111 alternative conceptions. And KI-2 verbalized 221 propositional knowledge statements and 108 alternative conceptions. The average number of propositional knowledge statements and alternative conceptions for Novice Student-Participant Group B were 253 and 119 respectfully.

Verbal analysis of each pre-lecture simulation transcript revealed student-participants were making predictions of simulation response to changing variables. Assessing the strength of these predictions and determining if making a prediction was a valid cognitive strategy that student-participants used to solve a simulation problem was of interest to the researcher. Key informants one and two had a total of 134 correct predictions and 57 incorrect predictions. In addition, with the pre-lecture simulation verbalization a total of 88 propositional knowledge statements and eight alternative conceptions were identified.

Simulation Content Module One: Mechanics of Ventilation: The Macro Concept

Mechanics of ventilation refers to the movement of gas in and out of the lungs as result of the relationship between the lungs and thorax, respiratory muscles, and elastic and nonelastic forces. As transpulmonary pressures are created with diaphragmatic contraction, intra-alveolar pressures decrease and gas enters the lung. Incoming gas must overcome elastic and non-elastic forces. Once gas enters the lung
and alveoli inflate, expiration occurs as a result of increasing surface tension, elastic and collagen fiber recoil of lung tissue. As a result of the lung and thoracic relationship, end-expiratory volume, or the functional residual capacity (FRC) is created at end-expiration. The FRC acts as a gas reservoir and helps to establish lung compliance. Compliance can be assessed by plotting changes in volume and pressure resulting in a volume-pressure curve. How gas moves in and out of the lung becomes the first step to understand how the oxygen molecule enters the respiratory system to begin its journey to the tissue beds.

**What Key Informants Understood About Mechanics of Ventilation**

Appendix I shows the simulation guide used by the student-participant. This guide serves as sample of a typical simulation guide used in the study.

**Propositional Knowledge**

Both KI-1 and KI-2 demonstrated an understanding of compliance from the beginning of the study. Both were able to define and describe compliance. This understanding remained stable throughout the entire study. Both key informants appeared to grasp variables that influence airway resistance, especially understanding the role diameter and length plays with influencing the nonelastic force. The simulation exercise illustrated the effects of altered compliance on the volume-pressure curve which seemed to strengthen KI-1 and KI-2's understanding of slope and its meaning in terms of compliance. KI-2 had difficulty with understanding the importance of the slope of the volume-pressure curve until he saw it change during the simulation (exercise included increasing and decreasing lung compliance). He stated: “Oh...I see the line
moves, flattened.....so, I guess as compliance decreases, this line becomes less. I mean flatter.” Both key informants retained this understanding. This concept was further developed by having key informants change lung elastance and surfactant. It was obvious from the number of predictions and verbal statements that KI-1 and KI-2 understood the reciprocal nature of lung compliance and elastance. Since the lung is an elastic organ, this concept is paramount in understanding volume-pressure relationships. KI-1 stated:

“As I increase the lung elastance.....I think lung compliance will decrease or the lung will become...uh stiff. I notice as I change elastance the line on the graph drops, I mean gets flatter.”

From this statement it is obvious KI-1 could interpret the volume-pressure graph and the dynamic nature of simulation graph changing as a result of a variable change (i.e., increasing elastance) helped her see its effect. Textbooks offer this concept in a static line drawing and it has been the experience of the researcher that students fail to see the relationships by observing a two dimensional line graph.

Another concept that was demonstrated to be well understood by KI-1 and KI-2 was the role surfactant plays with compliance. Both informants understood the importance of surfactant and its role in minimizing surface tension. The researcher assumed that this information was carried over from the previous semester’s human physiology course. It was obvious from their simulation data that KI-1 and KI-2 understood how surfactant influenced compliance. This understanding remained stable throughout the study.
The simulation exercise illustrated an increase in respiratory rate as compliance decreased. This was observed by KI-2 during the post course interview:

"Looks like as compliance drops, the rate increases...maybe because the patient is trying to get more air in...I am not sure"

From this statement KI-2 recognizes the importance of compliance and rate but has an underdeveloped understanding of elasticity and work of breathing. Superficially the concept appears to be understood, however probing deeper the student-participant demonstrated faulty knowledge of the concept.

Progressing from precourse interview to postcourse interview and assessment of concept maps, and verbal analysis of simulation performance suggests that KI-1 and KI-2 strengthen their understanding of volume-pressure relationships by running the simulation. Simulation-generated concepts related to compliance and elasticity remained fairly stable throughout the study.

Alternative Conceptions

The researcher found an alarming number of tenacious alternative conceptions relating to mechanics of ventilation (Tables 23-24, 31-32, and 49-50). Both informants were unable to define the FRC and described it as gas movement in and out of the lungs. KY-1 describes the FRC:

"The FRC is the air moves in and out"

While KY-2 describes the FRC as:

"It moves in with inspiration and stays there"

Both statements reflect the informants' poor understanding of the FRC and their failure
to describe it as a static volume. Additional alternative conceptions that the simulation diagnosed included FRC not changing with change in either elasticity or surfactant. The simulation demonstrated dynamic changes in the FRC as lung elasticity or surfactant changed. Neither informant seemed to notice this. In fact, on several occasions KI-1 and KI-2 stated that as elasticity increased, FRC increased. A statement that reflected KI-1’s poor understanding of what is responsible for the FRC was:

“The FRC is a result of elasticity of the lung”

He failed to describe the FRC as a product of the relationship between the lung and thorax. Furthermore KI-1 could not give a normal value for the FRC or relate it to the term “end-expiratory volume”—which was the term used in the simulation. In fact, the researcher found all student-participants failed to demonstrate understanding of the concept of “end-expiratory volume”. No student-participant at anytime associated end-expiratory volume with the FRC. This was not surprising since the researcher failed to connect the two terms at any time during formal instruction and course textbooks also failed to make this connection.

A key component of the critical juncture dealing with mechanics of ventilation is the creation of the FRC as a gas reservoir and as an influence of lung compliance. The FRC is established as a result of the lung and thoracic recoil relationship. This capacity of air establishes the primary source of oxygen molecules and is paramount in maintaining blood oxygenation. The simulation exercise verbal protocols revealed a lack of understanding of this concept. Superficially all student-participants were able to describe the FRC as a “gas reservoir” but further inquiry into their understanding
revealed multiple alternative conceptions. KI-1 and KI-2's concept maps were void of any reference to the FRC except as a "gas reservoir". Examination of the data revealed the inability of define the FRC or state its normal value (Tables 39-40, 49-50).

The FRC dynamically changed during the simulation exercise when volume-pressure relationships were changed. Volume-pressure curves shifted, blood oxygen levels dropped, and indices for work of breathing changed. At no time did KI-1 and KI-2 seem to note these changes or make verbal reference to them.

Examination questions regarding the FRC with the exception of being asked to define it and state its normal value were, for the most part, answered correctly (Tables 39-40). However, interview data, concept mapping, and simulation verbal protocols revealed only a superficial understanding of this key concept. Examination scores were skewed towards the right, reflecting, at least by paper and pencil examination data, the students understood the concepts found in mechanics of ventilation. But in contrast, data from other sources (i.e., post course interviews) revealed poor understanding.

What Influenced the Alternative Conception

Analysis of the data revealed KI-1 and KI-2 were unable to conceptualize several key concepts related to the mechanics of ventilation. Despite the simulation altering FRC levels with changes in lung compliance and elasticity, the textbook defining and explaining FRC using text and graphs, and instructor explanation, student-participants failed to fully grasp this concept. By KI-1 and KI-2 describing the FRC as a volume that moves in and out of the lung and not recognizing the role the FRC plays with establishing compliance, students would have a difficult time developing
additional complex concepts related to caring for patients with a loss of FRC (occurs
often with pulmonary disease). The researcher concluded that student-participants may
have failed to conceptualize lung volumes and capacities, making the FRC elusive to
visualize.

Understanding concepts such as positive end-expiratory pressure (PEEP),
continuous positive airway pressure, optimizing patient position, dynamic
hyperinflation, and atelectasis may be hampered without a thorough understanding of
the FRC. Simulation exercises were able to identify the existence of several alternative
conceptions that may have hampered further understanding of more advanced concepts.

It is obvious from these data that student-participants had difficulty with several
concepts related to mechanics of ventilation. A major misunderstood concept was the
FRC. Traditional textbook presentation (text and line graphs), lecture, and simulations
that show changing FRC values may not be sufficient for the learner to develop this
concept. Alternative methods to aid the conceptual development of this key idea may
include use of multimedia to demonstrate via animation the creation of FRC by the
lungs and thoracic relationship, demonstrating an actual measurement of a student’s
FRC using pulmonary function testing, and/or creating an classroom model for
demonstration.

Simulation Content Module Two: Ventilation-to Perfusion Ratios-Macro
Concept:

Atmospheric gas enters the lungs and inflates millions of alveolar sacs. During
inspiration oxygen enters the lung and diffuses into the blood while carbon dioxide
diffuses out of the blood and into the lung to expelled during expiration. The partial pressure of the inspired gas is greater than the oxygen tension within the lung. The lung oxygen tension is greater than incoming venous blood thus establishing a gradient between the lung and blood. This gradient allows oxygen to diffuse from the atmosphere into the blood. In contrast, carbon dioxide tension gradients are established in the reverse manner and carbon dioxide is allowed to be exhaled. Under normal condition, alveolar ventilation allows gas exchange as long as there is an physiologic relationship between alveolar gas and pulmonary capillary blood flow. This relationship is known as ventilation-to-perfusion ratio. When ventilation is matched to perfusion, normal gas exchange occurs by diffusion and blood gas levels remain normal. Altering the inspired gas composition and/or mismatching ventilation and perfusion results in altered gas exchange and reduced oxygen transport.

**What Key Informants Understood About Ventilation-to-Perfusion**

**Propositional Knowledge**

This simulation exercise focused on having the KI-1 and KI-2 manipulated deadspace and shunt fractions and observing the effects on blood oxygen levels. Emphasis was placed on establishing the effects of altering alveolar ventilation and deadspace on blood carbon dioxide levels. The researcher has found from his experience as an educator that alveolar ventilation and deadspace are aspects of ventilation-to-perfusion that are often poorly understood by students. The relationship between alveolar ventilation and blood carbon dioxide tension is paramount in understanding mechanical ventilatory support, to assess work of breathing, and to
determine severity of pulmonary disease. Use of simulation to strengthen the above concepts were judged to be warranted.

Interview and concept mapping focused on deadspace and intrapulmonary shunting along with normal gas exchange (Tables 33-34, 42,44, 51-52). The researcher adjusted the length of the second simulation—based on the experience with the first simulation—to better accommodate the time available for student-participants to complete simulation and interview exercises. Although intrapulmonary shunting was considered a part of this simulation, simulation manipulation of shunt fraction was transferred to the Oxygen Transport I simulation where it could be better examined.

KI-1 and KI-2 understood the process of gas exchange as a result of pressure gradients. It was well established by simulation and interview data that increasing respiratory rate results in “blowing off” carbon dioxide and increasing alveolar ventilation can increase blood oxygen levels. KI-2 stated:

“ As you increase your respiratory rate you should blow off your carbon dioxide and bring more oxygen into your lungs.”

Both key informants were able to relate alveolar ventilation with a change in blood carbon dioxide and oxygen levels. Both stated that hyperventilation results in blowing off carbon dioxide and increasing blood oxygen. KI-1 and KI-2 began to see a relationship between deadspace volume and blood carbon dioxide. Although this concept was not well developed during the simulation, they both stated “as deadspace increased and respiratory rate remained unchanged, partial pressure of arterial carbon dioxide (PaCO₂) increased”. With pre-course interview KI-1 stated: “Deadspace
increases...it \( (\text{PaCO}_2) \) will remain unchanged" (researcher asked her if deadspace increases and respiratory rate remained unchanged, what happens to \( \text{PaCO}_2 \)?). During the simulation exercise, this alternative conception seemed to get altered and KI-1 began to understand the relationship between ventilation and carbon dioxide levels. In contrast, data from postlecture and course interview, indicated both informants were unsure of the effects of increasing deadspace on \( \text{PaCO}_2 \) (Tables 25-26, 51, 52).

Postlecture interview, concept mapping (Tables 33-34), examination data (Tables 42 & 43), and post course interview supported KI-1 and KI-2's understanding of ventilation and \( \text{PaCO}_2 \). Furthermore these data sources revealed their understanding of the change in lung oxygen tension (\( \text{PAO}_2 \)) with change in inspired oxygen tension, the three types of deadspace, and definition of intrapulmonary shunt. It was further demonstrated that KI-1 and KI-2 had a good understanding of the effect of shunting on arterial blood oxygen tension (\( \text{PaO}_2 \)).

To supplement data collected on student-participants' understanding of ventilation-to-perfusion relationships, a silent interview was conducted. Each student-participant was given a diagram of an alveolus with a pulmonary capillary (see Appendix K).

This silent interview was conducted following class time. Each student-participant was instructed to label and give normals for: inspired oxygen concentration, partial pressures of oxygen and carbon dioxide in the lung and blood--both arterial and venous--and arterial and venous hemoglobin saturation of oxygen. In addition, fraction of inspired and expired carbon dioxide was to be labeled.
Results (see Tables 42 & 44) were disappointing for KI-1 and KI-2 since they had completed the simulation exercise that revealed this information. KI-1 and KI-2 identified the inspired oxygen concentration and pressure to be 21% and 158 torr respectfully, normal PAO$_2$ of 100 torr, and PaC0$_2$ to be 40 torr. The interview was scored with a maximum of 12 points that could be earned. The average score for KI-1 and KI-2 was 4.5. This simple exercise was disturbing due to the absence of correct values placed on the diagram.

Alternative Conceptions

During the simulation and throughout the postlecture data gathering, both KI-1 and KI-2 began to associate changes in deadspace with changes in PaO$_2$ than PaC0$_2$. Furthermore, both informants (and most other novice participants) stated as deadspace increased, blood oxygen levels decreased and blood carbon dioxide levels increased in a linear manner. Neither informant demonstrated understanding of the effects of changing deadspace on blood gases. As KI-2 stated:

"As deadspace increases, oxygen will decrease and C0$_2$ will decrease"

The relationship between PaO$_2$ and PaC0$_2$ with ventilation-to-perfusion abnormalities was not well developed at anytime during the study. The simulation exercise did not seem to enhance later understanding of these relationships as evidenced by the numerous alternative conceptions found in post-simulation data gathering.

KI-1 and KI-2 were unable to complete the silent interview diagram to a level that convinced the researcher they grasped normal gas tensions in the lung and blood. Neither informant was able to list normal values for arterial and venous oxygen blood.
values and hemoglobin saturations. Despite having these values a focus of two prior lectures, receiving normal values in another related course (CPSC 3210 Respiratory Therapy Fundamentals), and demonstrating understanding on the lecture examination, KI-1 and KI-2 failed to list normal values for the above variables when asked to recall normal values during the silent interview. Recall for these values remained difficult for all student-participants throughout the study.

Data analysis revealed a slow progression of understanding of normal values for blood oxygen levels. Normal PaO₂ often was listed as “95 torr” or 90-100 torr”. It was not until the near end of the course that student-participants began to list the normal range of PaO₂ as 80-100 torr. Conceptual development of normal blood oxygen values seemed to be hampered by student-participants inability to grasp a range of normal values. KI-1 and KI-2 seemed to understand more discrete numbers than a continuous data set. The persistence of this alternative conception may be the result of student’s preference for absolute values and novice learners lack the knowledge and clinical experience to recognize ranges in human oxygen measurements. What baffled the researcher was despite emphasis placed on normal blood tensions in lectures, worksheets, and in-class demonstration, uncertainty of normal values remained among these novice student-participants.

Other poorly formed set of concepts were hyperventilation and hypoventilation. Although all student-participants defined hyperventilation as a PaCO₂ less than 35 torr and hypoventilation as a PaCO₂ greater than 45 torr, KI-1 and KI-2 failed to grasp that these terms refer to over and under ventilation of alveoli respectfully. During the
simulation exercise they were instructed to increase and decrease minute ventilation. Both novices hesitated and appeared unsure how to do this. KI-1 stated:

"Let's see... to increase the minute ventilation or make the patient hyperventilate I will need to increase the rate"

In part this is correct, however, not at any time during the course of this study did KI-1 or KI-2 (and other student-participants) realize (at least verbally) that an increase in tidal volume could also result in hyperventilation. Neither informant stated a change in respiratory rate and/or tidal volume can result in hyperventilation. Several of the student-participants stated what KI-1 stated:

"Hyperventilation is breathing too fast"

This is how all student-participants defined hyperventilation. Added to this, a resistant alternative concept was that patients who breathe fast are hyperventilating despite PaCO₂ levels above 35 torr. Neither KI-1 or KI-2 were able to see the relationship between high deadspace volume, elevated respiratory rate, and normal PaCO₂. Once confronted with these variables with the simulation, they both claimed the patient was hyperventilating. This faulty understanding suggests that students may not fully develop the complex concept of how these three variables are related. The researcher has struggled with this concept over the years and realizes students enter his classroom with the pre-existing concept that "when a person has a fast respiratory rate, he or she is hyperventilating". As data shown, this alternative conception remained fairly resistant to change despite use of simulation and advanced instruction.
Traditional examination questions (and those used with this study) often ask the student to list or identify normal values for blood gases or to choose a definition of terms such as deadspace, shunt, and hyperventilation. Often exam scores support assessing the students as being successful in understanding these concepts. However, closer examination of the students’ conceptual development may reveal poorly formed concepts and the presence of significant alternative conceptions.

**What Influenced the Alternative Conceptions?**

Analysis of data revealed that KI-1 and KI-2 failed to fully conceptualize deadspace, alveolar ventilation, and normal gas pressures. It appeared to the researcher that student-participants were relying on rote memorization of facts related to these concepts and they may have been test-wise, thus passing examinations.

To correct these prevailing alternative conceptions the teacher may adopt the use of the data gathering techniques used in this study early in the instructional process. Doing so would allow poorly developed concepts to be revisited and corrected before moving on to new material. Teachers often are mislead into believing students are progressing in learning by relying on examination results. This is an example of how teachers unknowingly encourage and reinforce the development of alternative conceptions.

Use of multimedia animation programs to create a dynamic presentation illustrating changes in gas pressures within the lung and blood with changes in incoming gas composition, changes in FRC, shunt fraction, and deadspace may aid in helping to develop these concepts just discussed. Following animated presentation with
concept mapping and clinical interview may result in teachers assuring concepts are understood prior to moving on to new material.

**Simulation Content Module Three: Oxygen Transport I: Macro Concept:**

After oxygen enters the alveoli and diffuses across the alveolar-capillary membrane into the blood oxygen molecules either attach to hemoglobin found within the red blood cell or dissolved in plasma. Oxygen is transported to tissues via blood flow in these two states; dissolved in plasma and attached to hemoglobin. Normal arterial oxygen content is 20 mL/100 mL blood. Normal oxygen transport is 1000 mL/min. As cardiac output increases or decreases, oxygen delivery to the tissues is altered. After the body's tissue utilize needed oxygen, venous blood returns to the heart where it is pumped through pulmonary capillaries to become reoxygenated. Venous blood gas values allow for a gradient to exist between alveolar and blood oxygen tension. The arterial oxygen content is governed by the amount of hemoglobin and its saturation of oxygen. Oxygen transport is governed by oxygen content and blood flow or cardiac output. Changes in any of these variables will affect oxygen supply and demand.

A change in inspired oxygen percentage will increase the tension of inspired oxygen, increase PAO₂, and potentially increase PaO₂ assuming normal ventilation-to-perfusion relationships. During conditions of ventilation-to-perfusion mismatching, such as intrapulmonary shunting, this relationship becomes less predictable. The difference between the PAO₂ and PaO₂ becomes greater. Furthermore, as intrapulmonary shunting develops (as a result of pulmonary disease) the patient requires supplemental
oxygen. Despite an increase in the concentration of oxygen delivered to the lung and with shunting, the PaO₂ may not increase. This relationship between inspired oxygen percentage, PAO₂, PaO₂, and shunting (sometimes referred to as shunt fraction) is often assessed at the bedside to determine the type of oxygen support needed to return the patient's oxygen supply and demand balance to normal.

**What Key Informants Understood About Oxygen Transport I**

**Propositional Knowledge**

Simulation data revealed KI-1 and KI-2 understood that increasing the inspired oxygen percentage, gas tension in the lung increases, resulting in an increase in PaO₂ and arterial content of oxygen (Tables 19-20). KI-1 and KI-2 had only a few incorrect predictions regarding the effects of increasing inspired oxygen concentration on most measured and calculated indices of oxygen. These relationships seemed stable throughout the entire study leaving the researcher to conclude the simulation was effective in enhancing the understanding of what changes occurred with changes in inspired oxygen concentration. KI-2 stated:

"As you increase the FiO₂ (inspired oxygen concentration), the PIO₂ will go up since you have more oxygen in the air. If this goes up the P big A O₂ will also go up. I guess if the big A goes up, the P little A goes up.....yes, with the simulation, when I increased the oxygen percentage, these went up. PaO₂ mirrors the PAO₂. I also note that the saturation goes up too."

The key informants along with the other student-participants demonstrated understanding of how oxygen is carried in the blood and the influence of changing inspired oxygen concentration on oxygen transport. These concepts seemed to develop well and remained stable throughout the study.
Use of the oxygen dissociation curve (ODC) during the simulation showed that KI-1 and KI-2 could predict PaO₂ when given an arterial hemoglobin oxygen saturation value. Appropriate use of matching the X and Y axis on the curve was demonstrated. Both informants verbalized correctly during the simulation and interviews that a right or left shift in the ODC altered how hemoglobin loaded and unloaded oxygen. Another related conceptual understanding that seemed to develop over time, in part from simulation number three, is the advantages and disadvantages of the flat and steep portion of the ODC. Both informants were able to describe these advantages and disadvantages.

During the simulation, when intrapulmonary shunt fraction was increased to 15% and 30%, both informants noted the reduction in PaO₂. Only during the simulation did the informants verbalize correctly that the A-aD0₂ increased. This concept seemed to be less clear to them during subsequent interviews and concept mapping. KI-2 wrote on his course examination that an increase in the A-aD0₂ represented deadspace. Both KI-1 and KI-2 noted the need to increase the patient’s inspired oxygen concentration when the shunt fraction increased. KI-1 stated:

"As shunt increases less oxygen is getting into the blood....and maybe the surface area of the lung is less...maybe because the sacs are closed."

During the simulation exercise KI-1 and KI-2 predicted that decreasing the tidal volume would depress arterial oxygen pressures and content. In addition, both correctly predicted the PaC0₂ would increase. This key concept seemed to remain stable throughout the study. KI-2 stated: “As I decrease tidal volume C02 will increase since
there is less air going into the alveoli.” Both KI-1 and KI-2 correctly predicted and verbalized understanding of blood gas changes that occurred when the simulation exercise had them increase the shunt fraction to 30% and inspired oxygen to 30% while decreasing tidal volume by one-half. This model of extreme pulmonary disease was correctly assessed by both informants in terms of changes which occurred with alveolar and arterial blood gases. KI-2 stated:

“The $\text{SaO}_2$ should go up a little bit with the increase in oxygen, the $\text{PAO}_2$ should also go up..if the $\text{A-aD02}$ is increasing the patient is getting sicker. Since less oxygen getting across the membrane the $\text{CaO}_2$ will not go up much.”

A sample of student-participant concept maps for Oxygen Transport I simulation can be found in Appendix L.

Alternative Concepts

The simulation exercises revealed several significant alternative conceptions that prevailed throughout the study (Tables 19-20). The simulation did not appear to modify or correct several concepts. For instance, neither informant could describe effects increasing inspired oxygen, increasing shunt, or decrease in tidal volume on venous oxygenation. Both failed to recall normal values for $\text{Pv0}_2$ and $\text{Sv0}_2$.

KI-1 and KI-2 were uncertain of the effects of increased inspired oxygen on $\text{A-aD02}$. KI-2 struggled with verbalizing the definition of shunt:

“I can’t define shunt..I can see it but can’t put into words..I think shunt is a decrease in lung surface area.”

Neither KI-1 or KI-2 could predict correctly or discuss why the $\text{A-aD02}$ gradient does not increase during hypoventilation. Although, they recognized an increasing $\text{A-aD02}$
indicated shunting was worsening, each could not conceptualize why the gradient would remained unchanged during hypoventilation.

Following the simulation and lecture KI-1 and KI-2 were unable to discuss effects of increased shunt fraction on venous oxygenation. Throughout the entire study normal values for mixed venous oxygenation were difficult for these student-participants (and for others in both novice groups) to recall. Having no benchmark as normal values, the simulation did not appear to assist KI-1 or KI-2 in conceptualizing venous oxygenation. KI-1 stated:

“A decrease in $SvO_2$ will change hemoglobin’s affinity for oxygen...normal $SvO_2$ is 98%.”

The ability to interpret venous values is paramount in understanding the entire concept of oxygen supply and demand balance. At bedside, the Cardiopulmonary Science graduate will often have to interpret venous blood gas values as an indication of cardiac blood flow and how well the lungs are oxygenating the blood. This may include the assessment of a patient’s $CaO_2$-$CvO_2$ gradient. Results from simulation verbal protocols indicated informants were unable to see the importance of monitoring changes in the arterial-to-venous oxygen content gradient. At this point in the study, the key informants could not conceptualize the above concepts despite the simulation exercises exposing them to changes in venous blood gases as other variables were manipulated.

During the Oxygen Transport I simulation exercise and subsequent interviewing, KI-1 explained that if tidal volume decreased by one-half the $PaO_2$ also will decrease by one-half (Tables 19, 27 & 53). This tendency to relate a drop in tidal

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volume to changes in \( \text{PaO}_2 \) in a linear manner is a major alternative conception that needed addressing. This belief was similar to the previous discussion concerning the relationship between \( \text{PaO}_2 \) and oxygen saturation. Unique characteristics of hemoglobin and the different solubilities of oxygen and carbon dioxide make such linear relationships incorrect. Understanding the ODC and blood gases changes due to volume changes requires the learner to see the nonlinear relationship among these variables. Despite the nonlinear graphical representation of \( \text{PaO}_2 \) and \( \text{SaO}_2 \) with the simulation and numerical readout of a changing \( \text{PaO}_2 \) on the computer screen as tidal volume decreased (in a nonlinear manner), KI-1 and KI-2 did not seem to make the nonlinear relationship between \( \text{PaO}_2 \) and \( \text{SaO}_2 \). This findings suggests the instructor may need to assess student’s understanding of nonlinearity among this and other physiologic variables.

Although capable of listing normal values for arterial oxygenation and being able to calculate indices for oxygen content and delivery on written examinations, both informants were unable to list normal values for \( \text{CaO}_2 \), \( \text{CvO}_2 \), \( \text{PvO}_2 \), \( \text{SvO}_2 \), and oxygen delivery. Neither informant could calculate oxygen content or oxygen delivery during the postcourse interview despite doing so for the simulation, in-class worksheets, take home problems, and classroom instruction. Persistent misuse of variables in the oxygen content equation was predominant throughout the study. KI-1 stated in a postlecture interview: “To calculate oxygen content you multiply \( \text{PaO}_2 \) by 1.34.” While KI-2 stated: “Oxygen transport is cardiac output times \( \text{SaO}_2 \).” Both statements reflect serious alternative conceptions with respects to oxygen transport.
Out of curiosity the researcher recently polled four practicing graduates from Cardiopulmonary Science about normal oxygen content values. All four clinicians were unable to recall the correct equation for oxygen content and state normal its values. This finding among novice, intermediate (to be discussed), and expert clinicians is disturbing to the researcher. Emphasis on how teach these concepts in a more effective manner will need to be pursued because the inability to calculate or interpret oxygen transport values seriously impairs bedside assessment of the patient in cardiopulmonary failure. To assure adequate support of oxygen transport and utilization in a patient warrants the clinician to understand these concepts.

What Influenced the Alternative Conceptions

Analysis of KI-1 and KI-2 data reflects missing gaps in the understanding of arterial and venous oxygen transport. It appears these two informants did not fully understand the complete oxygen transport circuit as illustrated by poor understanding of venous blood oxygenation. Without a thorough understanding of this blood circuit, complete conceptualization of oxygen delivery may be impaired. It has been the experience of the researcher that students frequently fail to distinguish between volume and flow. The inability to determine how volume and flow differ would make understanding oxygen supply and demand difficult. Despite efforts to present in-class instruction, worksheets with related problems, and simulation work, alternative conceptions about these variables persisted. The researcher speculated that student-participants failed to have a good grasp of blood flow principles and tissue oxygen utilization at this point in the course. Re-thinking sequence of topics (e.g. placing
cardiovascular physiology first in this course versus last as it is currently presented) may help address this conceptual difficulties. Taking students to the bedside early in the program to calculate oxygen content and delivery and apply these values to an actual patient case may also aid in conceptual development.

Simulation Content Module Four—Control of Cardiac Output: The Macro Concept

Cardiac output is determined by preload, afterload, contractility, and heart rate. Preload is the amount of wall stretch during diastole and is described often as the volume of blood in the ventricle during diastole. Afterload is the degree of wall tension generated with ventricular contraction. Clinically afterload is often described as the force the ventricle encounters as it ejects stroke volume into the vascular space. Contractility is often described as the force of ventricular contraction. Heart rate is simply the number of heart beats per minute. These variables determine how much blood is ejected from the heart per beat and per minute—the cardiac output.

Cardiac output determines oxygen delivery to the tissues. As the determinants discussed above change there is the potential for change in cardiac output. Any change in cardiac output can alter oxygen supply to the tissues. For example, the loss of blood volume can result in a decrease in preload and cardiac output. Vasodilation may result in a decrease in blood pressure and a decrease in adequate tissue perfusion.

If blood volume decreases, sympathetic responses attempt to restore blood flow (thus preserving oxygen delivery) by increasing heart rate and/or vasoconstricting blood vessels. In addition, kidneys tend to retain fluid to preserve blood volume. If the heart is
ischemic (low on oxygen) or in failure (decreased pumping ability), cardiac output can decrease. In this instance the clinician will attempt to alter preload, afterload, and contractility to optimize blood flow to assure oxygen delivery. Assessment at the bedside of blood flow, oxygen supply and demand includes assessment of hemodynamics, venous oxygenation, and kidney function.

**What Key Informants Understood About the Control of Cardiac Output**

**Propositional Knowledge**

Informants were able to describe the blood flow circuit from left atrium to right atrium during postlecture and course interview. Principle of the anatomy of the blood flow circuit seemed to be intact.

Data analysis indicated KI-1 and KI-2 appeared to understand the principles found in this simulation better than the other content modules (Tables 29-30, 37-38, 47-48, & 55-56). Both were able to verbalize effects of increasing venous return on cardiac output, effects of hemorrhage on cardiac output and blood flow, and if right atrial pressure increases, venous return may decrease. These principles were clearly understood from verbal protocols generated during the simulation, interviews, and concept mapping. Both KI-1 and KI-2 understood that a failing left ventricle resulted in less blood being pumped out and fluid could back up in the lungs.

Both informants correctly predicted that removing 1000 mL of blood from the simulated patient would result in a loss of volume and a decrease in blood pressure. KI-1 and KI-2 along with other members of the novice groups seemed to understand, in part, the Frank-Starling Principle as it applies to blood flow entering the heart. All
student-participants verbalized this relationship. KI state: “What goes into the heart, comes out of the heart.”

This statement fails to take into the account a more complex concept about under and over stretch of the myocardium. It was interesting that all novice student-participants essentially defined this concept using the same words. The researcher sensed that this may have been a concept learned during the previous semester in the human physiology course. KI-1 and KI-2 were able to successfully interpret a graph demonstrating the relationship between venous return and right atrial pressure and cardiac output and right atrial pressure.

KI-1 stated:

“As right atrial pressure increases, venous return decreases...after a point.”

Both informants accurately predicted that the heart rate would increase in an attempt to increase the blood pressure if blood loss occurred. KI-1 stated:

“The body will try to keep blood pressure up by increasing heart rate if there is blood loss.”

The concepts of vascular space, volume, and pressure in the peripheral vessels was understood by both informants. The simulation exercise had the informants decrease blood volume with the central nervous system response turned off and then repeated the exercise with the central nervous system response turned back on. By performing these steps it appeared that the simulation was able to strengthen the understanding between blood loss and heart rate compensation. This concept remained stable throughout the study. It is worth noting that with the intermediate study group, the above concept was
consistently misunderstood. This group of participants failed to see the relationship between a high heart rate and low volume. This issue is further discussed later in this chapter.

The simulation exercise required the student-participants to decrease left ventricular contractility and predict effects on hemodynamics. KI-1 and KI-2 both stated that as contractility decreased the left ventricle would pump less blood and blood would back-up in the lungs. KI-2 stated:

“As contractility decreases, lets say.....during heart failure.....it can’t push out as much blood. Some of the blood will back up in the lungs causing edema”

The informants readily saw and verbalized effects of vasodilation on cardiac output. Both stated that vasodilation by the drug nitropresside can result in increased cardiac output.

Alternative Conceptions

Simulation verbal protocols, concept maps, and subsequent interviews revealed significant gaps in understanding of cardiovascular principles (Tables 21-22, 37-38, & 55-56). KI-1 and KI-2 could define preload and afterload, as KI-1 and KI-2 stated:

“Preload is the blood in the ventricle during filling.” (KI-1)

“Preload is blood in the heart during diastole.” (KI-2)

Both were unable to verbalize understanding of the clinical measurements of preload and afterload. This was despite correct identification of these measurements on the topic examination. Neither could explain why right atrial pressure and pulmonary capillary wedge pressure decreased with blood loss. However, KI-2 was able to state:
"As wedge goes up so does cardiac output." KI-2 described vasodilation as a means to increase mean arterial blood pressure. His concept map revealed a link between right atrial pressure and afterload. The way both informants struggled with explaining their prediction suggested significant gaps in their understanding of hemodynamics. Towards the end of the course there was evidence that both informants were gaining a better understanding of hemodynamics. Postcourse interview indicated KI-1 and KI-2 knew normal hemodynamics values, although they still struggled with the concepts of preload and afterload. The simulation seemed to strengthened their understanding of these concepts. It has been the experience of the researcher that most students fail to understand the concepts of hemodynamics well until these concepts are applied to actual patients and completion of the senior year of the program which emphasizes cardiovascular principles.

In sum, KI-1 and KI-2 were able to superficially define terms associated with hemodynamics and explains basic principles of blood flow adjustments made by the body during volume loss. They were consistently unable to conceptualize the real meaning of preload and afterload, how to assess these variables, and how those variables affect oxygen transport.

**What Influenced the Alternative Conceptions**

It was clear that students struggled to grasp concepts related to hemodynamics and control of cardiac output. Despite a simulation exercise that allowed the informants to see first hand what occurs to hemodynamics (via numerical and graphical output) when vascular volumes and pressures changed, students continued to show gaps in their
understanding. This was evident until completion of this study. The researcher reasoned that student-participants tended to see the cardiovascular system as a static system rather than a dynamic one. Coupled with a possibly poor differentiation between the concepts of volume and flow, students had difficulty with these concepts.

Textbooks often present study topic-related material in a two-dimension format which is a degree of underdimensioning. Simplification of the dynamic relationships in the cardiopulmonary physiology course and a lack of student experience in patient care may contribute to these identified knowledge gaps. In addition, the concepts of preload and afterload are often taught as separate concepts and are not integrated.

Perhaps introducing cardiopulmonary physiology with principles of cardiovascular physiology presented first, while simultaneously using interview and concept mapping as methods of identifying understanding and alternative conceptions, will result in better integration and reinforcement of concepts on a more regular basis. In addition, identifying a number of key principles that should be retained by the student and built upon these during subsequent course work. Although emphasis is placed on hemodynamic function and cardiac flow at the bedside during the student’s fourth semester of the curriculum, the experience of the researcher has been that many of the concepts taught during Cardiopulmonary Physiology and Advanced Techniques II are not transferred to the fourth semester and remediation is almost always necessary. The researcher has the primary responsibility among the faculty to teach hemodynamic monitoring in critically ill patients during the fourth semester. The researcher believes that students begin to assimilate and subsume concepts related to hemodynamics during
their senior year. Additionally, understanding is enhanced with those students who choose to work with the researcher during their final semester in a clinical elective focusing on assessing bedside hemodynamics.

**Use of Simulation Software in Advanced Techniques II Class**

The original intent of this research was to explore the use of cardiopulmonary simulation software in a cardiopulmonary physiology course. As with field work and a qualitative approach, the researcher altered the research plan and expanded the study period to include using simulation in an advanced course in respiratory care (following the Cardiopulmonary Physiology course). The first four simulation exercises during the Fall 1997 Semester were extensive, time consuming, and provided significant amount of data. The four simulations that were completed in Spring 1998 focused on a more narrow set of concepts. Simulation Five was developed, in part, to assess the degree of retention of propositional knowledge and alternative conceptions from the previous semester. A five-week time interval separated the two semesters (Fall 1997 and Spring 1998).

**Simulation Content Module Five: Oxygen Transport II: The Macro Concept**

As a continuation of the macro concepts found in simulation number three, this simulation dealt with a more focused approach to interpreting the ODC and the understanding of intrapulmonary shunting.

The ODC displays a nonlinear relationship between P0₂ and hemoglobin oxygen saturation. This nonlinear relationship is a result of the unique properties of the protein, hemoglobin, specifically cooperative binding. Two aspects of the curve result, the flat
portion where there is little change in hemoglobin oxygen saturation for any change in PO₂ and the steep portion where a small change in PO₂ will yield a big change in hemoglobin oxygen saturation. As you move from right to left on the curve, hemoglobin saturation decreases. Several benchmarks to associate with the ODC are the hemoglobin saturation for two PO₂’s: 27 torr and 60 torr. At these points hemoglobin saturation is 50% and 90% saturated respectfully. A curve similar to the ODC is the oxygen content curve which relates oxygen content to hemoglobin saturation.

Normal arterial blood oxygen is a product of normal end-capillary oxygen and venous oxygen content. When both measurements are in normal range, arterial oxygen content will be normal. When end-capillary oxygen levels decrease, both arterial and venous oxygen levels decrease. Likewise when end-capillary oxygen increases and venous and arterial oxygen levels remain unchanged or even decrease, intrapulmonary shunting is occurring.

**What the Key Informants Understand About Oxygen Transport II**

Both KI-1 and KI-2 correctly predicted the changes in oxygen indices with an increase in inspired oxygen, much like the data found in simulation three. KI-1 was able to identify the PaO₂ associated with a hemoglobin saturation of 50% and 90%. KI-2 was unable to state these values.

Both informants stated correctly that as minute ventilation increased PaCO₂ decreased and when PaCO₂ increases, the PAO₂ decreases. As KI-2 explained: “When CO₂ increases there is less room in the lung to hold oxygen so blood oxygen level drops...again, the little a is a mirror of the big A.”
Both informants correctly predicted that if end-capillary oxygen decreases, arterial and venous oxygen will decrease (Tables 56-57). KI-1 and KI-2 described the advantages and disadvantages of the steep and flat part of the ODC. Values for PaO₂ are stated to be 80-100 torr. Venous oxygen saturation is 75% was stated by KI-1.

Both informants were asked to describe how they would assess if a patient is oxygenated. KI-1 responded:

"I would look at skin color, work of breathing, heart rate, PaO₂, SvO₂, “

KI-2 responded:

"Look at the PaO₂, PAO₂, SvO₂ and V/Q ratio”

Neither informant included cardiovascular measurements, content measurements, assessment of oxygen delivery, or kidney function. No mention of additional indices such as shunt fraction, a/a ratio, PaO₂, FiO₂ ratio, or A-aDO₂ measurements were provided.

When asked during the post-lecture interview how to assess tissue oxygenation, both informants responded with assessing “venous oxygenation” (Tables 63-64). Like the informants, the other novices were able to conceptualize, in part, the meaning of a decrease in venous oxygen. KI-1 and KI-2 stated that a decrease in venous oxygen reflected a decrease in blood flow to tissues and that the tissues were extracting more oxygen, leaving less in the venous blood.
Alternative Conceptions

Both KI-1 and KI-2 did not understand the significance of decreasing arterial oxygen content while end-capillary oxygen and venous oxygen content remain unchanged. Neither were able to combine and synthesize these concepts to arrive at the concept of shunt. Neither recalled what end-capillary oxygen was or how to calculate it. KI-2 stated that normal CaO₂ and CvO₂ are 98% and 75% respectfully, an error in not only numbers, but also in units of measure. KI-2 stated he had a difficult time with remembering normal values. He also stated normal CaO₂ was 100 mL (normal value is 20 mL/100 mL blood).

Neither informant nor other members of the novice groups described clinical indices to assess oxygenation other than Pao₂, Sao₂, and SvO₂ (Tables 57-58 and 63-64). Additional measurements were not verbalized at any point in data collection. This is significant because this suggests that novice student awareness of how to assess oxygenation is limited to these values. Examination results also indicated poor understanding of values of bloods oxygen such as a/A ratio, A-aDO₂, PaO₂/FiO₂, CaO₂-CvO₂, oxygen extraction equation, mixed venous oxygen, and the clinical shunt equation. Student-participants could not list normal values for these measurement on examination. The lack of awareness of these indices could prohibit the complete conceptual development of oxygen supply and demand.

A resistant alternative concept that remained consistent with all novice student-participants was the body’s first response to low blood oxygen. All participants stated throughout both study courses that the body will respond first with an increase in
respiratory rate. This inability to see the role the cardiovascular system plays in assuring tissues oxygen supply when blood oxygen decreases precludes a full understanding of oxygen and supply in various disease states.

Both KI-1 and KI-2 stated that as blood volume decreased, blood flow increased and there was less time for oxygen to be extracted by tissues. This alternative conception does not include the important concept that tissues increase extraction of oxygen with decreased blood flow. Student-participants seemed to focus on altered blood flow in terms of blood flowing by tissue beds and not blood volume. In addition, they tended to describe low blood volume with an increased blood velocity and with insufficient time for the tissues to extract oxygen. Neither informant seemed to grasp this concept in their verbalization, however, with pencil-paper examinations they correctly chose items that stated that when blood volume decreases, tissues will increase their extraction of oxygen.

**What Influenced the Alternative Conceptions**

This group of novice learners seemed to have had difficulty with recalling normal values associated with oxygen transport and utilization. Although the simulations focused on oxygen indices such as \(\text{PaO}_2\), \(\text{SaO}_2\), \(\text{PvO}_2\), \(\text{SvO}_2\), \(\text{CaO}_2\), and \(\text{CvO}_2\), other indices should have been better understood and recalled. Classroom instruction emphasized most of the all clinical measurements used to assess both how well the lungs oxygenate the blood and how well the tissues are oxygenated.

The poor understanding of the relationship between end-capillary, arterial, and venous oxygen content may have resulted from these concepts not being explained well.
in the course textbook and lectures. Asking novice students to problem-solve the related simulation problems may have been inappropriate due to an inadequate understanding of these concepts.

The persistence of the belief that the respiratory rate compensates first when blood oxygen decreases perplexed the researcher. Despite frequent reinforcement during both courses of study concerning the role of the cardiovascular system during low blood oxygen states, the alternative conception persisted with all student-participants.

Possible remedies may include a multimedia animation presentation of oxygen loading and unloading at the tissue level with blood oxygen measurements changing under a variety of physiologic conditions. Promoting a dynamic representation of oxygen transport and utilization during altered blood flow states may be effective. Use of physiologic monitors such as an impedance transducer across the chest wall, pulse oximetry and electrocardiograms to monitor physiologic changes that occur with various conditions (such as exercise) may assist the student to visualize and understand physiologic change. Such a demonstration could occur following a lecture series and involve a sedentary and athletic individual—allowing contrast of response.

**Simulation Content Module Six and Seven: Preload, Afterload, and Contractility: The Macro Concept**

This macro concept is a continuation of macro concepts associated with simulation number four. A closer look at these principles shows that as blood volume is increased or decreased preload changes accordingly. Removing fluid volume from the
body will decrease cardiac flow, preload, and blood pressures (arterial and pulmonary).
Likewise, as preload increases with both an increase in fluid administration and as the ventricle becomes less compliant and thus is less willing to receive volume.

Afterload will increase with arteriole constriction or decrease with vasodilation.
As afterload increases, the work of the heart increases and stroke volume or cardiac output may decrease. Administration of a vasodilator can increase cardiac output while excessive vasodilation can decrease mean arterial blood pressure.

Altered contractility can influence how much blood is ejected from the heart.
Decrease contractility, as seen with heart failure, decreases stroke volume. In contrast, increased contractility increases the force of contraction and amount of blood ejected from each ventricle. As cardiac output decreases with altered contractility, preload, and/or afterload, blood flow can diminish compromising oxygen transport and delivery.

**What the Key Informants Understood About Preload, Afterload, and Contractility**

Simulation six and seven simulated changes with preload, afterload, and contractility. Key informants increased blood volume and predicted correctly the change in cardiac output, stroke volume, and left ventricular end-diastolic pressure and volume.

KI-2 stated:

"As you give 1000 mL everything will increase"

Both KI-1 and KI-2 stated that an increase in body fluids will increase stroke volume, cardiac output, and contractility (Tables 59-60). Conceptual development of effects of preload and cardiac flow improved with this simulation. KI-1 stated: "Until seeing this (simulation) I really did not understand preload. Now that I give fluid, I
think LVEDV ..which must be the wedge, will increase with fluid.” With alteration of afterload by infusing nitropresside, KI-1 stated that stroke volume and cardiac output decrease, whereas KI-2 indicated that these values will increase. KI-1 stated:

“A vasodilator will create more space for the blood to go”

but fails to state that cardiac output will increase. KI-1 seems unsure of effects of what a change in afterload will do to output from the heart, whereas KI-2 stated that vasodilation is associated with less resistance, allowing cardiac output to increase.

In contrast, KI-1 stated that a reduction in afterload can increase oxygen delivery. This statement contradicted what she had predicted in the simulation suggesting guessing. When asked what effect does an increase in afterload have on oxygen delivery, KI-1 explained:

“If you decrease afterload, you increase oxygen delivery....less resistance.”

It appears from this statement that K1 had modified her previous understanding by visualizing the actual effects of altered afterload with drug therapy.

Both informants perceived that an increase in afterload can decrease blood flow from the heart resulting in decreased oxygen delivery. Both stated that an increase in afterload increased resistance.

Both informants demonstrated understanding concerning how altered contractility affects cardiac output and oxygen delivery. They stated that as ventricular contractility decreased due to disease, cardiac output or the amount of blood pumped per minute will decreased and less blood will be ejected meant less oxygen being carried to the tissues. Both informants also connected an increase in pulmonary
capillary wedge pressure with a decrease in ventricular contractility. KI-2 stated: “As the left ventricle decreases its pumping ability, less blood is pushed out....the blood.......can back up in the lungs.”

Both informants were successful in describing the effects of increasing preload and its effect on heart rate. As preload increases, heart rate decreases. Although informants did not speculate why, the researcher felt they may have understood that better cardiac flow resulted in the need for a slower heart rate.

A silent interview was provided to all student-participants which consisted of four clinical case histories (see Appendix M). Four case histories that dealt with hypovolemia, hypervolemia, left ventricular failure, and septic shock. Clinical hemodynamic measurements, blood gases, and medical history were provided. Key informants were asked to diagnosed each case correctly and suggest treatment (see Tables 64-65).

Alternative Conceptions

Neither informant understood the terms: left ventricular end-diastolic volume or left ventricular end-diastolic pressure—both seemed to guess at their meaning. They did not associate end-diastolic pressure with pulmonary capillary wedge pressure. KI-1 associated a decrease in afterload with a decrease in venous return. Although this is correct, KI-1 did not develop this concept to include changing the afterload can change the stroke volume. KI-1 simply stated: “Decrease afterload you decrease venous return.” This statement indicates a belief of an absolute occurrence and not a dynamic variation that can occur with changing afterload. In addition, prior to the simulation exercise, KI-
2 stated that a decreased afterload will decrease stroke volume. This alternative conception seemed to dissipate as the simulation progressed. KI-2 recognized that a reduction in afterload will provide less resistance and increase stroke volume. He stated: "Oh...I see this now.....as the space gets.....uh....bigger, more blood get get out."

During this entire study with hemodynamics the key informants, along with the other members of novice groups, failed to differentiate that each ventricle has a preload and afterload. Each student-participant described these concepts as they applied to the left ventricle. The researcher speculated that most student-participants focused on the left ventricle and failed to conceptualized that the right ventricle encounters a afterload and sustains a preload. This is often observed clinically with students have difficulty with describing clinical measurements of preload and afterload for both ventricles.

During the silent interview neither key informant knew the treatment for case two (hypervolemia) (Tables 65 & 66). Furthermore, KI-1 described septic shock as profound vasoconstriction, a decrease in SVR, and a drop in cardiac output (which are incorrect concepts). This suggested she may have had incomplete understanding of clinical interpretation of hemodynamic parameters.

**What Influenced the Alternative Conceptions**

This simulation resulted in the fewest number of alternative conceptions. Aside from not knowing the terms left ventricular end-diastolic volume and pressure, KI-1 and KI-2 seemed to understand the main concepts associated with this simulation exercise. The researcher sensed uncertainty with KI-1 with vascular volume changes and cardiac flow; however as the simulation progressed, these uncertainties seemed to
disappear somewhat. The lack of associating the right side of the heart with a preload and afterload may be a result of a lack of emphasis placed on this concept in class and using textbooks which focus on left ventricular function. These knowledge gaps may be addressed by adjustments to lecture content.

Simulation Content Module Eight: Oxygen Dependency: The Macro Concept

Propositional Knowledge

Oxygen consumption behaves in a nonlinear or biphasic with being influenced by tissue oxygen consumption and local blood flow. For a given range of cardiac flows, oxygen consumption is independent of flow. In other words, oxygen consumption remains constant over a wide range of blood flow values. However, there is a cardiac flow rate in which consumption becomes dependent upon flow. Below this blood flow rate, oxygen consumption is directly proportional to blood flow. In the transport-independent region, oxygen consumption is determined by cellular oxygen consumption. In the transport dependent region oxygen consumption changes proportional to oxygen delivery.

What Key Informants Understood About Oxygen Dependency

Both key informants stated that low blood flow results in decreased oxygen transport. Lower than 21% inspired oxygen will result in hypoxemia. These two concepts were shared by all student-participants. However, this appeared to be the extent of understanding of the principles of this simulation (Tables 61-62 & 67-68).
Alternative Conceptions

The simulation exercise required the student-participant to set parameters that established oxygen consumption to be blood flow dependent. With this complex simulation no student-participant was able to explain or predict changes in oxygen consumption, oxygen delivery, or other indices of oxygen when cardiac output dropped below 4L/min while breathing 11% oxygen. A widespread gap in knowledge existed in all the novice group participants. The researcher concluded this lack of understanding was due to inadequate presentation of these concepts in class. In addition, the course textbook did not include these concepts.

What Influenced the Alternative Conceptions

The lack of instruction or reading assignment on the biphasic nature of oxygen consumption obviously led to the widespread alternative conceptions and gaps in understanding of these concepts. The researcher will need to include in the course an overview of cellular respiration and the biphasic nature of oxygen consumption to assist learners to better grasp these concepts. The verbal data associated with the simulation suggested that undergraduate cardiopulmonary students were unable to problem-solve oxygen dependency related problems (Table 61-62).

Final Interview

Using the final interview as an opportunity to seek how well the student-participant understood oxygen transport and utilization, the researcher asked each member of both groups three questions:
1. Describe in general terms how oxygen is transported from the atmosphere to the lungs, blood, and tissues.

2. Why can venous oxygen reflect how well the patient is oxygenated?

3. Define, describe, and give an example of each of the four types of hypoxia.

The first question focused on the pathway oxygen travels from “mouth to mitochondria”. This global question would assure the researcher that the student-participants understood the pathway and the process oxygen travels from the atmosphere to the tissues. The second question focused on a poorly understood concept throughout the entire study: venous oxygenation. The last question required the student-participant to synthesize information and generate an explanation with an example. The four types of hypoxia were defined and discussed in early October 1997 and the researcher believed that if the student-participant could integrate most of the major concepts relating to oxygen transport and utilization that were presented over the two courses of study, the four types of hypoxia could be understood and defined.

Results of the Final Interview

Both key informants were able to trace the how oxygen molecules traveled from the mouth to mitochondria. In addition, they were able to describe how oxygen is transported and delivered to the tissues. Venous oxygen values were known by the two informants as well as what a decrease in Pv02 and Sv02 may represent in terms of blood flow to the tissues. All student-participants understood that a decrease in venous oxygenation could indicate a decrease in blood supply to the tissues. However, none of
the participants stated that a decrease in venous oxygenation may also reflect an increase in oxygen consumption.

The most alarming aspect of this final interview was the inability of any of the student-participants to define, describe, or give an example of each of the four types of hypoxia. Each student-participant either claimed they did not remember or demonstrated significant alternative conceptions. A typical response was given by K-2 was:

"Researcher: Please define, describe, and give an example of the four types of hypoxias."

KI-2: "let me see........let me think about this...hypoxia...uh......I am drawing a blank......hypoxic is due to the lack of oxygen in the gas we breathe......breathing less then we need. Anemic is a decrease in hemoglobin attached to......don’t know....I don’t know the others."

From analysis of the transcripts, fours types of hypoxia are not understood by these student-participants. It is obvious the researcher needed to emphasize these concepts over the two study courses.

From the above discussion, data collected during this study suggested that use of simulation software may be used to assess student’s level of conceptual understanding and diagnose alternative conceptions. There was a modest number of concepts that the simulation seemed to enhance leading the researcher to conclude that use of simulation may enhance understanding.

What are the Effects of Using Cardiopulmonary Simulation Software prior to Lecture in Initial Concept Formation?

This questions was of particular interest to the researcher. It was anticipated that simulation may act an advance organizer for new incoming material.

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Analysis of data revealed modest support for use of simulation prior to lecture. Use of simulation prior to lecture was investigated by Brant, Hooper, and Sugrue (1991) who reported positive effects with a group of college-level genetics students. This large group study supported the use of pre-lecture simulation as a means to enhance conceptual development. In contrast, this study focused on a small group with intense study of two key informants. Results of Brant and colleagues study may not be able to be transferred to this study group. Other than the study by Brant and colleagues, the researcher was unable to locate other studies examining the effects of simulation prior to lecture. This researcher anticipated that the use of simulation prior to lecture would act as an advance organizer and ready the learner’s cognitive structure to facilitate learning of new concepts.

To support this possible effect of pre-lecture use of simulation, sample data from Oxygen Transport I and II simulation were evaluated for evidence that the simulation aided conceptual development during lecture (Tables 19-20 & 57-58). A sample of these data are presented below.

Concepts that were introduced in Oxygen Transport I and II content module that appeared to be better understood by Novice Group A than Novice Groups B during and immediately following lecture are listed below. Using simulation verbal protocols along with pre- and post lecture interviews, coded data revealed the following concepts that may have been better understood as a result of use of simulation prior to lecture. Included:
1. Changes in gas composition altered oxygen tensions and content from alveoli to tissue beds;
2. As tidal volume decreased, blood oxygen levels decrease;
3. As intrapulmonary shunting increases, PaO₂ decreases;
4. As intrapulmonary shunting increases, an increase in inspired oxygen percentage may increase the PaO₂.
5. Using the ODC for identifying PO₂ when given a S0₂;
6. Advantages and disadvantages of the steep and flat portion of the ODC;
7. Calculating oxygen content during and immediately following lecture;
8. A decrease in venous oxygenation reveals increased extraction of oxygen by the tissues leaving less in venous blood.

Triangulated data and number of propositional knowledge statements and alternative concepts suggested that those exposed to simulation exercises prior to lecture understood the above concepts better than those that experienced simulation at the end of the course. Caution needs to be exercised while interpreting this conclusion due to the small number of participants. Although trends in the qualitative data suggests a modest effect in use of simulation prior to lecture, results can only be applied to this particular study group. Future research may look at the use of prelecture simulation as an advance organizer. A larger cohort may show effective use of simulation as means to prime cognitive function and prepare the learner for new material.
Does the Post Instructional Use of Cardiopulmonary Software Aid in Assessing Conceptual Development and in Identification and Remediation of Alternative Conceptions?

The researcher found little difference between pre- and postlecture simulation performance (see Table 71) and conceptual inventories (see Tables 5 and 6) between both novice groups to conclude that a strong difference did not exist between the use of simulation software before and after lecture. However, using simulation at the conclusion of lecture as a means of assessing understanding and diagnosing alternative conceptions was found effective if these data were combined with other sources such as interview and concept mapping. Table 70 lists macro concepts that were identified as common with both novice groups at the conclusion of the study. Triangulated data from both groups revealed similar findings, leading the researcher to conclude that the sequencing of the simulation software may not have mattered in overall conceptual development.

Table 72 reflect resistant alternative conceptions and concepts that were poorly understood by all student-participants. These data were compiled from all data from the Novice Group A and then Novice Group B. A comparison revealed little difference leading the researcher to combine findings. This further supports the conclusion that sequencing the simulation may not be as important as combining simulation data with other data to monitor conceptual development and to identify alternative conceptions.
Can Cardiopulmonary Simulation Software be Used by the Instructor and Learner (Novice) to Identify Critical Junctures in Understanding Oxygen Transport and Utilization?

A critical juncture is a point in a course where learners must possess essential knowledge that was constructed from previously taught concepts in order to understand new subsequent information. This study began with an initial set of six critical junctures and these were modified as the study unfolded and collected data were analyzed. On multiple occasions the list of critical junctures were submitted to the panel of experts (see Appendix J) for further modification and approval. The final set of critical junctures (see Table 4) was thought to be necessary for learners to master in order to possess a thorough understanding of oxygen transport and utilization.

The simulation topics were developed in part, to include concepts found in the critical junctures. Final analysis of all the data and the development of both macro conceptual inventories revealed significant gaps in knowledge related to many of the critical junctures. Tables 5 and 6 essentially reveal fragments of concepts related to each of the critical junctures. Each concept in the inventory for both groups was found in simulation verbal protocols with supportive data from the other sources (i.e., interviews). The researcher could not conclude that use of simulation could identify if the student-participants moved through each juncture successfully by focusing on simulation data alone. This was the case with either novice group. Although use of simulation software was an effective means of monitoring conceptual development and diagnosing alternative conceptions, it was unable to thoroughly assess student-
participant’s progression through the junctures. The researcher speculated that this may be a result of the student-participants' inability to acquire the necessary knowledge associated with each critical juncture. As a result of having an incomplete understanding of oxygen transport and utilization and/or the material selected for each of the simulation exercise was incomplete (i.e., failing to assess all aspects of the critical junctures). The former statement is evident in student-participant’s awareness of Critical Juncture E—Tissue Oxygenation. The widespread lack of understanding of concepts related to how tissues use oxygen demonstrated a significant gap in conceptual development. Perhaps using simulation to identify which critical junctures were not passed through may be a possible use for this type of software. Further research is needed to clarify this use of simulation. The cardiopulmonary simulation program used in this study is versatile enough for simulation exercises to be designed to study each of these critical junctures. A limitation of this study included not using the computer simulation program to its full capability and designing more diagnostic simulation exercises. For example, simulation exercises were void of principles that dealt with Critical Junctures B 2.3, C 3.1, E, and F 6.2 from Table 5. The incomplete coverage of these critical junctures may limit study conclusions concerning the use of simulation software.

In sum, the use of simulation software as a means to assess student progress through a set of teacher-generated critical junctures appears to be limited. Possible improvement in the nature of the simulation itself or use simulation in conjunction with other data may be effective in assessing passing through the junctures.
Use of Simulation Software with Intermediate Students

As previously discussed, Patel and Groen (1991) suggested the use of the term intermediate to designate learners that fall between the novice and expert spectrum. Using Patel and Groen's definition of intermediate, the student-participants in this study were considered intermediates—possessing basic science knowledge (i.e., respiratory care) but have limited clinical experience. Literature supports that the intermediate learner is capable of forming some patterns of phenomena and can use available information selectively to generate solutions (Patel, Groen, & Scott, 1988). The intermediates in this study had completed formal respiratory care education, were approximately a third into their cardiovascular technology training, successfully completed their entry-level credential examination (certification in respiratory care), and were employed on as part-time respiratory therapists. The researcher assumed at the beginning of this project that these intermediates possessed expertise in the domain of respiratory care and modest experience in bedside problem-solving with clinical problems. It was further assumed that intermediates would use a combination of general learning skills with domain-specific skills for forward reasoning of clinical problems.

The researcher chose a convenience sample of three senior Cardiopulmonary Science students to participate as intermediates. These intermediates reflected student-participants that were at the top, middle, and lower rank among their class members. For the sake of simplicity for this discussion intermediate students will be referred to as I1, I2, and I3 to represent intermediate student one, two, and three respectfully (see Table 1).
The intermediate component of this research project began with student-participant orientation and self-assessment using the National Board for Respiratory Care's examination content matrix for advanced practitioners. The examination matrix contains a complete outline of the material that the credentialing exam assesses. The researcher was interested in learning what areas of oxygen transport and utilization the intermediate student-participants felt they were uncertain of. Providing each intermediate with the matrix, they were instructed to identify any term they were uncertain of. Data were complied and unknown or poorly understood concepts related to oxygen transport and utilization were isolated and placed in tables for each intermediate (Tables 74-76). These tables revealed a possible over confidence with possessing self-knowledge due to small number of concepts that they judged as uncertain. It is interesting to note that several concepts listed by the intermediates were the same concepts the novice groups struggled with. This includes mixed venous oxygenation, shunt studies, A-aD0₂, and deadspace.

Answering the Research Questions

Can Cardiopulmonary Simulation Software Enhance Learning Propositional Knowledge and/or Help Diagnose Alternative Conceptions in Intermediates?

The researcher chose two self-contained case files from the simulation program. These files represented clinical cases that intermediates typically encounter in a hospital setting. Both cases required advanced knowledge and clinical experience to manage the patient successfully. Again, the researcher made the assumption that the intermediate student-participants had acquired the knowledge and possessed a modest degree of
clinical experience. Following a pilot study and assessment of its results (see Appendix D), the researcher chose Penny and Hallie in the simulation program case files. Penny suffered from acute pneumonia and Hallie developed pleural bleeding and hypotension. Tables 77 and 78 summarize an expert panel’s recommendation for an optimal approach to solving these cases from a medical management point of view. These tables follow the traditional approach to assess and treat a patient: inspect and assess, obtain diagnostic information, arrive at a diagnosis, and provide treatment. It was anticipated by the researcher that the intermediate student-participants would approach each case in a similar manner.

Following the gathering of the verbal protocols from each intermediate student-participant for a total of two cases (case one administered in Fall 1997 and case two administered in spring 1998), data were analyzed and tabled. A sample of transcripts are detailed in Tables 79 and 80. These tables list the major steps taken by II (Table 79) and I2 (Table 80) along with researcher-identified propositional knowledge statements and alternative conceptions.

Table 79 reveals significant deviation from the expert management of the Penny case. II begins with assessing breath sounds rather than assessing vital signs and performing a general inspection which would yield a more global assessment of the patient and lead to a quicker diagnosis. Within several minutes of the simulation, a warning sign appeared stating the case patient was "hypoxic" (low blood oxygen). {Note that the simulation program contained appropriate warnings when the patient experienced life-threatening conditions} What was notable in II's response was her
choice to place the patient on 100% oxygen. The information provided at the beginning of the case is sufficient to warranted assessing a room air baseline arterial blood gases early in the case management. By choosing 100% oxygen, II demonstrated faulty knowledge as to selecting an appropriate oxygen level. II chose not to do this, so she arbitrarily chose 100% oxygen when the need was made obvious. Without further assessment, II administered a bronchodilator to “treat the wheezing” and chose a dose of 1.0 mg albuterol every thirty minutes. This represents a suboptimal initial dose with an excessive frequency—indicating uncertainty with the drug dosage. It appeared after viewing the videotape of the student responding to the data on the computer screen, II chose randomly a dose to administer. What interested the researcher was why II and I3 did not know the correct dosage of this beta agonist during either case problems, despite administering it daily when working in the hospital setting.

Early in the case management II obtained an x-ray almost out of uncertainty as to what to do. II stated after obtaining x-rays results—without commenting on them:

“I am not sure what to do at this point. I am not sure what drug to give.”

II chose to assess the patient’s response to the increased oxygen by obtaining an arterial blood gas. II assessed vital signs but did not respond to an elevated heart rate. II seemed to choose randomly at the laboratory tests and procedures, such as an echocardiogram, which was not indicated. Because II did not obtain information from a physical examination, she obtained insufficient data to managed this patient. II chose to administer furosemide, a diuretic, without rationale for this action. II was also unsure of the correct dosage for this medication. II obtained another blood oxygen measurement
and noted that the level was decreasing. II responded by stating: “I will need to get the PaO₂ up.” She looked randomly at the treatment choices and failed to implement any form of treatment to increase blood oxygen. II seemed unsure of what to do. II assessed vital signs and noted that the patient’s respiratory rate was high and stated:

“I think she needs a phlebotomy”

The researcher was baffled as to why II chose to remove blood as a therapeutic modality for this patient with tachycardia. II chose to review the client’s metabolic panel and randomly looked at it, failing to assess venous oxygenation—which was below normal values. II obtained another set of vital signs and based on the high respiratory rate (48 BPM) chose to intubate the patient. Faulty knowledge may have motivated II to choose this treatment. II failed to obtain other parameters to better assess the need to place the patient on mechanical ventilation.

At this point in the case management, II did not demonstrate characteristics of an intermediate learner. She failed to see a pattern in the patient’s condition, seemingly choosing treatments at random, and demonstrating significant alternative conceptions with choosing a phlebotomy based on high respiratory rate, giving a diuretic for non-stated reasons, and administering nonindicated pharmacologic agents and inappropriate drug dosage and oxygen dosages.

Another critical omission was made by II while placing the patient on mechanical ventilation in the assist-control mode, while failing to assess the PaC0₂. Even after II notes a respiratory rate of 48, the PaC0₂ was not assessed.
An alarming move was made by II when she chose to change the ventilator mode from assist-control to control in an effort to slow the patient’s respiratory rate. This is contraindicated and life-threatening with a spontaneously breathing patient. In addition, II increased the tidal volume with no reason provided.

Throughout the case, the patient’s PaCO₂ increased, respiratory rate remained high, deadspace increased, and venous oxygenation decreased. II remarked on multiple occasions that she was unsure of normals for venous oxygen levels and hemodynamic values. Furthermore, II did not make reference to the high minute volume (32 L/min), elevated deadspace, and increased PaCO₂ to adjust the patient’s mechanical ventilator. Failing to compile this information inhibits II from making informed decisions.

Attempts to decrease the patient’s PaCO₂ by changing modes of mechanical ventilation, increasing tidal volume, and sedating the patient (II was not sure of drug to administer or the drug dosage needed to properly sedate the patient) resulted in the patient developing dynamic hyperinflation. It was clear that II was unable to detect this potentially dangerous condition. A significant alternative conception existed when II attempted to increase tidal volume while the patient had a minute ventilation of 32 liters—without inquiring about the volume of deadspace or degree of inadvertent positive end-expiratory pressure.

II chose to administer a vasoactive drug based solely on heart rate and blood pressure and not hemodynamic values. This indicated II possessed incomplete knowledge about what was important to assess prior to giving a potent vasoactive drug. II demonstrated uncertainty concerning patient care management throughout the
remainder of the case. Toward the end of the simulation she identified the need to
change ventilator mode and chose several at random. She stated she was unsure
concerning why the patient’s respiratory rate was so high. At this point II became
frustrated and stopped the case.

Never in the course of the case management did II correctly diagnose the patient
with pneumonia or determine dynamic hyperinflation was the cause of increased PaCO₂
and the high work of breathing. The researcher believed that data needed to make these
connections were made available as II performed a variety of assessments.

During the case management of Penny, II generated numerous alternative
conceptions and gaps in her knowledge. The simulation permitted the recognition of a
limited number of propositional knowledge statements, for examples: recognizing the
need for oxygen based on low blood oxygen (propositional knowledge), the need to
reduce carbon dioxide levels (propositional knowledge), and to reduce the work of
breathing (propositional knowledge). However, this simulation exercise was successful
in identifying a significant number of alternative conceptions. Most disturbing was the
lack of data gathering, lack of interpretation of what data was collected, and choosing
treatments without rationale.

The researcher concluded based on the data summarized in Table 79 that II
exhibited several faulty propositional knowledge and significant alternative
conceptions. These conclusions may be a result of II lacking clinical experience which
may have limited her ability to problem solve. However, at the point II participated in
this research project, she would be expected to recognize the key points in the Penny

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case and be reasonably successful at managing the patient to an acceptable clinical end-
point or to the point of discharge.

Table 80 describes I2 performance with case number two. I2 began by assessing
blood gases, hemodynamic values, and breath sounds. These were appropriate steps to
take and represented good understanding of the need to assess cardiopulmonary
function based on the signs and symptoms the patient exhibited. Again, the expert panel
suggested performing a physical examination as the first step towards reaching a
working diagnosis.

A significant alternative conception arose following the assessment of
hemodynamics and vital signs. Data revealed hypovolemia with heart rate elevated to
compensate the low blood pressure. I2 failed to associate the data to reach this
conclusion but instead attempted to decrease the patient’s heart rate. During the course
of the case management, I2 never connected the low blood pressure and physiologic
compensation of increased heart rate.

As the case developed, I2 recognized the need to administer fluid based on low
blood pressure and thready pulse. However, I2 insisted on attempting to reduce the
heart rate and randomly reviewed the drug list and was uncertain which one to choose.
Another significant alternative conception arose when I2 considered administering a
vasodilator. This is contraindicated in a hypotensive state.

Once the simulation program provided a warning that urine output is low, I2
stated: “This must be due to the low blood pressure...I’ll give dopamine.”
Although dopamine is indicated to increase blood pressure, administering it during low

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blood flow states results in reduced blood flow and oxygen delivery to tissues. Again, I2 demonstrated faulty knowledge by giving this drug at this time.

After obtaining a chest x-ray, the patient was found to have a right sided pleural effusion. I2 recognized the need to remove the effusion and, thus performed a thoracentesis. I2 followed this procedure with placement of a chest tube.

I2 demonstrated another example of propositional knowledge was when I2 chose to assess hemoglobin and hematocrit levels and stated:

“She needs blood, I’ll give some”

Although I2 administered blood, he chose to administer a volume (333 mL) of blood at random, without rationale. I2 continued throughout the case to decrease the heart rate. He administered additional dopamine and assessed the jugular veins to evaluate fluid status. I2 assessed pleural drainage for amount of drainage and the chemistry of the drained fluid. These actions suggested that I2 had the knowledge base to give fluids for low blood pressure and to assess response to therapy (i.e., chest tubes).

I2 assessed PvO₂ but failed to comment on the low SvO₂ and associated the low venous oxygen with low blood flow. He assessed the patient’s hemoglobin level and stated:

“SaO₂ 97% and hemoglobin of 9 grams....maybe she is losing blood through her chest tube.”

This indicated that I2 made the connection between the low blood pressure and the source of bleeding. However, once this connection was made, I2 stopped the case. He stated: “I am not sure what to do now.” As with I1’s simulation performance, the case
management verbal protocols by I2 revealed a limited number of propositional knowledge statements and alternative conceptions. I2 demonstrated a correct diagnosis and his attempts to treat were reasonable. However, significant alternative conceptions arose during the simulation. A particular alternative conception was indicated by the attempts to decrease the patient’s heart rate in view of hypovolemia and hypotension. I2 was exposed on multiple occasions to the concept of how the body compensates for blood loss (i.e., increase in heart rate). From the simulation data, I2 may possess faulty knowledge regarding cardiovascular volume adjustments. In addition, I2 did not rely upon hemodynamic parameters to guide administration of fluids and vasoactive medications.

The researcher concluded that I2 was more thorough with his case than I1 was. Both student-participants demonstrated a modest number of correct concepts. However, both possessed significant alternative conceptions that went undiagnosed up to the time of this study.

The researcher compiled a list of all drugs that were encountered by all intermediate student-participants in both simulations (Tables 84-85). Major alternative conceptions were identified by the lack of awareness of drug dosages. Aside from I2 knowing the dosage for albuterol, no other drug dosages were known by the intermediate student-participants. Transcripts revealed student-participants did not know the dose of each drug encountered. This finding disturbed the researcher and will need to be addressed with future course work with students enrolled in the Cardiopulmonary Science program. Although the intermediate group was small, these
data may be transfer to other students undergoing similar instruction while in the Cardiopulmonary Science Program.

Table 81 summarizes most of the major alternative conceptions identified from verbal protocols of both simulation cases. It is clear that there are significant alternative conceptions needing correction. Most were addressed with the study in April 1998 during student-participants' research debriefing. No follow up was done to assure these alternative conceptions were corrected.

The data reported in Tables 79, 80, and 81 suggest that cardiopulmonary simulation software may be effective in the identifying propositional knowledge and alternative conceptions. Possible use of the simulation program with seniors students may be for assessing overall understanding of cardiopulmonary physiologic principles prior to completion of the program so appropriate remediation was provided.

Does the Use of Cardiopulmonary simulation Software Enhance the Learning of Propositional Knowledge in Intermediates?

The researcher assessed the degree of enhancement of learning propositional knowledge by analyzing the number of responses and the follow-up to those responses that the intermediate student-participant did while managing the patient. If I1 or I2 completed a step (e.g., gave a drug) and followed up with assessing its response, the researcher felt enhancement of learning occurred. The numbers of these instances are summarized in Table 84. From this table, most of the student-participant's responses were evaluated and in most cases further adjustments were made. For example after a dose of dopamine was given (Table 84), the drug dosage was adjusted to achieve the
desired response. The researcher concluded that by assessing response and receiving real time feedback, the student-participant may strengthen his understanding of the underlying principles of the case. There are only a few instances that the intermediates did not follow up with assessing response.

Can Cardiopulmonary Simulation Software be used by the Instructor and Learner to Identify Critical Junctures in Understanding and remediation of Alternative Conceptions?

Referring to the critical junctures established for the novice group study, the researcher attempted to determine if simulation performance can help the instructor or learner determine that learning has moved forward successfully through each juncture. Data were compiled from simulation verbal protocols I1 and I2 and categorized under each of the critical junctures (Tables 94-96). Verbal data from student-participants are listed and underlined in these tables. Analysis revealed an incomplete number of propositional knowledge statements to support any evidence that intermediate student-participants moved through each of the junctures. The researcher doubted that the intermediate group were aware of the critical junctures and would have been unable to self-assess their progress using simulation. The incomplete data suggests that simulation software may not be an effective for either the instructor or learner to determine if the learner has passed through teacher-generated critical junctures.

**Final Intermediate Student-Participant Interview**

Tables 86 through 93 summarize interview and concept map data from all intermediate student-participants which focused on assessing oxygen transport and
utilization. These data support the findings in Tables 77, 78, and 79. Interview questions were broken into three sections: (a) assessing a patient's level of oxygenation, (b) assessing tissue oxygenation, and (c) assessing the role the cardiovascular system plays in oxygenation.

Assessing the Patient’s Oxygenation

This question focused on asking the intermediate student-participant how to assess in general terms a patient’s level of oxygenation. The number of propositional knowledge statements were more numerous than what were generated by a similar question to the novice groups. Intermediate learners looked beyond physiologic measurement and included, for example, assessment of work of breathing, capillary refill, breath sounds, patient sensorium, skin color, and patient position. Patel and Groen (1991) describe intermediates as possessing more clinical knowledge than novices and these data results support that claim.

The intermediate student-participants demonstrated a number of significant alternative conceptions with the interview. These included using a limited number of clinical indices to assess oxygenation such as PaO₂ and SaO₂. Additional indices such as shunt fraction, a/A ratio, and a-aD0₂ were not mentioned. Hemodynamics were not mentioned as an assessment of oxygenation. All three intermediate student-participants were unsure of normal values for venous oxygenation and the importance assessing these values.
Assessing Tissue Oxygenation

All three intermediate student-participants emphasized assessing blood flow and hemoglobin levels. There were no mention of assessing organ function, lactate acid levels, and assessing venous oxygenation. More disturbing to the researcher was the inability of any of the intermediate group members to define, describe, or give an example of the four types of hypoxia. It was clear from these data that this group of intermediate learners possessed significant gaps in their understanding of tissue oxygenation. The researcher concluded that these learners were exposed to the same curriculum as the novice groups and were not exposed to concepts associated with tissue oxygenation. However, the researcher assumed that the intermediate group members would problem-solve and be able to define the four types of hypoxia.

Assessing the Role of the Cardiovascular System

None of the three intermediate student-participants were able to answer what role the cardiovascular system plays in oxygenation. This finding suggests that maybe the intermediates were unsure what the researcher was asking or they actually did not know the role this system plays in providing oxygen. The researcher felt this finding needed exploration concerning why the uncertainties and gaps existed in senior students. A possible reason for such a finding is the lack of integration of pulmonary and cardiac physiology and the tendency of the researcher to teach these sections as separate entities. In addition, emphasis on the role the cardiovascular system plays in assuring oxygenation may not be emphasized during the cardiovascular technology course work. Regardless, the researcher will need to evaluate the curriculum to identify
changes needed and with follow-up to assure these key concepts are demonstrated by soon-to-be graduates of Cardiopulmonary Science.

Limitations of this Research

Results from this research are limited due to the use of the small number of student-participants studied. Although results from this study have significant implications for educators, the results can only be applied to this study group cardiopulmonary science students.

The program was written by a physician (Samsel, 1994) for teaching advanced physiology, the researcher found the science related to the eight simulation topics to be accurate. However, since this program has not been validated by clinical studies, results from this study must be considered limited to these student-participants.
CONCLUSIONS

Understanding how students learn and problem solve in a variety of contexts is a major focus of cognitive theories. Theories of meaningful learning, information-processing, and constructivism are examples of frameworks from which educational research arises. Results from such research can guide teachers to be more effective in the classroom and to help to assure learning takes place. It was the goal of this research to add to the body of cognitive science the effects of using simulation as a heuristic for understanding oxygen transport and utilization.

Research on use of simulation indicates the varieties of cognitive strategies enacted by students in complex situations and the range of differences between novices and intermediate learners help validate the use of this instructional format as an example of constructivism. Simulation offers the teacher and learner alternative means for building knowledge and assessing what the learner knows and what the teacher should teach.

This study looked at how learners interacted with an advanced simulation program to assess conceptual development and to diagnoses alternative conceptions. Results of this study support the knowledge claims cited by Mintzes, Wandersee, and Novak (1997) to better understand why discrepancies occur between what the learners learn and what the teacher teaches. Use of simulation was successful in identifying preconceived ideas, misunderstandings, and alternative conceptions while providing the researcher with information to promote better conceptualization among learners in a cardiopulmonary physiology and advanced respiratory care courses.
Using a small group of participants, this study was able to focus on several key questions regarding the effective use of simulation. A small group helped determine whether the desired effects occurred and the nature of undesired effects. Use of small groups of learners to determine actual behavior or response to experimental teaching design is a long-standing and accepted tenet of instructional design research (Gredler, 1996).

The results of this study support the use of simulation software as an effective means of identifying conceptual development and to diagnose problems and gaps in knowledge that learners may possess. This study suggests the use of simulation along with other assessment tools such as clinical interview and concept mapping can be helpful in guiding teachers to plan instruction to minimize these gaps and alternative conceptions that arise during a course or series of courses.

Simulation software was successful in identifying what novice and intermediate learners knew about area of oxygen transport and utilization in humans. The researcher is confident that the use of simulation may also be effective in other knowledge domains.

Results from this study indicated that the use of simulation software in this study group was unsuccessful in diagnosing whether the student-participant progressed through the identified critical junctures. Use of other data collecting techniques such as interview and concept mapping may be more effective. Additional research will be necessary to determine the role these techniques play in identifying critical junctures.
Sequencing the use of simulation software may not be as critical in augmenting conceptual development as much as an aid in diagnosing what the learner knows. Supporting Ausubel’s call to assess what the learner knows and then teach him/her accordingly, this study supports the use of simulation as a means of assessing propositional knowledge and alternative conceptions in both novice and intermediate learners (Ausubel, 1978). Assessing reasoning skills and knowledge in a specific domain prior to formal instruction and then adjusting instruction as needed may be an appropriate strategy with use of simulation. Conversely, using simulation to assess awareness of the main concepts of complex material just taught may encourage the teacher to provide remediation to the learners.

Results from this study provided the researcher with valuable information concerning what students may or may not be learning in the classroom. Without these data many of the identified alternative conceptions and knowledge gaps may have gone unnoticed in future student groups. Information gained from this study will improve the researcher’s instructional strategies and enable the researcher to attain the original goal of becoming a better teacher of cardiopulmonary physiology.

Implications for future research with simulation include studying small cohorts across several years to determine if findings similar to this research develop. Expansion of the use of simulation prior to lecture with a larger, more diverse group may be useful since, at least in theory, a simulation experience effectively planned could act as an advance organizer. The researcher recommends that future simulation content modules be written to correlate with course content, textbook, and clinical practice. Although the
Simulation exercises used in this study were designed to capture major themes in cardiopulmonary physiology and an advanced respiratory care course, future use of this simulation program may be more effective with a concerted effort to coordinate course content with the textbook and clinical education.

As the knowledge base for medical science becomes increasingly complex, the respiratory care practitioner must be able to apply multifaceted concepts to patient care. Respiratory care educators must respond to this need by improving educational outcomes of professional programs. Results of this study may guide individual teachers to become better prepared to instill knowledge into our students.
REFERENCES


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APPENDIX A
GOWIN'S VEE DIAGRAM OF THE RESEARCH

World Views
(Noval, 1984).
*Once what the learner knows can be determined, the learning experience can be optimally planned
*Better conceptual understanding improves systematic thinking and problem-solving
*Care of the patient with cardiopulmonary disease is optimized by the practitioner who integrates qualitative and quantitative data derived from patient assessment
*Improved clinical reasoning enhances patient care
*Health care providers who can reason, problem-solve, reflect, and explore are an asset to society

THEORIES
*Meaningful learning
*Systems thinking
*Protocol analysis
*Verbal analysis
*Dual-coding theory
*Cardiopulmonary Science
*Stage theory of expertise

PRINCIPLES
*Concepts are patterns or regularities in objects or events
*Concepts are what we think with
*Humans encode information in language or in picture-like representations.

CONCEPTS
*Concepts and propositions
*Meaningful learning
*Human cardiopulmonary system
*Human constructivism
*Respiratory care/cardiovascular technology
*Simulation

Research Question
The nature of the undergraduates' understanding of oxygen transport and utilization in humans: Can cardiopulmonary software enhance learning of propositional knowledge and/or diagnose alternative conceptions in novices and intermediates?

Subquestions
What effects does the use of cardiopulmonary simulation software prior to classroom instruction have on motivation to learn and on initial concept development?

Can the post-instructional use of cardiopulmonary simulation software aid in self-assessing conceptual development and in identifying alternative conceptions?

Can cardiopulmonary simulation software be used by the instructor and students, both novices and intermediates, to identify critical junctures in understanding of concepts associated with oxygen transport and utilization in humans?

Value Claims
(hypothetical).
*Use of cardiopulmonary simulation software will better prepare the practitioner or learner to reason clinically, problem-solve, and provide patient care.

By identifying how learners develop complex concepts and propositions, classroom instruction can be planned and improved accordingly.

KNOWLEDGE CLAIMS
Use of cardiopulmonary software may result in the following effects on learning:
*Learners will learn how to learn cardiopulmonary physiology
*Learners will increase their scientific explanatory skills
*Learners will show evidence of growth in pattern recognition
*Alternative conceptions about the cardiopulmonary system function can be identified and addressed
*Learners will integrate cardiopulmonary variables involved with oxygen transport and utilization, and be willing and able to apply such concepts to patients with lung and/or heart disease

TRANSFORMATIONS
*Pre- and posttest scores
*Comparison of participants' response to expert-validated simulation responses
*Coded verbal data from transcripts and verbal protocols of student-participants at key stages during study
*Coded verbal, written, and fieldnote data of classroom activities
*Table of emerging alternative conceptions and critical juncture

(appendix continued)
OBJECTS/EVENTS
*Cardiovascular Science students were grouped by prior knowledge into novice and intermediate categories
*Novice Group A experienced and responded to preinstructional simulation software
*Novice Group B experienced and responded to postinstructional simulation software instruction and assessment
*Novice Groups A & B were interviewed and performed think-aloud protocols for identifying alternative conceptions and critical junctures
*Alternative conceptions were addressed via instruction for novice groups
*Novice groups were posttested with simulation software
*Intermediates were assessed with simulation software, with their alternative conceptions identified and addressed
*Intermediates confronted a novel problem via simulation software to assess understanding of cardiovascular concepts being studied

TRANSFORMATIONS CONTINUED
*Statistical analysis of pre-and-posttest scores (ANCOVA)
*Concept maps resulting from postsimulation exercises
*Tabulated poststudy questionnaire responses from research participants
*Verbal data (i.e., fieldnotes) from debriefing
APPENDIX B
SAMPLE OF PANEL DISPLAYS FROM SIMBIOSYSTM PHYSIOLOGY LABS

Tabs across the bottom of the screen are used to select other views.

(appendix continued)
The patient is a normal weight, alert man. His complexion shows no pallor. Vital Signs: HR 78, BP 101/71, RR 11, Temp 37°C. The pulse is regular at a rate of 78. Examination of the head reveals no unusual findings. Breathing is shallow. The extremities appear normal. The abdomen is nondistended.

Time Stamped Results from Individual Examinations

Move back to the prior or to the home level
Select clinical and/or physiological parameters for display.
Select numerical values, waveforms or curves for display.
The Standard Concept Map Checklist

<table>
<thead>
<tr>
<th>Questions</th>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td>1. Does the map contain seed concepts?</td>
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<td></td>
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<tr>
<td>2. Are all the links between concepts precisely labeled?</td>
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<td>3. Does the map have labeled cross-links?</td>
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<tr>
<td>4. Does the map contain examples (preferable novel examples)?</td>
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<td>5. Is the map treelike instead of stringy?</td>
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<tr>
<td>6. Is the superordinate (top) concept the best, given the way the rest of the concepts are linked?</td>
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<td>7. Are the examples included appropriate?</td>
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<td>8. Is the map of acceptable scientific quality?</td>
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<td>9. Has the mapper used the proper map symbols and followed standard mapping conventions?</td>
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<tr>
<td>10. Is the map limited to approximately 12 elements?</td>
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**Total**
(5 points per question possible for a total of 50 points)
RESULTS OF THE PILOT STUDY

Three of the data gathering activities for this research were piloted during the 1997 Summer Semester. Three student-participants agreed to participate in this limited pilot study. The student-participants were classified as Junior Cardiopulmonary Science students and were enrolled in CPSC 3400 Clinical Applications and Procedures III, which is clinical instruction in the intensive care units at LSU University Hospital:

This pilot study focused on the following activities:

1. concept mapping of researcher-generated seed concepts;
2. running a simulated patient case with the SimBioSys® program; and
3. doing pre-and postinterviews on the topic.

Activity One

Each of the three student-participants had experience with constructing concept maps during the Spring 1997 course work. Although these student have not completed about ten maps, which is considered necessary for competency with map making (Minzes, Wandersee, and Novak, 1997), the researcher judged that they possessed sufficient experience to create a satisfactory map.

The researcher selected topics related to cardiac blood flow and hemodynamics (a subjunction oxygen transport). This topic was also chosen due to the student clinical assignment, where these concepts had just been, in part, addressed and discussed (relevant to patients being cared for in an intensive care unit). As a result, the researcher assumed that concepts relating to cardiovascular function would be fresh on the student minds.
To create a concept map, the following seed concepts were provided to each student-participant:

1. preload;
2. afterload;
3. cardiac output;
4. blood flow;
5. arterial blood pressure;
6. right atrial pressure;
7. pulmonary capillary wedge pressure;
8. pulmonary arterial blood pressure; and
9. heart rate.

Student-participants reviewed (under the researcher's guidelines) the purpose of concept maps, techniques of construction, and how maps are evaluated. The researcher used map evaluation strategies as outlined by Novak (1984) for each of the three created maps. All three concept maps revealed several alternative conceptions (identified below).

Student-Participants

Student-participant S's map revealed the better understanding, with both actual mapping and the topic being discussed. His map contained the least number of alternative conceptions. The following assessment form was used to evaluate his concept map:
<table>
<thead>
<tr>
<th>Criteria</th>
<th>Assessment of c-map</th>
<th>Score (points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propositions</td>
<td>18 connected concepts</td>
<td>18</td>
</tr>
<tr>
<td>Hierarchy</td>
<td>3 levels</td>
<td>3</td>
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<tr>
<td>Cross-links</td>
<td>11 valid cross links</td>
<td>110</td>
</tr>
<tr>
<td>Examples</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Notes</td>
<td></td>
<td>131 total points</td>
</tr>
</tbody>
</table>

Student-participant S had difficulty with creating appropriate cross-linking words. For example, he connected the term “hemodynamics” with “blood flow” with the words, “has to do with”. His map revealed the concept “stroke volume” lower on the hierarchy than “determinants of stroke volume” (i.e., preload, afterload). Stroke volume is a more general term and should be located higher in the map. “Right atrial pressure” was connected to “pressure” with the link “may be”. Overall, student-participant S had a good grasp of the concept of hemodynamics as exemplified by a well done concept map.

A sample of interview questions derived from student-participant S's map are listed below with sample responses (underlined statements represent alternative conception):

1. Tell me what is the relationship between blood flow and cardiac output?
   “Blood flow is necessary for cardiac output...it is blood flowing out of the heart. _Blood flow depends upon heart rate_

2. What relationship exists between cardiac output and pressures?
   “Pressures are responsible for cardiac output”

3. Can you be more specific?
   “Cardiac output or blood leaving the heart is pushed out by
the pressure from the ventricles. I imagine that as pressure increases, so will blood leaving the heart.”

Student-participant S then was asked to complete a “Student Laboratory Exercise” as found in the SBS manual. This researcher selected the E2-Cardiac Function Exercise from the simulation program. Full description of this is available in the simulation program operator’s manual.

Following successful completion of the E2 Exercise, the student-participant was able to answer study questions 1-5 to the satisfaction of the researcher. However, to complete the exercise, the student-participant required some assistance with clarification or explanation of questions or concepts presented in various steps of the exercise. Specifically, this student-participant was unfamiliar with pressure-volume loops and calculating left ventricular end-diastolic volumes. Furthermore, he was unsure of the concepts of ventricular compliance, changes in slope of the end-diastolic pressure-volume relationships, and why cardiac output changes with the administration of Nitroprusside (indicating his uncertainty with the effects of this drug).

Student-participant S did grasp the concept of ventricular filling/preload and stroke volume as he correctly completed worksheet 3 without assistance. This is a difficult concept students struggle to understand (i.e., as preload increases, stroke volume potentially can increase, delivering increased blood flow, thus oxygen, to the tissues). This concept was a focal point of the study by Patel and associates (1989) regarding misconceptions about heart failure.

Student-participant S’s comments were favorable towards seeing many of the concepts he has learned in previous course work “come alive” with a simulated patient.
He was able to see relationships he “has not seen before.” Following the exercise, student-participant S engaged a simulated patient using SimBioSys™ Physiology Labs (Samsel, 1994). A patient with respiratory failure was chosen and the student-participant managed him with regard to placing the patient on mechanical ventilation, assuring oxygenation, and administering appropriate drugs and fluids. As the simulation unfolded, his comments were recorded. The researcher had difficulty in getting this student-participant (and the other two student-participants) to “think-aloud”. This component of the project was needed to be practiced by the participants in order for them to deliver what is expected. Despite their limited verbalization, the recordings revealed appropriate decision making initially to stabilize the patient and assure oxygenation. As the simulation continued, the patient’s condition worsened and the student-participant required assistance to “manage” the patient. This was a result of both the student-participant’s unfamiliarity with the simulation program and his uncertainty about the treatment concepts. It was this researcher’s impression that if S were better acquainted with the actual layout and function of the simulation, he would have performed better. It was evident that participants required an orientation to the program prior to testing or evaluation.

Other observations by the researcher about how student S used the resources available to him in the program included choosing a minimal number of diagnostic and lab tests, obtaining a single chest x-ray (no repeat x-rays to assess effects of therapy), and making no attempts to complete a thorough cardiopulmonary physical exam. These steps are standard in the care of the type of patient presented in the simulation.
The researcher anticipated this simulation program could address several key questions such as: (a) why users fail to acquire sufficient information to manage a patient, (b) what faulty propositions exist in the users knowledge, (c) what is lacking in the understanding of management and treatment options, and (d) what aspects of the patient's disease process are learners uncertain with? It became obvious which aspects of the patient's management and treatment the student-participant was comfortable with, and those aspects that he was not.

Debriefing the users following the simulation aided their understanding of the patient cases. However, the intent of this study was to diagnose conceptual development and identification of alternative conceptions using the cardiopulmonary simulation program—thus prohibiting use of the program to debrief the user immediately following completion of the simulation. Study subjects were encouraged to repeat the simulation and discuss management strategies with the researcher following completion of this study.

Following the simulation exercise, student-participant S was re-interviewed with the same questions used previously. In addition, questions were included about decisions made during the simulation and inquiries were made into the student-participant's perception of the simulation program, screen interface, and the applicability of using this program as a learning tool.

Results of the interview revealed an overall better understanding of the concepts found in the exercise E2. In addition, questions his about decision making raised several concerns for this researcher. The student-participant's understanding of drugs to manage
cardiovascular dynamics was lacking, what fluids to administer and how much to give was also an area of uncertainty, and the static curve viewers supplied as an option in SimBioSys™ (Samsel, 1994) were not used as a management tool. Comments about the use of SimBioSys™ was favorable and student-participant S stated that he felt it was an effective teaching tool.

The student-participant was a 22-year-old male who is in the upper quarter of his class, in terms of academic achievement and GPA. The findings of this brief pilot study with this particular student-participant alarmed this researcher, for he assumed prior to this pilot, that this student had mastered many of the concepts related to care of the cardiopulmonary patient that are included in various courses within the Cardiopulmonary Science curriculum. Instead, a number of the alternative conceptions revealed appearing in both the exercise and simulation were identified.

Student-participant S (as with the other two student-participants) did not create a post-exercise/simulation concept map. This researcher felt that adequate information was derived from the single map, interviews, and SimBioSys™ (Samsel, 1994) program to end this pilot study at the completion of the second interview.

**Student-participant K**

Student-participant K underwent the same procedure that student-participant S experienced with her initial concept map was evaluated:
<table>
<thead>
<tr>
<th>Criteria</th>
<th>Assessment of c-map</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Propositions</td>
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<tr>
<td>Hierarchy</td>
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<td>4</td>
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<tr>
<td>Cross-links</td>
<td>6 valid cross links</td>
<td>60</td>
</tr>
<tr>
<td>Examples</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Notes</td>
<td></td>
<td>78 total points</td>
</tr>
</tbody>
</table>

Student-participant K became frustrated with concept mapping, and required encouragement and assistance. Her concept map revealed several significant alternative conceptions that could impede further learning of more complex concepts. For example, K reflected in her map that “heart rate” is derived from “stroke volume” and “PCBP” is a result of “PVR.” Furthermore, she thought that “afterload” in the lungs results in “SVR” and “ABP.” These are all faulty propositions that need modification to continue to build upon this student-participant’s basic understanding of hemodynamics.

Post concept map interviewing and completion of both the exercise and the simulation revealed further alternative conceptions and faulty clinical reasoning.

This student-participant was assigned the SimBioSys™ Physiology (Samsel, 1994) exercise E3—Control of Cardiac Output. Student-participant K required more time to complete the exercise than S did, and asked more questions. Furthermore, she required additional assistance with completing the simulation (a 66-year-old male with chronic lung diseases). Again, this may be, in part, a result of her being unfamiliar with the program itself.

As with student-participant S, student-subject K failed to gather sufficient...
information to adequately manage a simulated patient suffering from chronic obstructive lung disease. In addition, she failed to choose correct medication, know proper drug dosages of those drugs she did choose, and know how to assess the effects of such agents.

**Student-participant M**

Student-participant M performed poorly on most components of this pilot study. It became evident that M possessed significant alternative conceptions. Her concept map revealed, for example, she thought the ability of the heart to contract depends upon "heart rate" and she failed to use the concepts of preload and afterload, which are key concepts under the construct of "hemodynamics".

Her map's analysis revealed the following:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Assessment of c-map</th>
<th>Score (points)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Propositions</strong></td>
<td>11 connected concepts</td>
<td>11</td>
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<tr>
<td><strong>Hierarchy</strong></td>
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<td><strong>Cross-links</strong></td>
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<tr>
<td><strong>Examples</strong></td>
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<td>0</td>
</tr>
<tr>
<td><strong>Notes</strong></td>
<td>59 total points</td>
<td></td>
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</tbody>
</table>

Interview data also revealed faulty understanding. Completion of the laboratory exercise E4 --Autonomic Circulatory Control in SimBioSys™ Physiology Labs [Samsel, 1994 #274] was difficult for M to complete without assistance. She was only able to partially complete the associated study questions.
Student-participant M was assigned a simulated case dealing with an asthmatic patient, and she initially treated the patient with appropriate drugs and oxygen. But she failed to recognize the importance of a physical examination and the placement of an arterial line for blood pressure monitoring and blood sampling. She intubated the patient without attempting pharmacologic treatment first. Once the patient was placed on the mechanical ventilator, she was unsure of patient parameters to establish safe and effective artificial ventilation. These observations represent a sample of data collected during this pilot study.

Student-participant M revealed significant alternative conceptions that were alarming to this researcher. At this point of this student’s education, this degree of faulty reasoning should not be present.

Implications of this Pilot for the Researcher’s Dissertation Research

It was anticipated, from this limited pilot study, that the SimBioSys™ program (Samsel, 1994) can help identify users’ faulty propositions and alternative conceptions. Data derived may aid in planning effective remediation of participants in the study and provide valuable information for planning future course content, selecting teaching strategies, and the suggesting the role plays in a cardiopulmonary physiology course.

Identified Limitations of Research Project from Pilot Activities

It was evident that the intermediate students had difficulty just orientating to the SimBioSys™ program (Samsel, 1994). Leaving students alone to self-direct themselves through both the exercises and simulations may be unrealistic. A better option is to provide a thorough orientation to the program prior to data collection.
The time required to complete the data gathering was extensive. To limit the number of hours student-participants will be required to participate, part of the study (concept mapping) can be completed within the assigned course times. Additional work may be completed at the completion of the school day. Cardiopulmonary Science students are held accountable to 4:00 p.m. Monday thru Friday, with classes typically ending around 3:00 p.m. This will allow sufficient time for participants to complete the research exercises on school time.

Other considerations, as a result of this pilot, were choosing the grain size for the verbal data, determining the length of segmentation, and organizing the data to enter it into the NU*DIST™ (Richard, 1996)and Q-Note™ (Brackett, 1997) Programs. This researcher anticipated using larger grain analysis with segmentation of verbal data that include several sentences and concepts, to better evaluate why a student-participants are thinking, what they are thinking and to better assess concept formation and clinical reasoning.
APPENDIX E
INSTITUTIONAL REVIEW BOARD APPROVAL FORM

LOUISIANA STATE UNIVERSITY
MEDICAL CENTER - Shreveport
Institutional Review Board for Human Research (IRB)

INITIAL REVIEW OF PROTOCOL:
REPORT OF COMMITTEE ACTION

Location or Source of Subject Population
☒ LSUMC-S ☐ VA ☐ BOTH ☐ Other

If protocol includes VA patient, VA R&D Committee must review and approve protocol prior to entering VA patients.

Project No.: #97-536

Project Title: The Nature of Undergraduates' Conceptual Understanding of Oxygen Transport and Utilization in Humans: Can Cardiopulmonary Simulation Software Enhance Learning of Propositional Knowledge and/or Diagnose Alternative conceptions

Principal Investigator: Dennis R. Wissing, M.D.

This is to certify that the Institutional Review Board for Human Research reviewed the above project on 08/12/97. The IRB has evaluated the project in accordance with the guidelines established for activities involving human research subjects.

Recommendation of Institutional Review Board: Approved by Exemption.

Comments or required modifications:

Dr. Wissing requested exception under category 2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: a. Information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; b. Any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' final standing, employability, or reputation. Brief Description: This study will explore the use of an interactive computer-based simulation program as a teaching aid in an undergraduate cardiopulmonary physiology course. The simulation program, Simbiodys (Critical Care Concepts, Chicago, IL), will be evaluated for its effectiveness as a pre-and-post instructional tool for the development and monitoring of conceptualization and understanding of transport and utilization.

If revisions are required, they should be submitted to the Office of Grants Administration for review and approval by the IRB Chairman before proceeding with this study.

Signed: R. Oliver Satter, M.D.
Chairman, Institutional Review Board
Addendum

August 12, 1997

To: Institutional Review Board

From: Dennis R. Wissing

Re: Confidentiality of study participants

Student participant's name will not be used, recorded, or published in any manner during or following this proposed study. Each participant's name will be coded and remain anonymous.
APPENDIX F
PARTICIPANT PERMISSION FORM

Louisiana State University Medical Center - Shreveport
Institutional Review Board for Human Research

CONSENT FORM

Project title:
The Nature of the Undergraduate's Conceptual Understanding of Oxygen Transport and Utilization in Humans: Can Cardiopulmonary Simulation Software Enhance Learning of Propositional Knowledge and/or Diagnose Alternative Conceptions in Novices and Intermediates?

This Consent Form gives detailed information about the research study which you have been asked to participate in. You may decline participation or withdraw from this study at anytime.

PURPOSE OF STUDY AND SELECTIONS OF SUBJECTS

1. You are invited to participate in a research study of an educational research study examining how Cardiopulmonary Science students develop concepts about oxygen transport and utilization.
2. This researcher hopes to learn how student best learn the concepts related to oxygen transport and utilization in an effort to improve instructional strategies in Cardiopulmonary Science.
3. You were selected as a possible participant in this study due to the course you are currently enrolled in (Cardiopulmonary Physiology) or the progress you have achieved in the Cardiopulmonary Science program (senior student).
4. If you choose to participate, you may experience the following results:
   a. Increased understanding of cardiopulmonary physiology
   b. Improved problem solving skills and clinical reasoning with the care of the patient with pulmonary and/or cardiac disease
   c. Improved study skill
5. Participation in this study will not adversely influence your grade for any course in the Cardiopulmonary Science curriculum.
6. You can expect a minimum of one hour a week for eight weeks (a percentage of this time will be included in the scheduled time for the Cardiopulmonary Physiology course. Other time will be on your own time.
7. Questions or comments should be directed to the principle investigator: Dennis R. Wissing, MHS, RRT. Phone 318-675-6814.

Signature of participant ___________________________ Date __________

Signature of Principle Investigator ___________________________ Date __________
APPENDIX G
CARDIOPULMONARY PHYSIOLOGY PRE- AND POSTEST

This test is a sample of questions related to anatomy of the respiratory system and the mechanics of ventilation. It is to assess your entry-level understanding of cardiopulmonary physiology. Results of this test will aid in planning course content. This test will not effect your course grade.

8. At the end of an expiration the natural tendency of the lungs and thorax is for the:
   a. Lungs and thorax to expand outward
   b. Chestwall to recoil outward and the lungs recoil inward
   c. Lungs to remain static and the chestwall to expand outward
   d. Chestwall and lungs to recoil inward

2. Which of the following statements best describes lung compliance?
   a. The willingness of the lung to expand
   b. Friction to the flow of gas
   c. Elasticity of the lung
   d. Pressure generated during breathing

3. Airway resistance is increased when:
   a. Compliance of the lung increases
   b. Gas viscosity decreases
   c. Length of the airway shortens
   d. Airway diameter decreases

4. Which of the following statements are true regarding pleural pressure?
   a. During inspiration, pleural pressure becomes slightly negative
   b. Pleural pressure always remains negative during quiet breathing
   c. Following a forceful cough, pleural pressures become negative
   d. Pleural pressures and alveolar pressures are equal during inspiration

5. At the end of a normal expiration, the amount of air in the lungs is called:
   a. Tidal volume
   b. Residual volume
   c. Expiratory reserve volume
   d. Functional residual capacity
6. As lung volume increases, surface tension in the alveolus will increase
   a. True
   b. False
   c. Remains the same

7. As lung elastance increases, lung compliance will:
   a. Increase
   b. Decrease
   c. Remain unchanged

8. As the volume-pressure curve flattens, the lungs become:
   a. More compliant
   b. Less elastic
   c. Stiff or less compliant
   d. Less resistive

9. As the functional residual capacity decreases, which of the following will occur?
   a. Arterial carbon dioxide levels increase
   b. Respiratory rate will decrease
   c. Lung compliance will increase
   d. Blood oxygen levels tend to decrease

10. Normal oxygen tension of air entering the lung is about what?
    a. 50 torr
    b. 100 torr
    c. 150 torr
    d. 760 torr

11. As alveolar ventilation increases PaCO₂ will:
    a. Decrease
    b. Increase
    c. Remain unchanged

12. When ventilation is in excess of blood flow what ventilation-to-perfusion abnormality is present?
    G. Deadspace
    H. Shunting
13. As deadspace increases and alveolar ventilation remains unchanged, arterial CO₂ will:

a. Decrease
b. Increase
c. Remain unchanged

14. Pulmonary circulation can best be described as:

a. Low pressure vessels that carry blood with low oxygen content
b. Vessels under high pressure going away from the heart
c. Vessels that carry oxygen to the tissues
d. A blood reservoir

15. Oxygen is transported by:

I. Attached to hemoglobin
II. Dissolved in plasma
III. Bound to the red blood cell
IV. Lipid molecules in the blood

a. I,II
b. I
c. III
d. IV

16. Which of the following variables has the greatest influence in oxygen content?

I. Blood volume
II. Hemoglobin levels
III. PaO₂
IV. SaO₂

a. I,II
b. III,IV
c. II,IV
d. I,III

17. Normal oxygen content of arterial blood is what?

a. 1 mL/kg
b. 20 mL/dL
c. 250 mL
d. 1000 mL/dL
18. As cardiac output decreases mixed venous oxygen levels tend to:
   a. Decrease
   b. Increase
   c. Remain unchanged

19. Preload of the ventricle is defined as:
   a. Filling volume during diastole
   b. Resistance to ventricular ejection
   c. Blood remaining in the ventricle at end-systole
   d. The size of the ventricle of the heart

20. Afterload is best described as:
   a. Filling volume during diastole
   a. Resistance to ventricular ejection
   b. Blood remaining in the ventricle at end-systole
   c. The size of the ventricle of the heart

21. An increased in intravenous fluid can result in which of the following?
   a. A reduction in afterload
   b. An increase in Preload
   c. An elevated heart rate
   d. A decrease in ventricular contractility

22. Normal oxygen consumption by tissues per minute is about:
   a. 100 mL
   b. 250 mL
   c. 1000 mL
   d. 2500 mL

23. Oxygen dissociation curve demonstrates a linear relationship between how well hemoglobin saturated with oxygen and the PaO₂
   a. True
   b. False

24. Oxygen consumption is independent of blood volume at any blood flow rate.
   a. True
   b. False
25. By-product of cellular respiration is what?
   a. Lactate acid
   b. Oxygen
   c. Carbon dioxide
   d. Hydrogen

26. As carbon dioxide levels increase, pH will:
   a. Decrease
   b. Increase
   c. Remain unchanged

27. As intrapulmonary shunting occurs, the primary blood gas value to decreases is:
   a. PaO₂
   b. PaCO₂
   c. HC0₃
   d. pH

28. Pulmonary surfactant results in which of the following?
   a. Increased respiratory rate
   b. Altered pulmonary blood flow
   c. Reduced PaO₂
   d. Decreased surface tension

29. At end-expiration, alveolar pressures are about:
   a. + 1.0 CMH₂O
   b. -5 CMH₂O
   c. -2 CMH₂O
   d. 0 CMH₂O

30. As the patient’s functional residual capacity decreases, which of the following tend to occur?
   a. Tidal volume increases
   b. Pulmonary elastance decreases
   c. Lungs become less compliant
   d. Respiratory rate is reduced

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APPENDIX H
PRE- AND POSTLECTURE INTERVIEW

Subject______________
Date________________

1. Describe how the lungs and thorax works together to accomplish an inspiration and expiration.
2. Why is the oxygen tension less in the alveoli than that of inspired air?
3. If deadspace increases and alveolar ventilation remains unchanged, what occurs with arterial carbon dioxide levels?
4. If a person breathes 100% oxygen, nitrogen is washed out of the lung. This process usually takes about 7 minutes. If nitrogen washout takes longer than 7 minutes, what could cause this?
5. Can you tell me the difference between lung compliance and airway resistance?
6. Describe the anatomical and physiological differences between pulmonary and systemic circulations.
7. Describe the events that takes place during gas exchange across the alveolar-capillary membrane.
8. Tell me the two ways oxygen is carried in blood.
9. How does the cardiopulmonary system initially compensate for low levels of arterial oxygen?
10. How can you determine if the patient has adequate oxygen?
11. What effects does an increased in carbon dioxide have on arterial pH?
12. How does the body compensate for an increase in metabolic acid (e.g., lactate)?
13. What is responsible for the normal stimulus to breathe?
14. What is hyperventilation?
15. Can you tell me the difference between a shunt and deadspace?
16. Briefly trace the flow of blood from the right atrium to the left ventricle.
17. Can you describe what occurs in the lung if the left ventricle fails to pump adequately?
18. What effects would arteriole constriction potentially have on stroke volume?
19. Can you describe the Frank-Starling mechanism?
20. Can you define preload and afterload of the heart?
APPENDIX I
SAMPLE SIMULATION GUIDE

SimBioSys® Physiology Lab exercises
Lung Mechanics

Purpose of the exercise

To evaluate the effects of changing lung compliance on volume-pressure curves of the thorax, lung, and combined lung and thorax. In addition, to assess the effects of altered lung compliance on functional residual capacity (FRC).

Pre-simulation concepts and relationships to understand prior to beginning the exercise:

1. Compliance is the willingness to expand. There are three different compliances for the RCP to consider:
   1. The compliance of the thorax;
   2. The compliance of the lungs and
   3. Combined thorax and lung compliance—often referred to as “total compliance” or “respiratory system compliance.”

Normal values for total compliance is 100 mL/CMH₂O

The RCP can visualize total compliance by creating a volume-pressure curve that plots volume on the Y axis to pressure within the lung/thorax on the X axis.

This exercise will illustrate volume-pressure curves for all three compliances—as listed above.

The flatter the lung compliance curve is, the less compliant the lungs are.
The flatter the thoracic compliance curve, the less compliant the thorax is.
The flatter the total compliance is, the less compliant the lungs and/or thorax are(is).

Compliance when plotted graphically, can be assessed by the slope of the graph.

As the lungs becomes more elastic (i.e., increased elastance), compliance decreases. In other words, as compliance decreases, elastance increases (and visa versa).
Another example of such a relationship, is airway resistance (AWR) and its relationship to airway conductance. As airway resistance increases, airway conductance decreases (and visa versa).

As the amount of alveolar surfactant decreases, lung compliance decreases. Various lung diseases result in a loss of pulmonary surfactant.

End-expiratory lung volume represents the amount of gas in the lung at end-expiration. This gas volume (which is actually a capacity consisting of the residual volume and expiratory reserve volume) is equal to the functional residual capacity (FRC). If the end-expiratory volume is greater than FRC, the patient is trapping air. Air trapping occurs with various lung diseases and rapid respiratory rates.

Minute volume is the amount of gas (air) that a person moves in and out of the lungs per minute. Normal minute volume is 5 liters per minute (LPM).

**Instruction to begin the exercise using the simulation program**

1. Go to File and “load case E7.”

2. A variety of smaller windows (called viewers) will be seen—minimize all windows except: Measurement, Lung Mechanics, and Lung Volumes:
   * Minimize the “EKG” monitor box
   * Minimize the three color graph
   * You will see three black and white graphs appearing in the back of all the windows on the desktop. Click the right mouse any where within one of these graphs and these graphs will move to the top of the desktop. Using the right mouse, click anywhere within the graph
   * Minimize Clinical Tools

3. At this point, there should be four windows left on the desktop:
   a. Measurements;
   b. Lung Mechanics;
   c. Lung Volumes, and
   d. Three colored graph.

4. Click on the “blue plus sign” found in the toolbar—upper left hand corner of the screen.

5. Click on the words “Lung Mechanics” found on the left side of the viewer

6. A list of available parameters will appear on the right side of the viewer.

7. Click once on the following:
   a. Lung surfactant;
b. Minute volume, and
c. RS compliance.

8. Click “Finished”.

9. Arrange all windows on the desktop convenient for viewing.

To begin the exercise:

1. Note the shape of the volume-pressure curves for the thorax, lungs, and respiratory system.

2. List the initial values for each variable listed in the table below. As the exercise continues, you will be listing values in each of the columns:

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>End-Expiratory Volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End-Expiratory Pleural Pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Airway Pressure (PAO)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lung Surfactant</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minute Ventilation</td>
<td></td>
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<tr>
<td>Lung Elastance</td>
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<td>Airway Conductance</td>
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<td>FRC</td>
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<td>RS Compliance</td>
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3. Look at the desktop—click on “Lung Elastance”—note that on the toolbar several red arrows appear. Click on the larger down arrow and lower the lung elastance to about .5 or .6 (may need to fine tune the number with the smaller red arrow).
4. What occurs with the three colored graph:

5. List new numerical numbers for the variables in the above table in column A- What changed and why?

6. Increase the lung elastance level (recall, this will decrease RS compliance) to 8.0.

7. List new numerical numbers for the variables in the above table in column B-What changed and why? Note change in the shape of the volume-pressure curves.

7. Decrease lung surfactant (while keeping lung elastance at 800) to .50.

8. List new numerical numbers for the variables in the above table in column C-What changed and why? Note change in the shape of the volume-pressure curves.
APPENDIX J
EXPERT PANEL

1. Steven Conrad, MD, Ph.D.
   Professor of Medicine
   Director of the Medical Intensive Care Unit
   Director of Department of Emergency Medicine
   LSU Medical Center
   Shreveport, Louisiana

2. Terry S. LeGrand, Ph.D., RRT
   Cellular and Molecular Physiologist
   Assistant Professor
   University of Texas Health Science Center At San Antonio
   &
   Director of Clinical Education
   School of Allied Health Sciences
   Department of Respiratory Care

3. Diana Merendino, MHS, RRT
   Program Director
   School of Respiratory Therapy
   Bossier Parish Community College
   Bossier City, Louisiana
   &
   Assistant Professor
   LSU Medical Center
   School of Allied Health Professions
   Department of Cardiopulmonary Science
APPENDIX K
SILENT INTERVIEW WITH DIAGRAM PROVIDED TO THE NOVICE GROUP TO LABEL GAS PRESSURES
APPENDIX L
SAMPLE CONCEPT MAPS CREATED BY KI and K2
OXYGEN TRANSPORT begins with INSPIRATION

in which OXYGEN enters the ALVEOLI
diffuses across BLOOD into ACM
dissolved in Plasma, attached to Hemoglobin

carried to Tissues
carried to Perfusion

is called Deadspace

is called SHUNT

where CO2 exists the body

without Ventilation
APPENDIX M
SILENT INTERVIEW USING HEMODYNAMIC CASE HISTORIES

Case #1

A 60 year-old man comes to the emergency department (ED) complaining of severe chest pain. Past medical history includes a MI three years ago. He is pale, sweating, and anxious. Vital signs were BP 130/80 torr, HR 100 BPM, and RR 16 BPM. He was admitted to the ICU with the diagnosis of a possible acute MI. Two hours later his BP drops to 100/75 torr (MAP 83.3), HR increased to 125/minute and RR 22 b/min. His skin was cold and clammy. Bilateral early inspiratory crackles were heard with auscultation. A PA catheter was placed with the following measurements: RAP 8 torr, MPAP 31 torr, PCWP 23 torr, cardiac output is 3.5, and cardiac index 2.2 m². Room air PaO₂ was 60 torr and SVR was 1630 dynes/sec/cm⁵. Urine output was only 50 mls past two hours.

Case #2

56 year-old female post-operative patient is in the SICU following trauma from a motor vehicle accident. She has several IV’s, is semi-alert, and vital signs are: BP 130/99, HR 133 B/M, RR 23 B/M. Measurements from the PA catheter are RAP 16 torr, PAP 44/29 torr, PCWP 22 torr, and cardiac output 8.2 LPM. Skin is warm.

Case #3

23 year-old male arrived to the ED following a gun shot to the chest. Initial examination revealed a right hemopneumothorax. He was intubated and placed on the Servo 300 ventilator. A chest tube was placed and blood gases obtained. Vital signs were: BP 100/60 torr, HR 144 B/M, and RR 33 B/M. A PA catheter was placed with the following measurements obtained: CVP 2 torr, PAP 18/8 torr, PCWP 6 torr, and cardiac output 3.8 LPM. His skin was cold and clammy. No urine output for the past 1.5 hours.

Case #4

55 year-old male arrives to the MICU from a medical/surgical floor (admitted the prior week with LLL pneumonia). Due to respiratory distress and carbon dioxide retention, he requires intubation and is placed on a mechanical ventilator. A PA catheter is placed along with an arterial line. The following data were obtained by the RCP: BP 100 torr, HR 133 B/M, Temp 39.9 degrees C, RAP 6 torr, PAP 30/20 torr, PCWP 5 torr, cardiac output 8 LPM, SVR 400 dynes/sec/cm³, SvO₂ 83%, PaO₂ 55 torr, and FiO₂ 50%.
Dennis Robert Wissing was born on February 11, 1954, in Vincennes, Indiana. He attended Rivet High School and graduated in 1972. Upon graduating from high school Mr. Wissing enrolled in general studies at Vincennes University. While a full-time student he became interested in respiratory care. In 1994 Mr. Wissing enrolled in the first respiratory therapy class at Vincennes University. While a full-time respiratory therapy student, Mr. Wissing was employed at the Good Samaritan Hospital in Vincennes, Indiana, as a respiratory therapist. He graduated with an associate degree in respiratory therapy in 1976 from Vincennes University. Mr. Wissing successfully earned his professional credential in respiratory therapy by becoming a registered respiratory therapist in 1976.

Mr. Wissing continued his professional education in respiratory therapy by pursuing a baccalaureate degree in respiratory therapy from Kansas City Medical Center in Kansas City, Kansas. Upon graduation in 1978 he began full-time employment at Trinity Lutheran Hospital as a respiratory therapy supervisor.

Moving from Kansas City in 1981 Mr. Wissing accepted a job as department head for Cardiopulmonary Services at St. Francis Cabrini Hospital in Alexandria, Louisiana. He remained in this position until 1984 when he transferred to Louisiana State University Medical Center in Shreveport, Louisiana, to become a program director for an undergraduate program in cardiopulmonary science. In the same year, he began working on a master of Health Science degree at Louisiana State University Medical Center. Upon completion of the degree in 1987 he was promoted to Associate
Professor of Cardiopulmonary Science. Mr. Wissing has published a modest number of research articles, is involved with medical research and has co-edited a book on bioinstrumentation with James Wandersee, Ph.D.

In late 1994 Mr. Wissing was accepted for doctoral work at Louisiana State University in Baton Rouge to study Science Education in the Department of Curriculum and Instruction. In the Fall of 1998 Mr. Wissing successfully defended his dissertation on December 18, 1998.

Mr. Wissing is married to Vicki Wissing and had two children, Michael and Karen. Mr. Wissing continues to live in Shreveport, Louisiana.
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Dennis R. Wissing

Major Field: Curriculum and Instruction

Title of Dissertation: The Nature of Undergraduates' Conceptual Understanding of Oxygen Transport and Utilization in Humans: Can Cardiopulmonary Simulation Software Enhance Learning of Propositional Knowledge and/or Diagnose Alternative Conceptions in Novices and Intermediates?

Approved:

[Signatures]

EXAMINING COMMITTEE:

[Signatures]

Date of Examination: October 26, 1998
IMAGE EVALUATION
TEST TARGET (QA-3)

150mm
6"

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