IMPACT OF FREE VS. GUIDED EXPLORATORY LEARNING VIA INTERACTIVE COMPUTER SIMULATION ON STUDENTS' LEARNING

by

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ABSTRACT

Computer simulations are increasingly recognized as educational tools that facilitate students' learning in a safe environment. However, the way in which the simulations are used can have considerable impact on learning outcomes. Some have argued that exploratory learning is an effective strategy for learning new materials; but others have expressed concern that allowing free exploration may result in less efficient, or even inaccurate, learning and therefore encourage more guided exploration. The purpose of this research is to compare learning outcomes of nursing students in a critical care course when using an interactive computer simulation designed to teach fundamentals of oxygenation management under two exploratory learning methods (free versus guided exploration). The conceptual framework for the study was derived from the Informatics Research Organizing Model. The experimental study used a pretest-posttest design. Students in an existing or just finished critical care course were invited to participate in the study. Following a pretest that included a paper and pencil assessment of students' oxygenation management knowledge and two computer-generated clinical scenarios, students were encouraged to learn about the simulation using either guided or free exploration. The Guided Exploration group was given tasks to achieve, while the Free Exploration group was asked to learn about the instructional oxygenation management simulation without any specific tasks. Students then completed a posttest that was identical to the pretest with the addition of one novel clinical scenario to assess knowledge transfer. The results of data analysis using paired t-tests showed no significant differences in learning in the post test for the total group. The independent t-test showed no differences in the mean score between the Free and Guided Exploration groups.

CHAPTER ONE

Introduction

Computers were first introduced into nursing education by Mary Ann Bitzer in the early 1960's, when she wrote a program using PLATO (Programmed Logic for Automatic Teaching Operations), a computer-based educational system, for teaching obstetrical nursing as part of her master's thesis. Not only was her program the first computer simulation in nursing education, but also it was one of the first in the health care field. Bitzer's thesis results showed that students learned and retained the same amount of material using the computer simulation, but in one-third the time it would have taken using the classic lecture method (Ball & Hannah, 1984; Saba & McCormick, 1996). In the mid 70s, Tymchyshyn led a project to develop and evaluate authoring models for CAI programs. Grobe also implemented and evaluated a computer video interactive system (Ball & Hannah, 1984). In the mid 80's, Sheila Ryan and colleagues developed COMMES (Creighton On-line Multiple Medical Education Service), the first artificial intelligence system for nursing (Saba & McCormick, 1996). So, for over 45 years, nurse researchers have been exploring the use of computers for educational purposes.

Studies in a variety of disciplines have suggested the effectiveness of instructional technology. For example, Herriot et al. (2003) found that using CAI was effective for changing students' knowledge and attitudes towards learning nutrition. Shim et al. (2003) reported that computer simulations influence learning by allowing comfortable interaction with the computers and increase students' understanding of target concepts. Carins et al. (1992) found that simulations provide a realistic context for learning work-related skills that increase learners' awareness of their abilities, promote cooperative action and group problem solving, and provide students with insight into various work roles and the demands of those roles. Fletcher (1995) found that using simulations facilitated students' development of critical thinking in anesthesia education. Eaves & Flagg (2001) found that when the US Air force used interactive technology to simulate a medical unit, students not only enhanced their skills, but also increased their abilities to confidentially organize and prioritize patient care and perform with confidence on busy in-patient units.

Despite growing evidence for the effectiveness of instructional technology, there is still limited use of computers in classrooms and lack of coordinated plans for computer technology implementation (Wells et al., 2003). More than 15 years ago, Thomas (1985) surveyed 157 National League of Nursing (NLN)-accredited baccalaureates of higher degree nursing programs about the status of, and barriers to, computer use in nursing education. Thomas' findings indicated that the limited use of computers observed was due to the lack of high quality software and dearth of experienced faculty to operate the available programs. More recently, Carty & Rosenfeld (1998) explored the status of computer and information technology in nursing education and reported that computers are available for all students in all nursing programs, but diploma programs have less technology than baccalaureate and higher degree programs. The researchers reported that computer-assisted instruction was the most prevalent type of application.

The introduction of computers into education offers faculty new possibilities for making nursing education more accessible and also more engaging (Rizzolo, 1990). At the same time, the introduction of computer-based instructional technology presents new challenges. Simply adopting the technology without planning for its effective integration into the curriculum is insufficient (Murphy, 1984). In addition, nurse educators must identify strategies that can be used to enable students to learn effectively through instructional technology (Herriot et al., 2003, Murphy, 1984).

Many instructional technologies are currently available to nurse educators, ranging from computer-assisted instruction and interactive video to web-enhanced or fully web-based courses. Computer simulations too are becoming increasingly popular. In fact, in 2004 the American Association of Colleges of Nursing (AACN) received funding to investigate the use of simulation technology to enhance education quality.

The purpose and sophistication of computer simulations vary widely, ranging from simple demonstrations of phenomena (e.g., heart or breath sounds) or principles (e.g., laws underlying hemodynamics) to teaching simple skills (e.g., “CathSim” which teaches students to start intravenous fluids) or more complex skills (e.g., coordinating care in an ICU). A variety of human patient simulators now exist that allow educators to simulate complex clinical environments such as intensive care units (Medley & Horne, 2005). In these virtual realities, instructors create realistic patient scenarios and then observe, in a safe environment, how students respond to specific problems (Medley & Horne, 2005; Nunn, 2004).

In essence, simulations are based on a simplified model of a complex system that is used to analyze and predict the behavior of the original system. Reality is simplified so that particular functions, relationships, and principles can be more effectively presented. The main purpose of simulations is to help learners build useful mental models of complex phenomena and to allow testing of those models within a safe environment

(Allesi & Trollip, 1985).

A number of researchers have investigated the impact of computer simulations on students' learning outcomes (e.g., Abrahamson et al., 2005; Christoffersen et al., 1996; 1998; Effken & Kadar, 2001; Engum et al., 2003). Morgan et al. (2002) compared computer simulations with traditional instructional technologies (e.g., videotapes) and found no significant differences in students' learning outcomesas measured by pretest -posttest. Other researchers (Gordon et al., 2001; Lee et al., 2003; Shim et al., 2003) have reported that computer simulations facilitate learning and training.

Interestingly, there seem to be some parallels between the use of computer simulations for learning and the way people learn to use computer software. People learn new software by trying to use it (exploration) and drawing on a combination of prior knowledge and information provided by the interface itself, as well as their own problem solving skills (Cox & Young, 2001). The same seems to be true for computer simulations. Simulations have been suggested as ideal for fostering exploratory learning strategies in students; indeed, exploratory learning may actually be inherent in simulations (Cox et al., 1987; Rieman & Young, 1996). Simulations offer students a learning experience in which they can explore a specific domain and discover elements within that domain. Thus,simulations can actually evoke discovery behaviors (Gellevij et al., 2002) that may lead to higher order synthesis and analysis (Cox et al., 1987).

Learning by exploration is intrinsically a self-directed and constructive mental activity to develop and apply knowledge that requires cognitive effort (Kashihara et al., 2000). Exploration is a task-oriented, time constrained process whose primary goal is performance of current tasks, with learning as a secondary outcome (Rieman & Young, 1996). A growing literature suggests that exploration facilitates learning to use computer applications such as word processing. However, little research exists on how best to facilitate effective exploratory learning. Some researchers (Christoffersen et al., 1996, 1998; Effken & Kadar, 2001) have examined exploratory learning in students using computer simulations. For some students in these studies, extent of exploration correlated with their ultimate depth of understanding of the target system. However, the results of the studies were inconclusive.

Problem Statement

Background of the Problem

Biomedical science and nursing knowledge are growing at an increasingly rapid rate (Spunt et al., 2004). It is important to expose students to a variety of different learning experiences so that they develop confidence in their skills (NLN, 2004). However, the increasing complexity of hospitalized patients and shorter lengths of stay make it increasingly difficult to provide students with the necessary range of clinical experiences. In many places, there is considerable competition for clinical sites, particularly with the increase of nursing programs and the number of students in those programs as nursing education tries to respond to the current nursing shortage. In this climate, there is no guarantee that students will have the necessary and sufficient clinical experience to produce the desired outcomes.

A critical care course is essential for today's nursing students. Oermann (1995) examined the employment patterns for nursing graduates in 10 hospitals in the Midwest. Her results revealed that 79% of graduates of nursing undergraduate programs chose critical care for their first position in nursing. If Oermann's findings are true across the country, then additional emphasis may be needed on preparing students to practice in critical care settings through clinical experience with critically ill patients. However, placing nursing students in this very complex environment may create untenable patient safety issues. Other alternatives that will not threaten patients' lives may need to be explored. As a result, nurse educators have been challenged to incorporate more complex content into the curriculum, but without increasing the amount of time or resources required to achieve desired learning outcomes.

Computer simulations may provide a way to help educators counter these problems. Computer simulations can be used to provide a safe, non-threatening, realistic environment in which students can practice, experiment, and learn from their mistakes (Cox et al., 1987; Fletcher, 1995; Gaba & DeAnda, 1988; Geisert & Futrell, 2000; Morgan et al, 2002; Wong & Chung, 2002). Educators can use computer simulations to create virtual experiences in which all students encounter the same set of clinical conditions, thereby ensuring that all the students have equivalent clinical experiences (Fletcher, 1995). Moreover, adding computer simulation scenarios that are unique to the clinical situation will increase students' confidence in their knowledge and skills (Fletcher, 1995), help students establish priorities and make decisions based on those priorities, then allow students and instructors to observe how well the students achieved their goals (Geisert & Futrell, 2000). Simulators can be used to build authentic activities that engage students in learning (Nicaise, 1998). Computer simulations may be used in the laboratory, in classrooms, or may be delivered to students in their homes via the Internet.

The literature suggests that there may be a trade-off, however, using computer simulations requires that educators need to learn the relationship between the new technology and pedagogy. Instructors need to translate old skills and apply them in new environments. When using complex and very sophisticated simulators, considerable time must be spent in developing the scenarios that students will use (Medley & Horne, 2005; Rauen, 2001); however, this may be balanced by a decrease in the time needed to actually teach students.

Depending on how the simulation is used, computer simulations may have the added benefit of helping students become skilled in using exploratory learning strategies (Shim et al., 2003). Exploratory learning can be understood as the inductive acquisition of knowledge from experience and environment (Howes, 1994). Exploratory learning can help students explore and discover, as well as generate and test hypotheses (de Jong, et al, 1999). Instructors can either structure exploration by giving students instructions (guided exploration) before they start their exploration process or allow their students to explore with no instructions (unguided, or free, exploration). Some researchers argue that learning by guided exploration is not only a preferred mode of knowledge acquisition, but also one of the more successful ones (Reiman, 1996), in part because it keeps students more focused (Carroll, 1990). Moreover, some claim that guided exploration supports students in the discovery process by helping learners to extract more knowledge (de Jong, et al, 1999). Kashihara (2000) warned that asking learners to explore freely might lead to cognitive overload because of the need to search and integrate different information from different resources. Furthermore, if the exploration space is very large, learners may not know what or how to explore and might lose their way. Trudel and Payne (1995) reported that guided exploration leads to successful learning by helping the learner focus more on each action that leads to the goal. Others disagree, proposing instead that extensive, free exploration leads to better learning outcomes and deeper learning (Christoffersen et al., 1996, 1998; Effken & Kadar, 2001).

This review suggests that there are still gaps in our knowledge about the conditions under which exploratory learning is most effective. Since exploratory learning is so tightly linked with computer simulations, filling those gaps in our knowledge is very important.

Jenkins (1978) argued that learning and memory depend on four components: (a) the nature of the learners (such as their abilities, interests, knowledge, purposes, etc.), (b) orienting tasks (e.g. instructions, directions, activities, apparatus, etc.), (c) the kinds of materials used (e.g. sensory mode, physical structure, psychological organization, psychological sequence, etc.), and (d) criterial tasks (e.g., recall, recognition, problem solving, performance, etc.). Carroll's work has focused mainly on the materials used (i.e., simulations). Others have focused on students' characteristics. For example, Marton and Saljo (1976) suggested that students typically adopt either a deep or a surface approach to learning.

Purpose of the Research

The purpose of this research is to compare learning outcomes of nursing students enrolled in a critical care course when using an interactive computer simulation designed to teach oxygen management principles under two exploratory learning methods (free vs. guided exploration).

Significance of the Problem

This research will contribute to our knowledge of how instructors can assist students to use exploratory learning strategies most effectively when exposed to computer simulations. This is highly significant because it will help instructors make more effective use of available simulations to improve students' learning outcomes.

Research Questions

In this study three questions will be addressed:

1- Is there an increase in students' knowledge of oxygenation management principles after working with an oxygenation management instructional computer simulation?
2- Does guided exploration of an oxygenation management instructional simulation improve students' learning outcomes (knowledge and application of oxygen management principles) more than free exploration?
3- Are there differential effects of guided vs. free exploration on students' abilities to transfer to novel situations the oxygenation management principles learned while using the oxygenation management instructional computer simulation?

Definitions

Ecological interface design (EID): a framework for human computer interface design for complex human-machine systems. The goals of EID are to exploit the power of human perception by presenting graphical representations of physical and functional aspects of the target system.

Exploratory learning: A self-directed and constructive mental activity accompanied by cognitive effort to develop and apply domain concepts/knowledge (Kashihara et al., 2000).

Free Exploration (FE): The learner is allowed to experiment with the simulation, but without a specific goal, and is expected to learn about the simulation and how various components relate.

Guided Exploration (GE): The learner is given specific sub-goals or tasks to achieve during exploratory learning.

Interactive computer simulation: A computer program that gives the illusion of reality.

Oxygenation management instructional simulation: An interactive simulation that displays relationships among variables that help to get oxygen to the cell and allows students to use simulated therapies to actively treat clinical problems in oxygenation management.

Knowledge: Information that has been synthesized in such a way that interrelationships are identified and formalized.

Summary

Nursing education is rapidly increasing its use of computer simulations. However, we know little about how best to utilize these new instructional tools. For example, we don’t know the best way to use simulations as a teaching strategy. This research will contribute to nursing science by comparing two instructional strategies that can be used to help nursing students maximize exploratory learning to achieve targeted learning outcomes when using computer simulations. By effectively using simulations as an instructional technology, nursing education may be able to satisfy the demand for adding complex content to the curriculum without increasing the amount of time required to teach the curriculum. In addition, computer simulations can be used to ensure that all nursing students encounter prototypical clinical situations, which cannot be done in today’s clinical settings. Moreover, simulations can be used to present students with complex clinical problems in an interactive, safe, and non-threatening environment before they encounter them in an actual clinical setting, thus increasing the likelihood of safe, effective patient care.

CHAPTER TWO

Introduction

In this chapter, I will first present the conceptual framework for the study and then discuss relevant literature, using the conceptual framework to organize the discussion. The literature review will focus on the major ideas, issues, and dilemmas related to using simulations in educational settings. In addition, I will summarize the extant research on exploratory learning.

Conceptual Framework

The conceptual framework for this research was derived from the Informatics Research Organizing Model (IROM) (Effken, 2001) (Figure 1). The IROM integrates the Systems Research Organizing Model (SROM), an organizing framework for Nursing Systems Research (Brewer et al., 2002) with the systems development life cycle (SDLC), as described by Thompson & Snyder-Halpern (1999). The IROM is composed of four constructs:

Client. This construct depicts clients as sources of data and information; for example, students have certain prior knowledge that they bring to the educational experience. Clients also are defined by their characteristics and behaviors.

Context. This construct is defined as the cultural, economic, social, and physical environment in which a nursing informatics intervention occurs.

Nursing Informatics Intervention. This construct is described in terms of the content, structure, and flow of information and also the information technology used.

Outcomes. This construct corresponds to information, knowledge and decisions, and actions to improve cost, quality, safety, and satisfaction. Learner goals and gaps in progress toward the goal might be captured here. Bi-directional arrows connect all four constructs, indicating how they are mutually related.

The systems development life cycle (SDLC) component provides a logical, dynamic process model for planning, analyzing, designing, implementing, and maintaining information systems in all types and sizes of health care settings. All four constructs need to be considered at each stage of the SDLC. Evaluation is suggested at all stages. The SDLC is centered in the middle of the model because the author believed that it should framed by the four constructs (Effken, 2001).

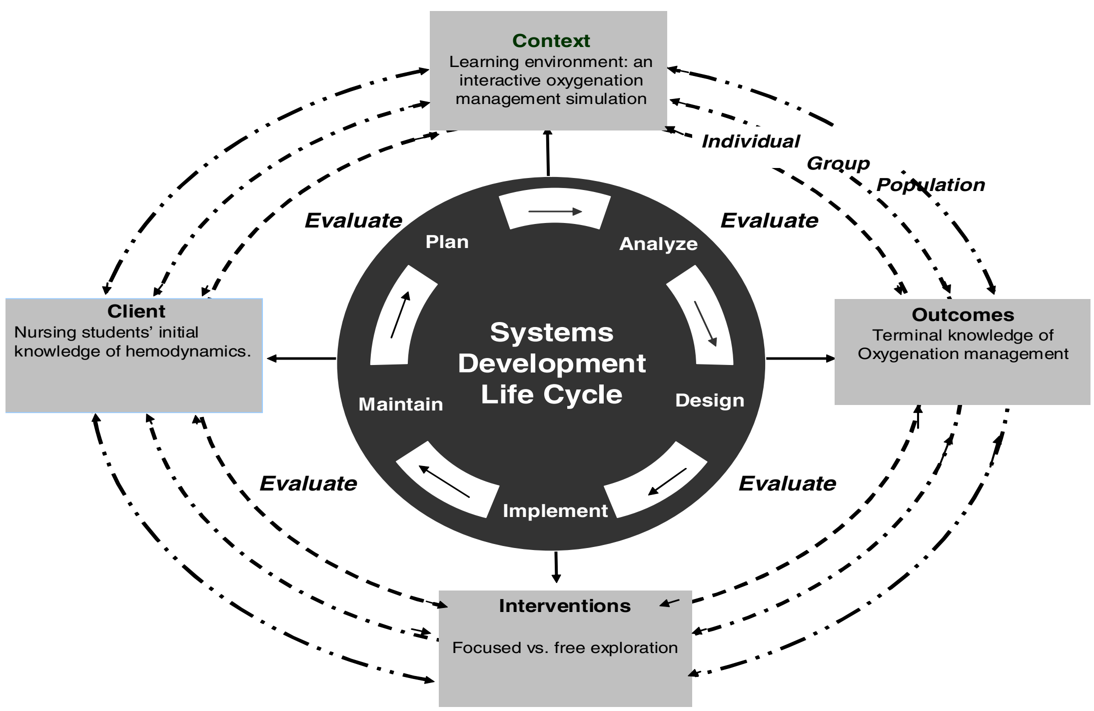

FIGURE 1. *The Informatics Research Organizing Model, as initially operationalized for this research*

In the adapted conceptual framework (Fig. 2), the four constructs in the framework are shown as they have been operationalized for this study. Client is operationalized as nursing students and their prior knowledge. The nursing informatics intervention is operationalized as type of exploration (guided vs. free). Context is operationalized as an oxygenation management instructional simulation. Outcome is operationalized as learning gained from the simulation. The conceptual model implies that when students who can be characterized as novice to advanced beginners in critical care concepts use the computer simulation to learn, their learning outcomes will vary. This variation will occur, in part, if learning is mediated by an intervention, such as manner of exploration (e.g., free vs. guided). The iterative learning process starts with the learner using either free or guided exploration to explore the simulation environment. Such exploration is intended to develop the perceptual skills of the learners (Fig. 2) and will enable them to learn how the simulation environment works. These four constructs will be used to frame the following review of literature:

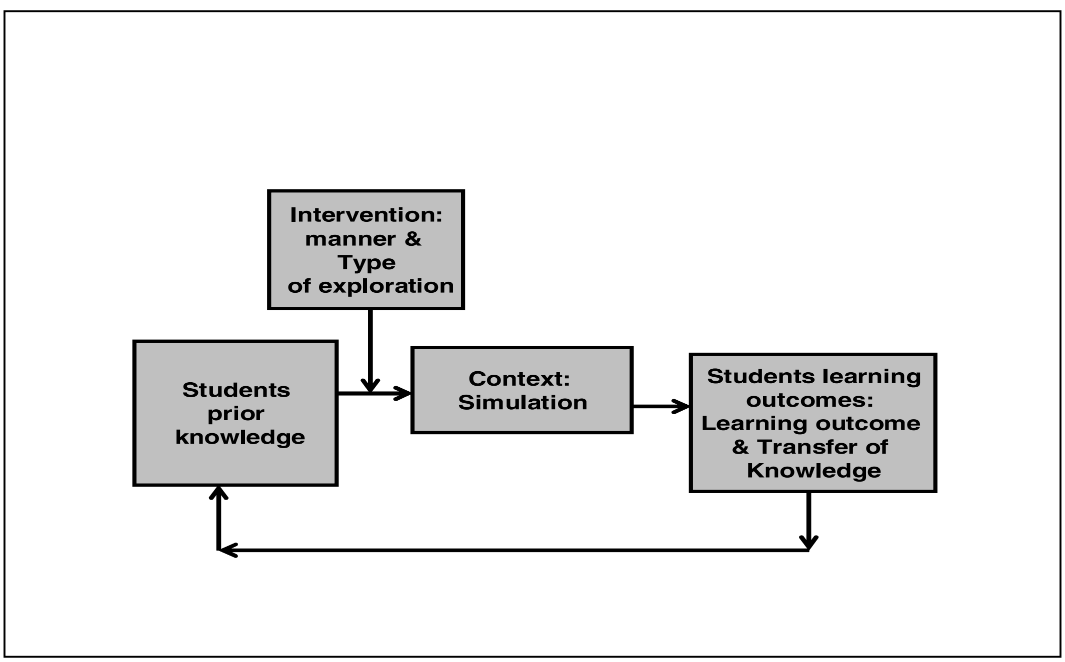

FIGURE 2. *Simplified conceptual framework*

Client

Students' learning can be affected by their background, or prior, knowledge (Means & Voss, 1985). For example, Thompson & Zamboanga, (2004) found that, beyond general ability, domain-specific prior knowledge facilitated students' learning in an introductory psychology class. Mitchell et al. (2005) described two types of relevant prior knowledge when learning to use hypermedia: domain expertise and system expertise. Domain expertise was defined as the familiarity of the subjects with the module, and system expertise was defined as how much the students enjoyed using the Web and computer-based learning packages and how frequently they used the computers. Mitchell et al. reported that students with lower domain knowledge showed greater improvement in their learning outcomes than those with higher domain knowledge. Moreover, students who enjoyed using the Web and Web-based learning were better able to cope with non-linear interactions. Lower levels of domain knowledge also have been reported to correlate positively with the number of navigational moves and the level of depth explored in the subject hierarchy (Chen & Ford, 1998). Similarly, in a qualitative study of 12 undergraduates, students with high domain knowledge were observed to navigate more easily, remembering where they had been and deciding how to reach their goal (Last et al., 2001).

Because the complexity of client needs in critical care requires nurses to possess a well-developed knowledge base, skills, and value system (Oermann & Provenzano, 1992), it is important to understand the students' learning needs in terms of their prior knowledge (Mitchell et al, 2005). Although one might expect that nursing students in the same college would have the same information and experiences through lectures, required readings, required clinical written work and printed syllabi (Angel et al., 2000); there has been little emphasis in the nursing literature on actually assessing students' prior knowledge, in contrast to psychology and education.

Context: The Computer Simulation

Harrell et al. (2000) defined a simulation as "the imitation of a dynamic system using a computer model in order to evaluate and improve system performance" (p. 5). Computer simulations have been used in many hazardous professions such as nuclear power, aviation, engineering, medicine, and nursing (Christoffersen et al., 1996; Gordon et al., 2001; Rauen, 2001, 2004; Ziv et al., 2003). Ziv et al. (2003) classified medical simulations in terms of their complexity (i.e., low-tech simulations such as models or mannequins that are used to teach simple physical maneuvers or procedures or high-tech, realistic patient simulations such as computer driven, full-sized human mannequins that allow handling complex and high risk clinical situations in lifelike settings). In between these two ends of the spectrum lie simulations that entail simulated standardized patients, screen-based computer simulations, or complex task trainers. The simulated, standardized patients employ actors as patients to facilitate training in history taking, physical examinations, and communications. The screen-based computer simulations include programs to train and assess clinical knowledge and decision-making. Finally, the complex task trainers combined high fidelity visual, audio, and haptic (touch) cues with actual tools that are integrated with computers to create virtual reality experiences that replicate clinical settings (e.g. ultrasound, bronchoscopy, etc.)

In nursing education, simulations have been used to teach theory, assessment, technology, pharmacology, and various skills (Rauen, 2001). The first simulations used in nursing employed rubber body parts to teach basic nursing skills, such as the insertion of intravenous or urinary catheters. The most complex simulations used in nursing include human patient simulators that allow instructors to create very realistic interactive scenarios and collect data about the student's performance. Other nursing simulations include CD-ROM applications that allow learners to analyze data and make decisions about simulated clinical situations by answering questions and selecting therapies (Rauen, 2004). Nehring & Lashley (2004) evaluated the use of human patient simulators in 66 nursing programs and 150 simulation centers, hospitals, and other higher education institutions. The researchers reported that simulators were largely used for undergraduate physical assessment, advanced undergraduate medical-surgical courses, graduate physical assessment, and nurse anesthesia courses. Moreover, programming the simulators required considerable faculty time and effort for effective use.

Simulations have proven to be effective in medical education for learning anatomical structure, as well as for improving diagnosis and treatment skills such as laparoscopy or anesthesia administration (Issenberg et al., 1999; Kashihara et al., 2002). Alinier et al. (2004) reported that nursing students who were given training through realistic scenarios using SimMan did better on an Objective Structured Clinical Examination (OSCE) than students who were not given training through the simulation.

An integrative review of research measuring the outcomes of computer-based simulations in education found that 75% of the studies reported positive effects of simulations on skill and/or knowledge acquisition (Ravert, 2002). Ravert recommended conducting further research to investigate the best way to use the high-fidelity computer-based human patient simulator, as well as to discover the best ways to use simulations in the ever-changing health care environment. In contrast, many research studies did not give clear and unequivocal outcomes of the simulations (De Jong & Van Joolinegen, 1998). For example, Chamber et al. (1994) analyzed videotapes of students using a simulation and found that the students were both unable to deal with unexpected results and unable to utilize all the experimenting possibilities that were available.

Ecological Interface Design. Ecological Interface Design (EID) is a theoretical framework for designing human-computer interfaces for complex sociotechnical systems (Vicente, 2002; Vicente & Rasmussen, 1992). The goals of EID are to allow people to deal with the demands of complex work domains by relying on their powerful perception-action system and to simultaneously provide the support people require to engage in more effortful analytical problem-solving activities that are needed to adapt to unanticipated contingencies (Vicente & Rasmussen, 1992). EID first defines the knowledge that needs to be represented in the interface and then designs an interface to enable better visualization of information and the means of control.

Vicente (1997) reported the results of a three-year research program to investigate the effects of an EID display on operator adaptation. He noted that providing critical and relevant information in the interface fostered adaptation (i.e., learning). Independent of the information content, the way the information was presented directed the attention of operators in such a way that they became attuned to the visual forms presented in the interface. He also concluded that the type and amount of training operators received influenced adaptation. Finally operators' pre-existing competencies (e.g., cognitive style, declarative or procedural knowledge, perceptual-motor skills, and population stereotypes) influenced their adaptation to the interface design.

Christoffersen et al. (1998) conducted a 6-month longitudinal study comparing an EID interface that describes the target system in terms of its physical and functional structure, with one presenting only the physical structure. Two groups of graduate engineering students were trained to complete complex control tasks on either the EID or the physical interface. The researchers reported that using EID led to students developing a functionally organized knowledge base and superior control performance, assuming that they actively reflect on the feedback they received from the interface. In a related, 1996, study, investigating the effect of EID on skill acquisition, the researchers reported that the EID interface produced more consistent control performance than did the physical interface design. Moreover, learners reported feeling that they had more time to complete required tasks.

Sharp and Helmicki (1998) compared an ecological (EID) and conventional (traditional) display in the context of a neonatal intensive care unit (NICU). The EID display presented physical and functional information in the form of graphical forms, while the conventional interface presented physical information in a typical alphanumeric format. Sixteen residents, fellows, and attendings were asked to diagnose clinical situations using the displays. The residents performed significantly better with the EID interface, while the interface effect was less prominent for the attending physicians. The authors hypothesized that the value the EID adds might diminish with time, or that the attending physicians have more experience using typical alphanumeric interfaces, or that the experimental power was too low. Overall the authors reported that the EID led to better performance than the conventional interface.

Nursing Intervention: Free vs. Guided Exploratory Learning

Learning through exploration is important because it can enhance acquisition of deep knowledge through meaningful incorporation of information into the learner's cognitive structure. The exploratory process itself is seen as an important skill in deepening knowledge (Njoo & Jong, 1993).

Exploratory learning may be either free (unguided) or focused (guided). In the former, students initiate exploratory activities and carry them out without any outside guidance or interference. In the latter, the instructor provides at least minimal guidance or instruction (Carroll, 1985, 1990; Kashihara, 2000; Oostendorp & Mul, 1999; Reiman, 1996; Reiman et al, 1996). Several theorists have compared the impact on learning via exploration with more or less instruction, for example, when learning to use a computer application (Caroll, 1985, 1990; Trudel & Payne, 1995, 1996). Initially, research in this area focused on free vs. guided exploration and more vs. less instruction.

Carroll's minimalist approach suggests that, when motivated students interact with well-designed simulations, only minimal instruction is needed to reach desired outcomes. Computer games are intrinsically motivating, reveal features incrementally, and are useful with no formal training; and instructional software should be similar (Carroll, 1982). Carroll et al. (1985) found that learners learn better when they must discover the information necessary to learn word processing than when instructions are given directly. Instruction manuals actually penalized and impeded active learning. In a study comparing guided exploration (GE) materials with commercially developed self-study (SS) materials for learning to use a commercial word processing system, Carroll et al. (1985) found that the learners using GE spent less time and performed better on the transfer of learning posttest than the learners using commercially self-study materials. Carroll hypothesized that the GE materials worked better because learners had to think actively about the system, formulate their own goals for using the system, and explore hypotheses about the system. Carroll concluded that active involvement with minimal instructional material might be as effective as more passive involvement with extensive instructional materials.

Exploratory behavior can be nested, which means that, during exploration, a given goal can lead to sub-goals, which can lead participants to explore other operations. Carroll et al. (1985) defined guided exploration as instructions for specific actions to be taken when using word processing (e.g., instructions for typing). Later Carroll would turn from specific instructions to assigning tasks to be achieved. His (1990) minimalist instructions assume that a teacher (or vendor, in the case of software) can guide exploration by giving only the instructions (e.g., in instruction manuals) necessary to help the student begin using an application or instrument. By emphasizing task oriented-exploration, instructors can keep learners more focused. Minimalist guidelines also prescribe checkpoint information and error recovery processes so that learners can detect and diagnose their own errors and get back on track.

Reiman (1996) investigated exploratory learning in natural situations by studying, through diaries and structured interviews, the behavior and attitudes of computer users learning to use new software packages. Reiman found that many users learn to use software by trial and error. As in computer games, mastering the software should be intrinsically motivating, features should be revealed incrementally, and the system should be at least minimally useful with no formal training. The results of this study suggested that task-free exploration is unlikely to occur, not because systems are uninteresting, but because users' fundamental goals are to complete their work-related-tasks.

Kashihara (2000) cautioned that asking learners to explore freely might cause cognitive overload if they need to search and integrate different information from different resources or if the exploration space is very large. Kashihara argued for exploration space control (ESC) by controlling the embedded information, information resources, exploration path, and presenting information so students are prevented from reaching impasses.

Trudel and Payne (1995) examined the nature of exploratory learning using a computer-simulated digital watch, hypothesizing that the success of exploratory learning is dependent on the degree to which learners reflect on their interactions and on how well they manage their goals. In their first experiment, subjects were divided into three groups: The first group was given no instructions and allowed to explore freely. The second group was given a list of goals to be achieved, but with no other limits on exploration. The third group not only received goals, but also had their resources constrained. That is, they were given a keystroke limit in which the goals were to be met. The results suggested that experimenter-provided goals yielded some benefits, but had less impact than the keystroke limit. A second experiment confirmed and extended the main findings of the first experiment. Because subjects were observed to switch opportunistically from goal to goal and mode to mode, the researchers sensed that limiting them to exploring one part of the device at a time would result in better learning. The researchers concluded that imposition of the keystroke limits had made each key stroke a precious resource and had forced the participants to reflect more fully on each action (cf. Shaw & Kinsella-Shaw's [1988] idea of fuel-coins, in which there is a cost for each movement towards a goal). Trudel and Payne (1996) also looked at the effect of prompting subjects to report verbally on their learning progress while they learned to program a computer-simulated digital watch. Subjects who reported every two minutes on what they had learned performed better on the posttest than the control group. Subjects who reported what they intended to do as part of self-monitoring made fewer errors than the control group. Subjects didn't need external prompting to effectively use reviewing in order to benefit from exploratory learning. In sum, the research showed that prompted reviewing and planning facilitated students' learning.

It can be difficult for learners to extract knowledge from a simulation (i.e., make sense of the information given in the simulation). For example, Njoo and De Jong (1993) found that learners encountered difficulty in discerning relevant variables, stating hypotheses, and interpreting the results of experiments. They suggested that instructors can help learners by providing them with support to deal with the low transparency and richness of the simulations. De Jong & Van Joolingen (1998, 1999) noted that a simulation itself may not improve learning if learners have insufficient prior knowledge.

Without sufficient prior knowledge, learners may not be able to state a hypothesis, interpret data accurately or engage in unsystematic experimentation. Providing learners with predefined hypotheses can positively influence the learning process and subsequent outcomes. Asking students to state their hypothesis before they start the experiment might improve performance (De Jong and Van Joolingen, 1998). Interestingly, Charney (1990) found that experimenter-supplied goals were more efficient in improving learning than learner-initiated goals.

Many studies have investigated the role of interface design in supporting exploration. Soto (1999) investigated the assumption that the success of exploration depends highly on the semantic similarity between the task description and labels of the display objects. The researcher used Microsoft Excel to administer tasks such as editing a bar graph using a graphics application (e.g., changing the graph type to column). The author used latent semantic analysis to evaluate the semantic similarity between task description and the labels in Excel's menu system. Participants performed tasks in an exploratory method and then recalled the same tasks after one week. Soto's results revealed that participants performed tasks faster if the menu system and tasks were semantically similar. Oostendorp & Mul (1999) investigated the kind of support a system needs to offer if it is to be explorable and result in better performance. Using exploration-supporting activities such as thinking aloud allowed learners to process what they saw on the screen more deeply and resulted in more effective exploratory behavior. Moreover, providing the learners with exploration-support features (e.g., using more distinctive colors and making them more salient) attracted learners' attention.

Learning Outcomes: Improve Learning Outcome

For learning to occur there must be a change in behavior. To understand that the behavior has changed, transfer needs to occur (Kirkpatrick, 1994). "A person can't be said to have learned something unless the person displays that learning on some other occasion" (Salomon & Perkins, 1989, p. 115). Baldwin and Ford (1988) mentioned that transfer is the product of learning and application events that share the same or similar stimuli. Therefore, the more similar the contexts of learning and the application of that learning, the more likely it is that knowledge or skills will transfer. Without initial mastery of content, there can be no transfer (Nolan, 1994). For "transfer to occur, the learner first must have acquired some skills or knowledge, what we commonly refer to as learning" (Stolovitch & Yapi, 1997, p. 65; see also Keller & Schallert, 1992). Moreover, transfer is thought to involve a complex interaction among the learner, the original tasks and the transfer tasks (Gagne & White, 1978). When students are not able to perform tasks slightly different from those learned in school, education is deemed to have failed (Mckeough et al., 1995). The role of the teacher is to provide instructional experiences that will facilitate transfer of required knowledge and skills beyond the initial learning context to new circumstances and different purposes (Mckeough et al., 1995).

Summary

This chapter presented the conceptual framework, the Informatics Research Organizing Model, which guides the research and how the model was operationalized for this research. In addition, relevant literature was reviewed related to each of the model's constructs. The review of literature revealed that there is considerable evidence for the use of computer simulation in education. However, just what strategies optimize this type of learning is still unknown Exploratory learning has been recommended as the preferred way to use computer simulations. However, there is still considerable disagreement about which type of exploratory learning (free or guided) results in better learning outcomes.

CHAPTER THREE

Introduction

This chapter describes in detail the research methods used to answer the research questions. After briefly reviewing the purpose of the research and the research questions, I describe the research design and procedures, the instructional simulation that provided the context for the research, and the plans for human subjects' protection and data analysis.

Purpose and Research Questions

The purpose of this research was to compare the learning outcomes of nursing students enrolled in a critical care course when using an interactive computer simulation designed to teach oxygen management principles under two exploratory learning methods (free vs. guided exploration).

Three research questions were addressed:

1- Is there an increase in students' knowledge of oxygenation management principles after working with an oxygenation management instructional computer simulation?

2- Does guided exploration of an oxygenation management instructional simulation improve students' learning outcomes (knowledge and application of oxygen management principles) more than free exploration?

3- Are there differential effects of guided vs. free exploration on students' abilities to transfer to novel situations the oxygenation management principles learned while using the oxygenation management instructional computer simulation?

Methods

Design

The experimental study used a pretest-posttest design. Participants were randomly assigned to one of two groups (free or guided exploration). The Guided Exploration (GE) group was given specific tasks (defined precisely under procedures) to perform; while the Free Exploration (FE) group was simply asked to learn about the simulation's various components and how they relate to each other. However, both groups had an overall goal for the experience: discover how each drug works on the variables, as well as the various relationships among the variables. Exploration time was limited to 30 minutes for both groups. Comparing students' knowledge of oxygen management via pre- and posttest assessed their overall learning with the simulation. Assessing the students' ability to transfer learning to a previously unseen scenario provided a measure of the depth of their knowledge.

Sample

A convenience sample of baccalaureate students who were currently enrolled in, or had recently completed a critical care course and volunteered to participate was randomly assigned to free or guided exploratory learning groups. Each volunteer was assigned an ID number. The ID numbers were written on a piece of paper and randomly selected. The first student ID drawn was assigned to the free exploration group, the second was assigned to the guided exploration group; the third drawn student was assigned for free exploration and so on, thus assuring equivalent numbers in each group. A power analysis suggested that with α set at 0.05, 1-β at 0.81, and estimated effect size set as moderate

(0.40), the required sample size needed was 26 in each group. Students were recruited from a fourth semester class and fifth semester class at The University of Arizona College of Nursing. Arrangements were made with course instructors to allow me to recruit student participants. Prepaid national and international phone cards worth $10 were mailed with a thank you letter to the students who participated in the experiment as compensation for their participation. Recruitment materials are included as Appendix A. The course instructors agreed to allow me to provide a 5-minute explanation of the study in each class. During the recruitment activity, I introduced myself to the students and told them about the purpose of the study. Specifically, I informed them that I was investigating what students learn when using an interactive computer simulation designed to teach oxygen management principles. I explained that this study was important because it might help instructors assist students to use educational computer simulations more effectively. Then I described the experiment. I told the students that they would complete a brief pre-test about critical care and then solve two clinical problems using the computer simulation. They would then get an opportunity to practice using the computer simulation, and then solve three additional clinical problems using the computer simulation, and finally complete a brief posttest about critical care. I also told the students that on completing the experiment, they would be compensated. I then asked if any of the students had any questions. I then distributed a recruitment form to the students that explained the purpose and significance of the study, and the experimental procedures (Appendix A). Students who volunteered to participate were asked to enter their names, phone numbers, and e-mail addresses on a list (Appendix A) or e-mail me. E-mail confirmation was sent to the students who volunteered. After I ascertained that oxygenation and oxygen management content has been covered in the class, I contacted the students via e-mail to schedule a date for their participation.

Instrumentation

Two types of instruments were used to measure students' learning with the oxygenation management simulation: a pencil and paper Oxygen Management Knowledge Test (OMKT) and computer simulated oxygenation management problems.

The *Oxygen Management Knowledge Test* (OMKT) is a two-part experimenter-designed instrument. The first part of the test asks about students' prior computer skills, and the second part includes 14 items that measure their oxygen management knowledge (Appendix C). As noted earlier, Jenkins (1978) argued that learning and memory depend on four components. One of those components is the nature of the learners (i.e., their abilities, interests, knowledge, purposes, etc). Characteristics of the learners need to be matched with instruction, and materials to understand the performance. Students can be classified in terms of their ability to solve problems in a specific knowledge domain as average or gifted students (Gorodetsky & Klavir, 2003). Through the OMKT, I was able to characterize the sample in terms of their oxygenation management knowledge as average or good. Ultimately, I added another level to characterize students who had not been exposed to this knowledge domain before. Thus, the final OMKT included questions at three levels of difficulty:

1) Questions that average students could be expected to answer without using the simulation, but their knowledge would be reinforced by the simulation

experience (Questions: 2, 4, 6, 8, and 9);

2) Questions that good students could be expected to answer and the display simply would reinforce their knowledge (Questions:1, 3, 5, 12, and 14); and

3) Questions for which students had no prior knowledge, but for which the information required could be learned through the simulation (Questions: 7, 10, 11, and13).

Content validity for the OMKT was assessed by an expert panel of three critical care nursing specialists (Lynn, 1986). Panelists were asked to work with the simulation to understand the display content and the relationships of the variables. Panelists then were given a copy of the test together with a Content Validity Index (CVI) that described how each item relates to the interactive computer simulation. The test was accompanied by a cover letter that described what the panelists needed to emphasize in their evaluation (Appendix D). The CVI (Appendix D) used a 4-point ordinal rating scale to evaluate relevancy toward the display contents:

1 = irrelevant item;

2 = unable to assess relevance without item revision;

3 = relevant but need minor alteration; and

4 = extremely relevant.

The CVI for each item was determined by the proportion of experts who rated the items as valid (i.e., assigning the item a rating of 3 or 4). The CVI for the entire test was computed as the proportion of items that received a rating of 3 by the experts (Lynn, 1986) and was calculated as 0.95 after deleting one question that all participants rated as

1.

Reliability was assessed using the split – half method. Coefficient Alpha was used for the dichotomous data from the questionnaire. For the dichotomous data this is equivalent to Kuder-Richardson 20 (KR20) coefficient (Maxim, 1999). The reported alpha was 0.49.

Computer simulated oxygenation management problems were selected from scenarios available on a prototype clinical simulation developed by Effken (2004) using the METI Human Patient Simulator and presented via a Dell PP01X model Laptop computer with a 15" colored monitor. The problems were used as a pre- and posttest to evaluate changes in the students' applications of their oxygenation management knowledge. Effken (2004) developed the prototype oxygenation management interactive computer simulation to facilitate doctors' and nurses' clinical decision making through an ecologically designed interactive graphical display. The display attempts to integrate the data presented in ways that highlight the functional relationships among variables to support rapid initial overall patient status assessment and provide the necessary structure for more in-depth problem solving. This is the first test of the simulation's use as an instructional tool.

The simulation shows the relationships among 12 variables used commonly in managing oxygenation in intensive care patients: central venous pressure, pulmonary artery wedge pressure, mean arterial pressure, systemic venous resistance, heart rate, stroke volume, cardiac output, extraction ratio, hemoglobin, arterial oxygen saturation, venous oxygen saturation, and oxygen delivery. In the lower portion of the display, a brief patient history is available.

The main part of the computer display represents the human oxygen delivery system. The lower third of the display contains variables such as intravascular pressures and other hemodynamic parameters that represent the physiology of the system; the middle portion of the simulation contains variables such as hemoglobin concentration and saturation, and blood and fluid oxygen content that represent the functions of the system; and the top portion contains variables such as oxygen supply and demand (functional goals of the system) (Figure. 3). Graphics have been used to depict the relationships among variables. For example, a dark reddish rectangle in the bottom middle part of the screen depicts how stroke volume (vertical dimension) and heart rate (horizontal dimension) contribute to cardiac output (the area of the rectangle). Variables are colored to show the relative value of oxygen content (areas with lower oxygen are blue; those with higher oxygen content are pink or red).

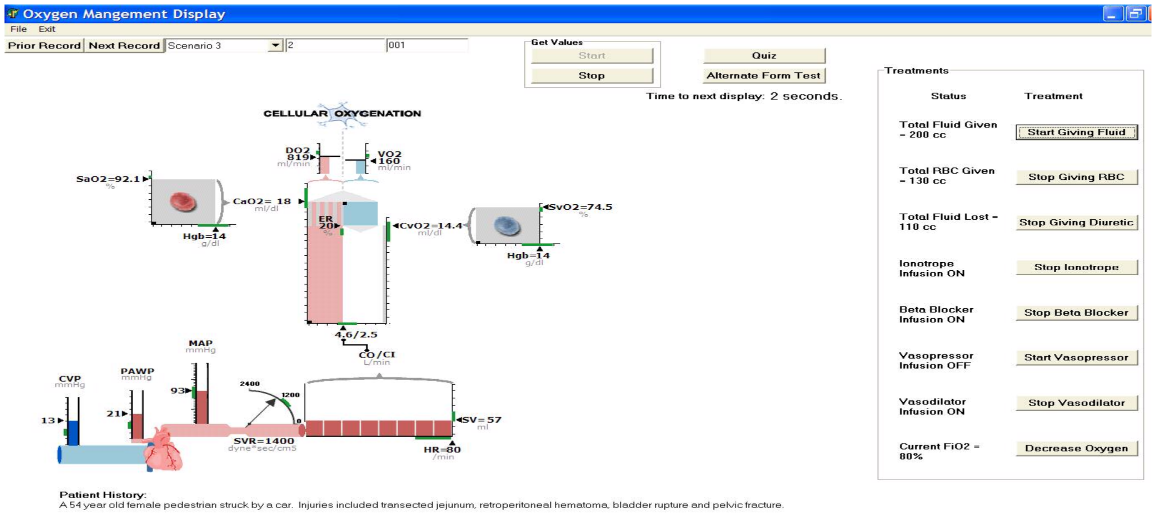

FIGURE 3. *The interface design display with the drug control window on the right*

The eight therapies located at the right side of the screen are used to interactively "treat" identified problems and observe the clinical outcomes. Students use the mouse to select or deselect drug therapies. An "on-off" indicator light indicates when a treatment has been selected. The available therapies are: Intravenous fluids, Blood transfusion, Diuretic, Inotrope, Beta Blocker, Vasopressor, Vasodilator, and Oxygen. The amount of fluid or blood infused is shown as well.

Three scenarios were selected from those created and used by Effken (2004) for this study. The first depicted a young patient who was bleeding internally from a gunshot wound to his abdomen. The second depicted a patient with atrial fibrillation and congestive heart failure. The third depicted a patient with adult respiratory distress syndrome (ARDS). Students' ability to apply their oxygen management knowledge was measured by their control of the following eight variables, which represent the major oxygen management variables shown in the display: Oxygen Delivery (DO_2), Arterial Oxygen Saturation (SaO_2), Hemoglobin (Hgb), Cardiac Output (CO), Heart Rate (HR), Mean Arterial Pressure (MAP), Systemic Venous Resistance (SVR), and Pulmonary Artery Wedge Pressure (PAWP).

Procedure

Each student was assigned an identification number prior to the experiment and only the ID number was used to identify data collected. Each student was tested individually in a research room at the College of Nursing. After reading a description of the experiment and reviewing a disclaimer form, participants were asked to complete the OMKT test. After a brief (approximately 15 minutes) orientation to the computer simulation (Appendix E), students were asked to identify and treat the clinical problems presented in two simulated oxygen management scenarios using the available drugs (Appendix F). I answered students' questions during the orientation, but not while they were working on case scenarios or exploring the simulation. Students had 10 minutes to correct each problem. Each student then was encouraged to take a 5-10 minute break to avoid fatigue.

Students then were given 30 minutes to explore the simulation. The GE group was given specific tasks to perform during the exploratory learning phase of the experiment, while the FE group was asked simply to learn about the simulation's various components and how they related to each other. Specifically, the GE group was instructed to try to understand how different therapies affected the variables shown in the display as they manipulated various drugs to achieve experimenter-defined targets (e.g., “Please use the available treatment to increase the Hgb to 15”) (Appendix G). The GE group was given a list of specific tasks to carry out during their exploration. The tasks were listed on a single sheet of paper, but I did not insist on their being completed in the order listed. The FE group was asked to explore the simulation freely and try to understand how various drugs acted on the variables in the display and how the variables related (Appendix H). Both groups had an overall goal for the exploratory phase: discover how each drug works on the individual variables, as well as the various relationships among the variables. During the 30-minute practice period, I remained with the students to monitor time and manage the instructional simulation (e.g., stop and restart the simulation if students preferred to evaluate the effects of each drug separately).

After the students completed the exploratory learning phase, they were given a posttest comprised of the OMKT and three computer-simulated case scenarios. Two case scenarios were identical to the pretest case scenarios, and the third was novel to assess knowledge transfer (Appendix G). Students were then debriefed about the experiment. The debriefing included asking them if they have any questions or comments that they would like to share. I answered their questions and encouraged them to contact me via e-mail if they had anything to add. A thank you letter was mailed to the students with phone cards that were worth $10.

Measures

The following dependent variables were measured:

- *Change in participants' knowledge of oxygen management,* as measured by changes in mean pre-and posttest scores on the OMKT.
- *Participants' ability to apply oxygen management knowledge*, as measured by changes in the:
    - *Mean number of variables in normal rang*e at the end of each simulated case for free and GE groups
    - *OMKT scores* for free and GE groups
- *Overall learning outcomes*, as measured by a composite learning variable computed as the sum of two normalized (as Z scores) outcome measures (number of variables in normal range, students' scores on the OMKT).
- *Knowledge transfer,* calculated as the mean percentage of the novel scenario variables in the normal range for free and GE groups.

Hypotheses

The following hypotheses were tested:

H1. The instructional simulation will increase students' general knowledge of oxygen management, as evidenced by significantly higher mean scores on the posttests than on the pretests.

H2. The GE group's learning outcomes will improve more, as evidenced by:

a) Greater improvement in the number of variables in normal range for the simulated clinical scenarios after the practice intervention (posttest), as compared with baseline performance (pre-test).

b) Significantly higher overall scores on the OMKT.

c) Significantly higher score on the composite learning outcome measure that contains: number of variables in normal range, students' scores on the OMKT.

H3. The GE group will transfer knowledge to novel situations, as evidenced by a higher number of variables in normal range on the transfer case scenario.

Data analysis

Microsoft ACCESS was used to manage data from the questionnaire. An Excel program was used to maintain simulation data. The Statistical Package for Social Sciences (SPSS) was used for data analysis. Demographics were summarized via descriptive statistics. Group means and standard deviations were calculated for each dependent variable (e.g., performance on the OMKT and number of variables in normal range). A *t*-test was done to compare mean scores for the two groups for the various research questions. For all analyses, α was set at 0.05 a priori.

The data analysis plan for each research question was as follows.

1. To determine if there was an increase in students' general knowledge and of oxygen management principles after working with the instructional computer simulation, students' mean pre-and posttest scores on the OMKT were compared via paired *t*-tests for matched groups.
2. An independent t-test was used to compare the differences in pre-and-posttest scores for free and GE groups for the learning outcome composite variable. The differences were calculated first by subtracting the pretest score from the posttest scores to produce a difference score (*d*). Based on the results of the *t*-test, further analyses were conducted, for example, *t*-tests using the component dependent measures in the composite variable.
3. To determine whether there were differences between free and guided groups in knowledge transfer, the differences in the number of variables maintained within normal range on the novel clinical case scenario pre-and-posttest were compared via independent *t-tests*.

Plan for human subjects protection

Human subjects' protection approval for the research was obtained from the University of Arizona Institutional Review Board (Appendix B). Special attention was paid to FERPA requirements because of participants' student status.

Summary

Chapter Three presented a detailed description of the study design, methods, measures, and data analysis techniques used for the study.

CHAPTER FOUR

Results

Introduction

The goal of this research was to compare the learning outcomes of nursing students when using an educational computer simulation under two types of exploration: free and guided. Chapter 4 first describes the sample and then summarizes the results of the study by research question.

Participants

Fifty-two nursing students at the University of Arizona College of Nursing volunteered to participate in the study. Thirty one students were in their fourth semester of study and 21 were in their fifth semester. All had completed the cardiovascular module of an advanced medical surgical course. Students were randomly assigned into two groups, Free Exploration (FE) or Guided Exploration (GE), with the constraint that students from the two classes were evenly distributed within groups. This process resulted in assigning 15 students from the fourth semester and 11 from the fifth semester to the FE group and 16 from the fourth semester and 10 from the fifth semester to the GE group. Table 1 shows the age distribution by groups. Inspection of Table 1 shows that most (73%) students in the FE group were between 21 and 25 years of age; in addition, all but one were female. Similarly, in the GE group, 77% were between 21-25 years of age; all were female.

TABLE 1. *Age distribution of study participants by group (n= 26)*

	Exploratory Group	
	Free Exploration	*Guided Exploratio*
Age (years)	*N (%)*	*N (%)*
<20	1 (4 %)	1 (4%)
21-25	19 (73 %)	20 (77%)
26-30	5 (19 %)	1 (4%)
31-35	0	2 (8 %)
36-40	0	1 (4 %)
41-45	0	0%
46-50	0	1 (4 %)
>50	1 (4 %)	0

Table 2 shows that computer use was quite heavy among these students. The patterns were quite similar with no statistical significance between the twogroups, although the GE group used the computer for slightly less time. Fifty per cent of the students in the FE group reported using the computer for 4-7 hours a day and nearly as many (46%) for 1-3 hours a day. This pattern was reversed for the GE group (4-7 hours per day = 42%; 1-3 hours per day = 54%). Reported use of the computer for school purposes was similar for FE (M = 3.5 hrs. per day, SD = 1.24) and GE (M = 3.2 hrs. per day, SD = 1.30) groups.

TABLE 2. *Daily computer use by students in each exploration group*

	Type of Exploration	
	Free (n = 26)	Guided (n = 26)
Hours of Computer Use Per Day	f (%)	f (%)
1-3	12 (46%)	14 (54%)
4-7	13 (50%)	11 (42%)
8-11	1 (4%)	1 (4%)

As shown in Table 3, the applications used by students in the two groups were quite similar, with word processing and Internet use consuming the largest percentage of their time. Inspection of Table 3 reveals that students in the FE group reported spending a higher percent of their computer time (54%) in exploring the Internet than did those in the GE group (34%) and somewhat less time on word processing and computer games. Approximately 25% of students' reported daily computer use was related to email. Over 96 percent of the students reported that they had used computer simulations as part of their course work; however, substantially fewer (3%) reported that they played computer games. It is obvious from the table that the total of the daily use is not 100%. This is because many students reported that they work with more than one program at the same time, for example, working with the MS Word and Internet at the same time. The independent *t*-test showed significantly higher mean scores for the FE group than the GE group on percentage of daily use of Excel and Internet with $t_{50} = 2.10$, $p<0.05$ and $t_{50} = 2.95$, $p<0.05$, respectively.

TABLE 3. *Average proportion of time (%) students spent in various computer activities*

	Free Exploration (n=26)			Guided Exploration (n=26)		
	M (SE)	*Min*	*Max*	*M (SE)*	*Min*	*Max*
MS Word	43% (5.60)	1%	100%	46% (5.21)	2%	100%
Excel	3 % (1.11) *	0%	20%	0.4% (0.22) *	0%	5%
Power Point	1% (0.57)	0%	10%	1% (1.15)	0%	30%
Access	1 % (0.51)	0%	10%	0.04 % (0.04)	0%	8%
Internet	54 % (5.60) *	5%	98%	34%(4.20) *	5%	86%
E-mails	26 % (3.88)	5%	90%	25%(3.38)	4%	60%
Computer Game	0.5 % (0.36)	0	8%	3% (1.25)	0%	30%

* p< 0.05

Results of the OMKT pretest were used to compare the groups in terms of their prior relevant knowledge (Figures 6 and 7). As shown in Table 4, mean scores for the OMKT pretest were 9.81 (*SE* = 0.34) for the FE group and 8.62 (*SE* = 0.47) for the GE group. Scores ranged from 7-13 for the FE group and from 4-13 for the GE group. An independent groups *t* test showed that these group means were significantly different, $t_{50} = 2.06$, $p<.05$. Results of the computer scenarios pretest were also used to compare the groups in terms of their prior knowledge. Scenario 1 mean scores were 2.23 (*SD* = 1.56) for the FE group and 2.04 (*SD* = 1.22) for the GE group. Scenario 2 mean scores were 2.00 (*SD* = 1.17) for the FE group and 2.08 (*SD* = 1.02) for the GE group (Figures 4- 9). An independent groups *t* test showed that the group means were not significantly different for Scenarios 1 and 2, $t_{50} = 0.5$, $p>.05$, and t_{50}

= -.25, p>.05, respectively.

TABLE 4. *Performance, by exploration group, on the OMKT pretest*

	Free Exploration (n = 26)			Guided Exploration (n = 26)		
	OMKT	Scenario 1	Scenario 2	OMKT	Scenario 1	Scenario 2
M (SD)	9.81 (1.74)*	2.23 (1.56)	2.00 (1.17)	8.62 (2.4)*	2.04 (1.22)	2.08 (1.02)
Min	7	0	0	4	0	0
Max	13	6	4	13	4	4

* p< 0.05

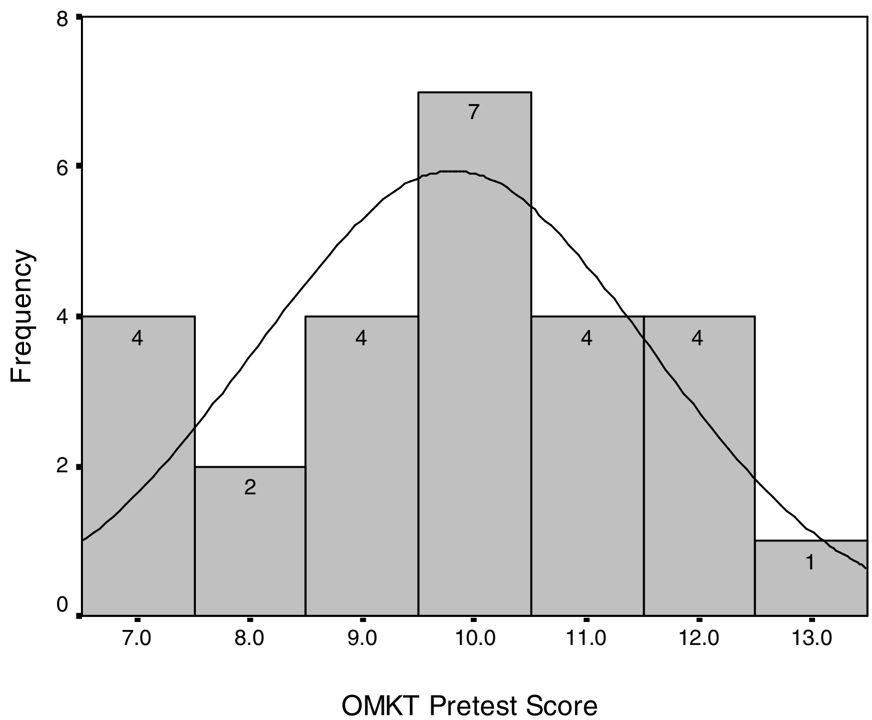

FIGURE 4. *Total OMKT pretest scores for the Free Exploration group (n = 26)*

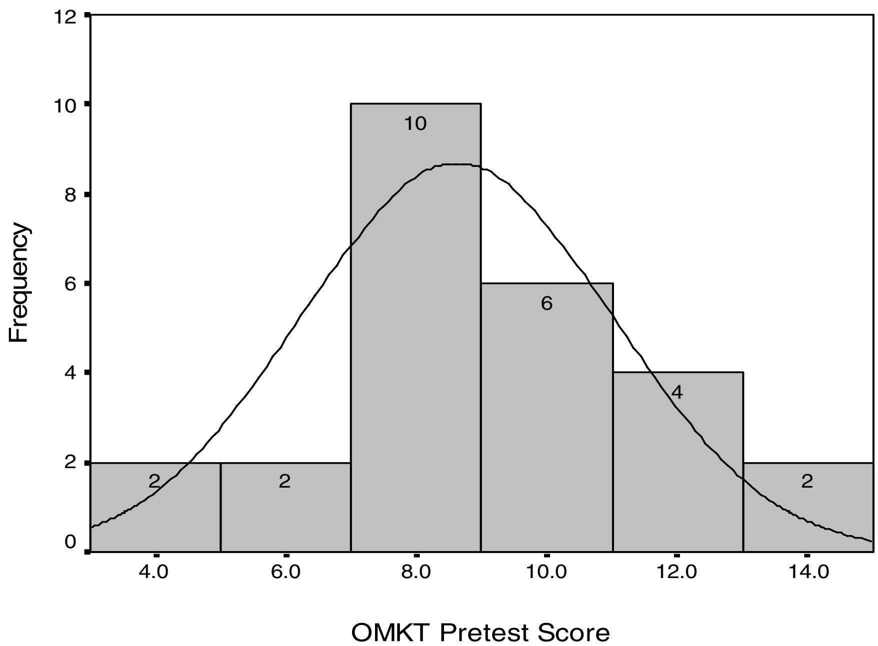

FIGURE 5. *Total OMKT pretest scores for the Guided Exploration group (n = 26)*

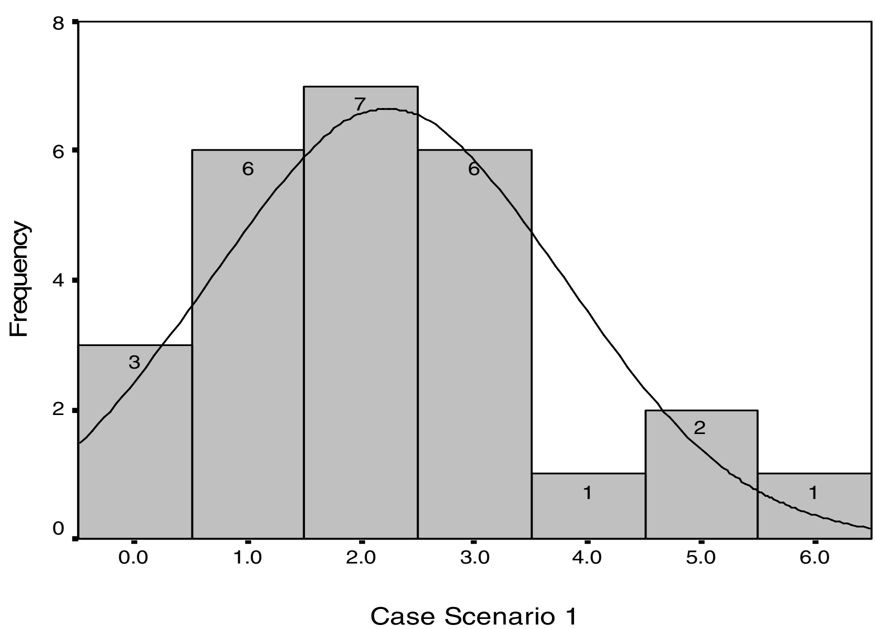

FIGURE 6. *Total Case Scenario 1 pretest scores for the Free Exploration group (n = 26)*

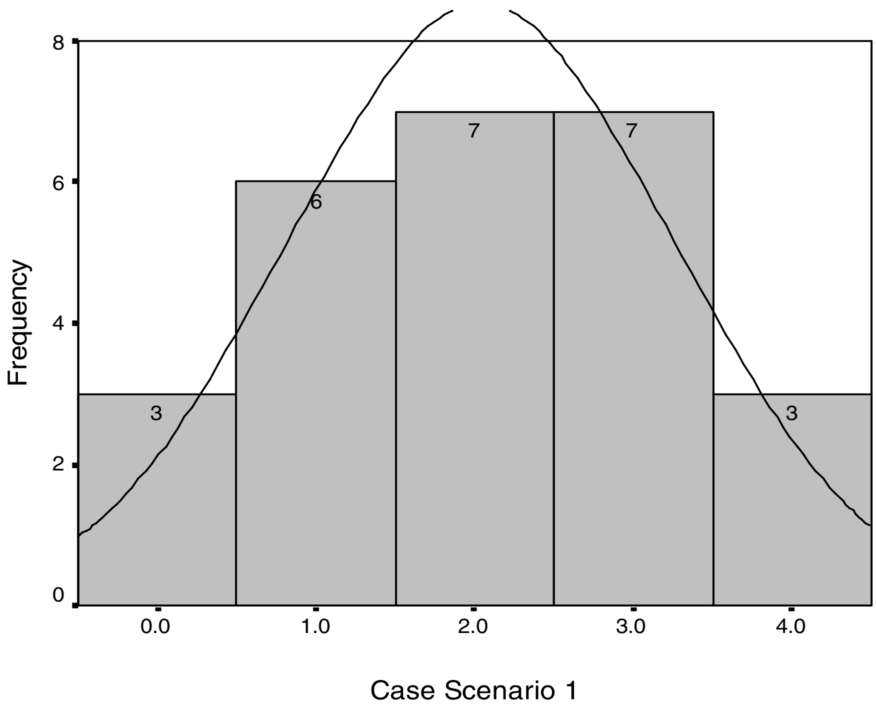

FIGURE 7. *Total Case Scenario 1 pretest scores for the Guided Exploration group (n = 26)*

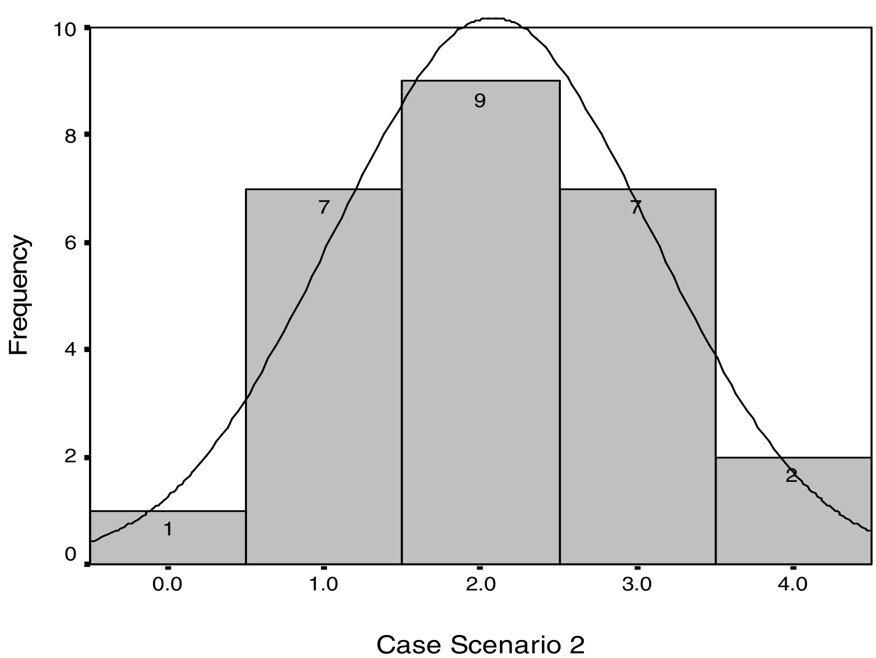

FIGURE 8. *Total Case Scenario 2 pretest scores for the Free Exploration group (n = 26)*

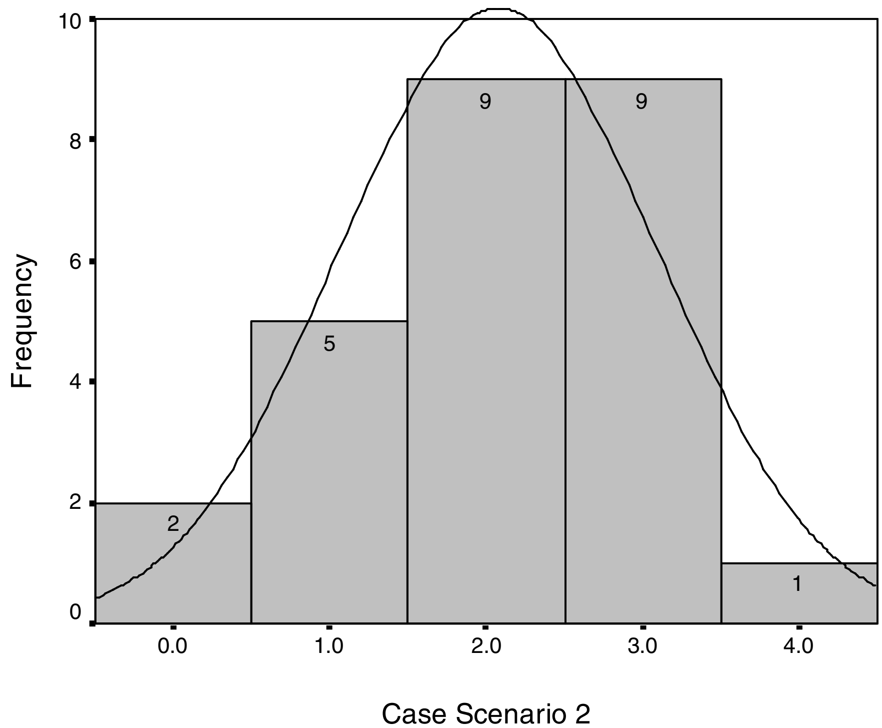

FIGURE 9. *Total Case Scenario 2 pretest scores for the Guided Exploration group (n = 26)*

Research Question 1

The first research question asked whether students' knowledge of oxygenation management principles, as measured by the OMKT, increased after working with an oxygenation management instructional computer simulation. Questions in the OMKT were developed at three levels of difficulty:

Level 1: Average students can answer the question without using the simulation, using the simulation can reinforce their knowledge.

Level 2: Good students can answer the question and the display will reinforce their understanding.

Level 3: Information that has not been taught and is not expected to be known *a* *priori*, but can be learned through the simulation.

OMKT mean total scores for all participants combined (N = 52) were 9.21 (SE = 0.30 on the pretest and increased slightly to 9.42 (SE = 0.30) on the posttest (see Table 5). A paired t test showed that these means did not differ significantly (t_{51}= -.91, p > .05). Given this result, further exploration was undertaken.

TABLE 5. *Pre and posttest scores on the Oxygen Management Knowledge Test (OMKT) (N=52)*

	M (SE)	*Min*	*Max*
Pretest	9.19 (0.30)	4	13
Posttest	9.44 (0.30)	4	14

Figure 10 shows the frequency of correct answers for each of the 14 OMKT questions in the pretest and posttest for the whole group (*N*=52).

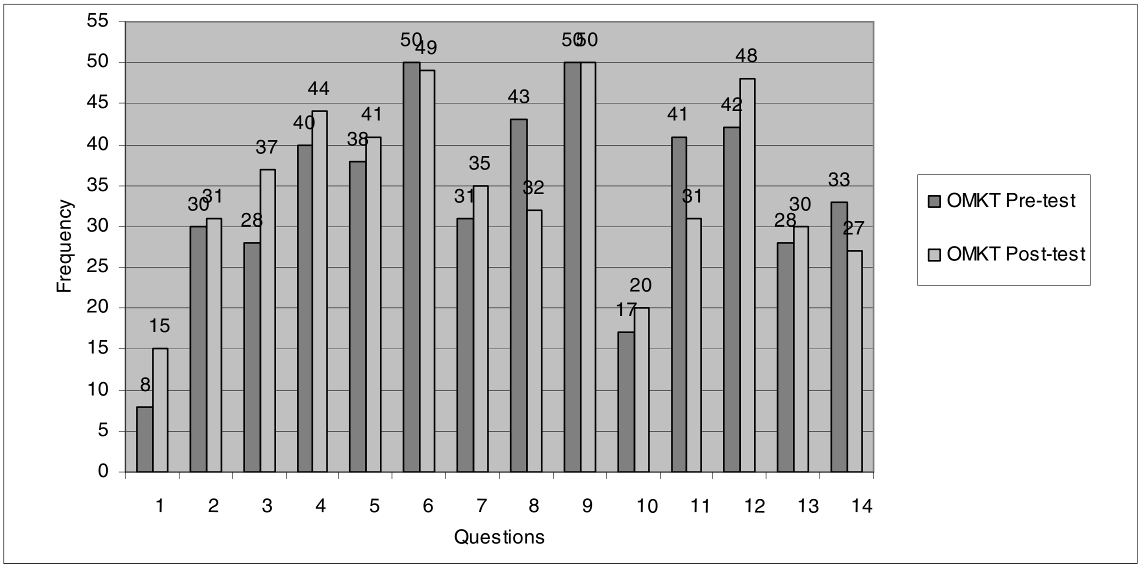

FIGURE 10. *Comparison of frequencies for the students' performance on the OMKT on the pretest and posttest*

TABLE 6. *Frequency and % of students' (N=52) correct responses to OMKT questions on the pre and posttests by level of difficulty*

	Frequency (%) of Correct Responses	
Level of Difficulty Question	Pre-test	Post-test
Level 1		
2. Suppose Dr. Mark ordered an Inotrope for Sally. Once you have started the Inotrope, which of the following change would you expect to find? a- Increased CVP b- Decreased HR c- Increased CO[a] d- Decreased Hgb		

	30 (58%)	31 (60%)
4. Sally's Hgb has dropped to 8.2 g/dl. Which of the following changes would you anticipate next?		
a- DO2 will increase.		
b- HR will not change		
c- CO will decrease		
d- Oxygen content will decrease[a]		
	40 (77%)	44 (85%)
6. You know that the major determinants of CO are:		
a- PAWP and SVR		
b- SV and HR[a]		
c- PAWP and HR		
d- PAWP, SVR, and HR	50 (92%)	49 (94%)
8. Sarah's heart rate has dropped. What other changes would you anticipate as a result?		
a- CO will increase		
b- CO will decrease[a]		
c- SV will increase	43 (83%)	32 (62%)
d- SVR will increase		
9. Sarah's cardiac output is falling. You expect t her oxygen delivery will:		
a- Decrease then will increase		
b- increase	50 (96%)	50 (96%)
c- decrease[a]		
d- not change		
Level 1 Mean	42.6	41.2
Level 2		
1. Based on the values above what would you expect to see in the physician's initial orders for Sally?		
a- Blood transfusion.		
b- Fluid replacement[a]	8 (15%)	15 (29%)
c- Oxygen		
d- An Inotrope		
3. Suppose Dr. Mark ordered packed red blood cells for Sally. Once the transfusion is		

complete, which of the following changes would you expect to see? a- Increased CO and SVR. b- Increase CO, CVP, and decrease DO_2. c- Decreased CVP, PAWP, CO, and SVR. d- Increased CVP, DO2, and PAWP[a]	28 (54%)	37 (71%)
5. Dr. Mark decided to order a vasodilator for Sally. Once the vasodilator is running, you would expect to see which of the following changes: a- Decreased SV, CVP, PAWP, and SVR[a] b- Decreased HR, CO, and increased SVR. c- Increased HR and CO d- Decreased Hgb and increased DO	38 (73%)	41 (79%)
12. Sarah's CaO2=18 ml/dl, as an ICU nurse y know that CaO2 is: a- The product of arterial oxygen saturation and hemoglobin[a] b- The sum of CVP and PAWP c- The product of SVR and MAP d- The ratio of CO to ER.	42(81%)	48(92%)
14. Sarah's SVR is rising; you know that an increased SVR will lead to: a- increased CO b- increased MAP c- increased CVP d- decreased CO[a]	33(64%)	27(52%)
Level 2 Mean	29.8	33.6
Level 3		
7. Sarah's heart rate is now 50 beats/min. As you call Dr. Nancy, you anticipate that she will order: a- Betablockers and Vasopressors b- Fluids and Oxygen c- Blood and Diuretics d- Inotrope, Diuretics and Vasodilators[a]	31 (60%)	35 (67%)

10. Dr. Nancy ordered a diuretic for Sarah. As you prepare to give this, you anticipate that the diuretic will: a- increase Sarah's CO and HR b- increase Sarah's Hgb, and DO2, and decrease CVP, and PAWP[a] c- decrease Sarah's CVP, PAWP and increase her SVR and MAP d- greatly decrease Sarah's Hgb, HR and DO2	17 (33%)	20 (39%)
11. Nurse Emma was caring for Sarah when she remembered reading in her book the other day about Extraction Ratio (ER); you will know that the ER is defined as: a- The ratio of SaO2 & Hgb (SaO2/Hgb). b- The ratio of CaO2 & Hgb (CaO2/Hgb). c- The ratio of CO & CI (CO/CI). d- The ratio of O2 uptake to O2 delivery (VO2/DO2) [a]	41 (79%)	31 (60%)
13. The main goal of oxygenation management is to: a- Manage the functions of oxygen and hemodynamics in the body. b- Manage the medications that treat major oxygenation and hemodynamic problems in the body. c- Manage the major Oxygen values that need to be investigated for ICU patients and know their normal values. d- Manage relationships among variables that help to get oxygen to the cell and treat related problems[a]	28 (54%)	30 (58%)
Level 3 Mean	29	29

(Note. Answers with ([a]) represent correct answer for this test question)

Table 6 shows students responses to questions by 'Level of Difficulty'. Inspection of Table 6 reveals that the mean number of correct responses on the posttest was lower than on the pretest for Level 1, the same for Level 3 and higher for Level 2. As shown in

Table 6, students' performance on the posttest improved on Questions 1, 2, 3, 4, 5, 7, 10, 12, and 13, showed no change on Question 9 and got worse on Questions 6, 8, 11, and 14. The average increase in frequency of correct answers for the nine questions on which students showed improvement from pre to posttest was 4.6. In contrast, the frequency of correct answers for questions 8, 11, and 14 decreased more dramatically (i.e., by 8, 11, and 14, respectively.) It is noteworthy that each of the three questions on which performance decreased from pre to post test required that the student understand the relationships among variables. For example, Question 8 asks about what changes occur when heart rate drops, Question 11 asks about what extraction ratio is, and Question 14 asks about the relationship of SVR and CO.

Question 8 asks about what changes might occur if heart rate (HR) drops. The issue about this question is that it has two potential correct answers, in that when heart rate drops the cardiac output decreases and the stroke volume increases. However, in the OMKT there is only one best answer that cardiac output would decrease because of the high preload and afterload. Thus the best answer for question 8 in the OMKT is that cardiac output will decrease. Question 8 is similar to Question 6 but is stated differently and is more related to the given case. It was expected that average students would have obtained this knowledge from their class, and that the display would reinforce it. The decrease in the frequency of correct responses to Question 8 on the posttest is surprising in two ways: First, several students failed to answer Question 8 correctly on the posttest but answered question 6 correctly in the pretest and posttest (n = 7). Second, there were students who answered this question as "decrease in cardiac output" on the pretest and answered that “stroke volume will increase” on the posttest (n = 9). This may indicate that the students learned from the display because Scenario 2 is a case of atrial fibrillation patient in which decreasing heart rate increases stroke volume and therefore cardiac output. As shown on Table 7, when considering both answers correct, the number of students who answered Question 8 increased in the pretest and posttest but still the frequency of correct answers on the posttest diminished by 7.

TABLE 7. *Frequency and % of students' (N=52) correct responses to question 8 in the OMKT on the pre and posttests when considering two answers correct*

	f (%)	
	Pretest	Posttest
Question 8		
Sarah's heart rate has dropped. What other changes would you anticipate as a result? e- CO will increase f- CO will decrease[a] g- SV will increase h- SVR will increase	49 (94%)	42 (81%)

Question 11 requires an understanding of Extraction Ratio (ER). ER is not discussed as part of the Advanced Med-Surg course, but since it is a central feature of the instructional display, I anticipated that they might learn to use it from working with the display. It may be that students simply ignored this variable because of its unfamiliarity and the display did not succeed in explaining it to them. Another explanation might be that the extraction ratio is a complex variable that consists of a ratio of two variables (oxygen uptake and oxygen consumption). I had emphasized in the exploration activity that students focus on single variables in their exploration. This was noticeable during their exploration. Looking back at the students' papers that they used to take notes during their exploration, only three students' added notes related to the extraction ratio.

Six fewer students answered question 14 correctly on the posttest. This question asks about the relationship between SVR and CO. During the experiment, some students commented that SVR is difficult to decrease when it is high. In addition, it may be that the relationship between the SVR and other variables was not clear in the display, and that interfered with their understanding how it is related to other variables.

Figures 11-13 show changes in the frequency of correct answers by 'Level of Question Difficulty.' The number of correct responses on the posttest was considerably lower than on the pretest for two Level 1 questions (Question 8), on one Level 2 question (Question14), and on one Level 3 question (Question 11).

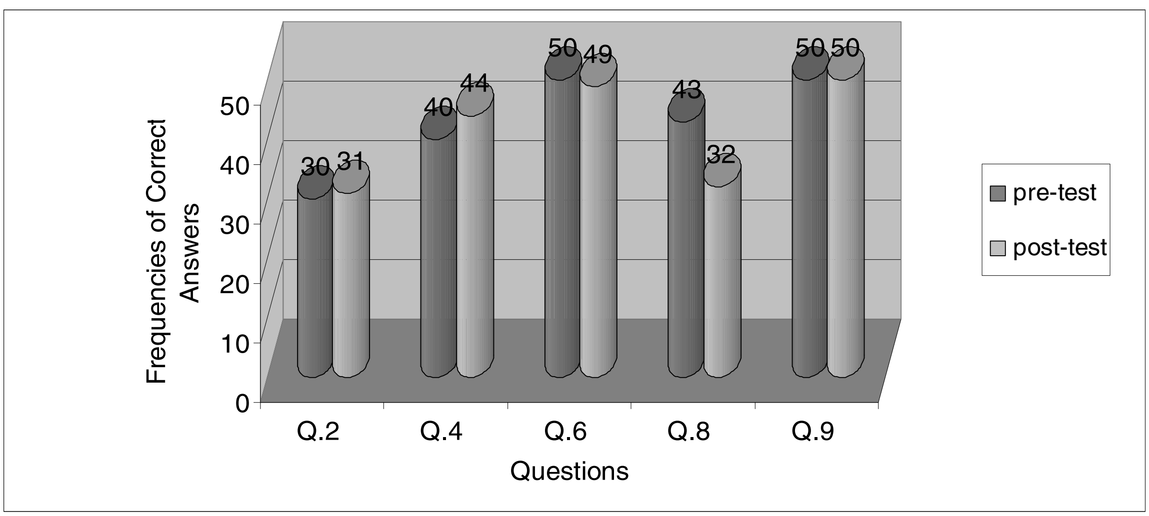

FIGURE 11. *Frequency of correct pre- and posttest responses to Level 1 OMKT questions (N = 52)*

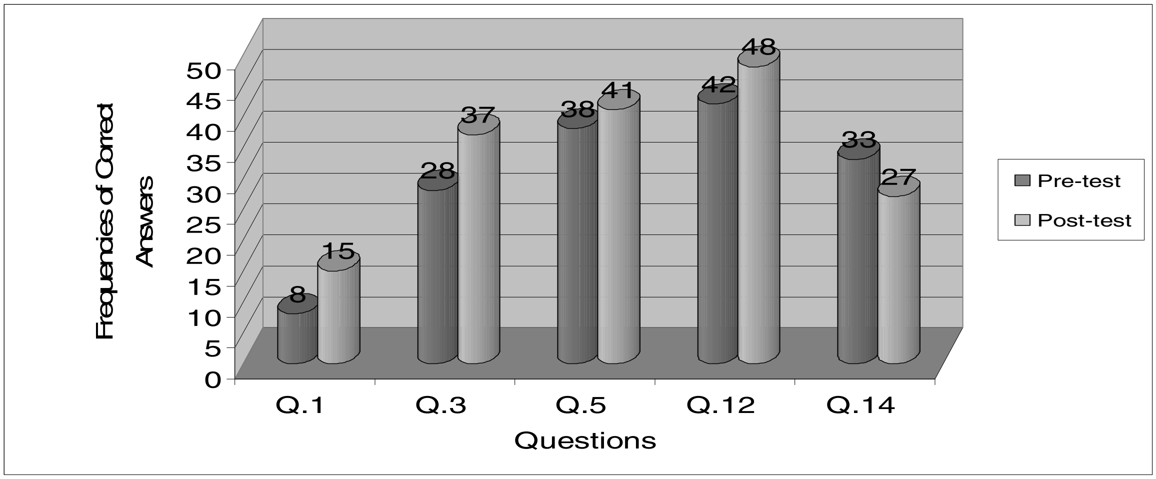

FIGURE 12. *Frequency of correct pre- and posttest responses to Level 2 OMKT questions (N = 52)*

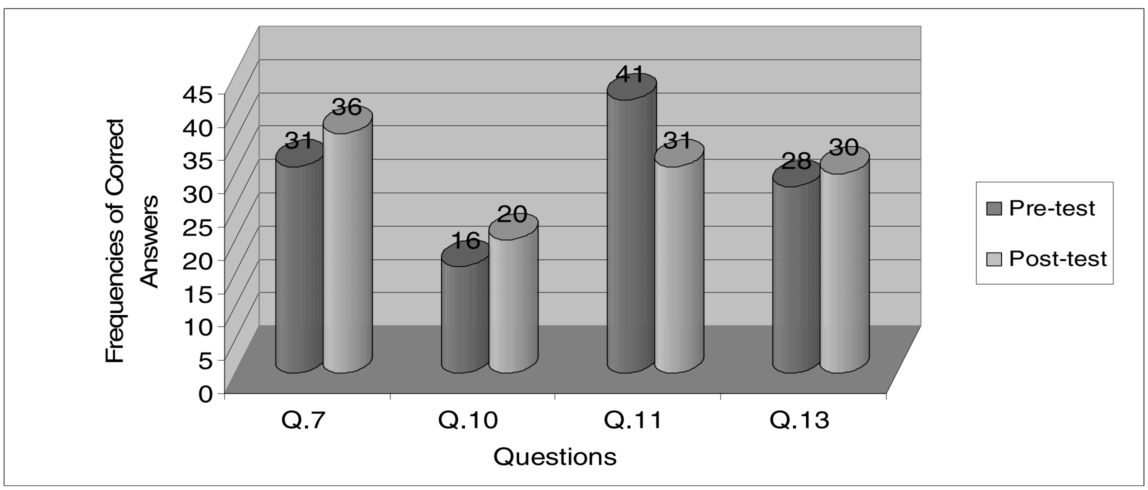

FIGURE 13. *Frequency of correct pre- and posttest responses to Level 3 OMKT questions (N = 52)*

Research Question 2

The second research question asked if type of exploration had any significant impact on students learning outcomes (knowledge and application of oxygen management principles). To measure performance, I used a composite learning outcome variable that is the sum of the normalized (*Z*-score) outcome measure (number of variables in normal range for case scenario 1 and 2, and students performance on the OMKT). The composite z-score was calculated as follows:

1) Differences between the number of outcome variables within normal ranges on the pre- and posttest were calculated for Scenario 1 for each student and then transformed into a *z*-score;
2) Differences between the number of outcome variables within normal ranges on the pre and posttest were calculated for Scenario 2 for each student and transformed into a *z*-score;
3) Differences in values between the pretest and posttest scores on the OMKT were calculated and then transformed to a *z*-score;
4) Z-scores for the three variables were added together to form the normalized composite learning outcome.

Examination of Table 8 reveals that the students in the FE group had a mean composite score of -.14 (*SE = 0.39*) and the GE group had a mean composite score of 0.14 (*SE = 0.23*). An independent group *t*-test was done to compare the differences in the composite learning outcome variable across groups. The results indicated that there were no overall significant differences on the overall learning outcome between the groups ($t_{50} = -.63$, $p>0.05$).

TABLE 8. *Mean, standard error, minimum, and maximum Z-scores for the OMKT, Case 1, Case 2, and the total composite score by exploratory group*

	Exploratory Group					
	Free (n=26)			Guided (n=26)		
Variables	*M (SE)*	*Min*	*Max*	*M (SE)*	*Min*	*Max*
OMKT	-.22 (0.19)	-2.52	1.67	0.22 (0.20)	-1.32	2.27
Case 1	-.20 (0.20)	-2.59	1.48	0.20 (0.19)	-1.91	1.47
Case 2	0.27 (0.20)	-1.96	2.50	-.27 (0.18)	-1.96	1.86
Composite Variable	-.14 (0.39)	-5.87	3.13	0.14 (0.23)	-2.57	2.45

OMKT performance. For the FE group, the mean pretest score was 9.81 (*SE* = 0.34) and the mean posttest score was 9.65 (*SE* = 0.38). For the GE group, the mean pretest score was 8.62 (*SE* = 0.47) and the mean posttest score was 9.19 (*SE* = 0.45) (Table 9). Difference scores (d) were calculated between pre and posttests for each group. A *t*-test revealed no significant difference in the difference scores for each exploration group ($t_{50} = -1.6$, $p>0.05$). A paired *t*-test was done to compare the learning outcomes of each group, as measured by the OMKT. Results of the*t* -test revealed that neither the FE group nor the GE group showed significant changes ($t_{25} = .49$, p>.05) and ($t_{25} = -1.73$, p>.05), respectively.

TABLE 9. *Individual OMKT scores and amount of change (d) by exploratory group*

Exploratory Group Subjects	*Pretest*	Posttest	differences
Free (n = 26)			
1	7	6	-1
3	9	8	-1
5	10	10	0
7	11	9	-2
9	10	10	0
11	11	11	0
13	11	11	0
15	12	11	-1
17	12	13	1
19	10	13	2
21	11	10	-1
23	9	7	-2
25	9	10	1
27	9	12	3
29	8	10	2
31	13	13	0
33	7	9	2
35	10	10	0

37	7	6	-1
39	7	8	1
41	8	7	-1
43	10	9	-1
45	10	10	0
47	12	8	-4
49	12	10	-2
51	10	10	0
M (SE)	9.81 (0.34)	9.65 (0.38)	-.15 (0.31)
Min	7	6	- 4
Max	13	13	3
Guided (*n* = 26)			
2	7	8	1
4	4	6	2
6	7	7	0
8	6	8	2
10	8	10	2
12	8	7	-1
14	6	8	2
16	7	8	1
18	4	4	0
20	9	8	-1

22	8	7	-1
24	11	10	-1
26	12	10	-2
28	8	10	2
30	13	13	0
32	9	10	1
34	9	11	2
36	12	11	-1
38	9	10	1
40	8	12	4
42	10	8	-2
44	8	9	1
46	11	14	3
48	8	11	3
50	9	7	-2
52	13	12	-1
M (SE)	8.62 (0.47)	9.19 (0.45)	0.58 (0.33)
Min	4	4	-2
Max	13	14	4

TABLE 10. *Frequency and % of correct responses to OMKT questions by level and exploration group*

	Exploratory Group			
	Free (*n* =26)		Guided (*n* =26)	
Level of Difficulty Question	Pre	Post	Pre	Post
Level 1				
2. Suppose Dr. Mark ordered an Inotrope for Sally. Once you have started the Inotrope, which of the following change would you expect to find? a- Increased CVP b- Decreased HR c- Increased CO[a] d- Decreased Hgb	18 (69%)	17 (65%)	12 (46%)	14 (54%)
4. Sally's Hgb has dropped to 8.2 g/dl. Which of the following changes would you anticipate next? a- DO2 will increase. b- HR will not change c- CO will decrease d- Oxygen content will decrease[a]	17 (65%)	21 (81%)	23 (89%)	23 (89%)
6. You know that the major determinants of CO are: a- PAWP and SVR b- SV and HR[a] c- PAWP and HR d- PAWP, SVR, and HR	25 (96%)	25 (96%)	25 (96%)	24 (92%)
8. Sarah's heart rate has dropped. What other changes would you anticipate as a result? a- CO will increase b- CO will decrease[a] c- SV will increase d- SVR will increase	25 (96%)	19 (73%)	18 (69%)	13 (50%)

*9. S*arah's cardiac output is falling. You expect that her oxygen delivery will: a- Decrease then will increase b- increase c- decrease[a] d- not change	24 (92%)	25 (96)	26 (100%)	25 (96%)
Mean	21.8	21.4	20.8	19.8
Level 2				
1. Based on the values above what would you expect to see in the physician's initial orders for Sally? a- Blood transfusion. b- Fluid replacement[a] c- Oxygen d- An Inotrope	4 (15%)	9 (35%)	4 (15%)	6 (23%)
3. Suppose Dr. Mark ordered packed red blood cells for Sally. Once the transfusion is complete, which of the following changes would you expect to see? a- Increased CO and SVR. b- Increase CO, CVP, and decrease DO_2. c- Decreased CVP, PAWP, CO, and SVR. d- Increased CVP, DO2, and PAWP[a]	19 (73%)	20 (77%)	9 (35%)	17 (65%)
5. Dr. Mark decided to order a vasodilator for Sally. Once the vasodilator is running, you would expect to see which of the following changes: a- Decreased SV, CVP, PAWP, and SVR[a] b- Decreased HR, CO, and increased SVR. c- Increased HR and CO d- Decreased Hgb and increased DO	18 (69%)	19 (73%)	20 (77%)	22 (85%)
12. Sarah's CaO2=18 ml/dl, as an ICU nurse you know that CaO2 is: a- The product of arterial oxygen	22	23	20	25

saturation and hemoglobin[a]	(85%)	(89%)	(77%)	(96%)
b- The sum of CVP and PAWP				
c- The product of SVR and MAP				
d- The ratio of CO to ER.				
14. Sarah's SVR is rising; you know that				
an increased SVR will lead to:	19	14	14	13
a- increased CO				
b- increased MAP	(73%)	(54%)	(54%)	(50%)
c- increased CVP				
d- decreased CO[a]				
Mean	16.4	17	13.4	16.6
Level 3				
7. Sarah's heart rate is now 50 beats/min. As you call Dr. Nancy, you anticipate that she will order:				
a- Betablockers and Vasopressors				
b- Fluids and Oxygen	16	19	15	16
c- Blood and Diuretics				
d- Inotrope, Diuretics and Vasodilators[a]	(62%)	(73%)	(58%)	(62%)
10. Dr. Nancy ordered a diuretic for Sarah. As you prepare to give this, you anticipate that the diuretic will:				
a- increase Sarah's CO and HR				
b- increase Sarah's Hgb, and DO2, and decrease CVP, and PAWP[a]	11	7	6	13
c- decrease Sarah's CVP, PAWP and increase her SVR and MAP	(42%)	(27%)	(23%)	(50%)
d- greatly decrease Sarah's Hgb, HR and DO2				
11. Nurse Emma was caring for Sarah when she remembered reading in her book the other day about Extraction Ratio (ER); you will know that the ER is defined as:	22	16	19	15
a- The ratio of SaO2 & Hgb (SaO2/Hgb).	(85%)	(62%)	(73%)	(58%)
b- The ratio of CaO2 & Hgb (CaO2/Hgb).				

c- The ratio of CO & CI (CO/CI). d- The ratio of O2 uptake to O2 delivery (VO2/DO2) [a]				
13. The main goal of oxygenation management is to: a- Manage the functions of oxygen and hemodynamics in the body. b- Manage the medications that treat major oxygenation and hemodynamic problems in the body. c- Manage the major Oxygen values that need to be investigated for ICU patients and know their normal values. d- Manage relationships among variables that help to get oxygen to the cell and treat related problems[a]	15 (58%)	17 (65%)	13 (50%)	13 (50%)
Mean	16	14.75	13.25	14.25
Overall Mean	18.21	17.92	16	17.07

Level 1: The questions that average students can answer and the simulation reinforces
Level 2: The questions that good student can answer and simulation reinforce
Level 3: The questions measures students learning from simulation
[a] The correct answer

FE performance on the OMKT. As shown in Table 10 (above) and Figure 14 (below), the FE group did best on questions 6, 8, and 9 (all Level 1) and least well on Questions 1 (Level 2), and 10 (Level 3) on the pretest. This is not too surprising, given the varying question difficulty. After freely exploring the simulation, students did best on Questions 6 and 9 and least well on Questions 1 and 10. Most improvement was seen on Questions 1, 4, and 7. Questions 1 (Level 2) and 7 (Level 3) ask about interventions in certain clinical situations, and Question 4 (Level 1) asks about the relationship among hemoglobin and oxygen content. Most degradation was seen on Questions 8 (Level 1), 11 (Level 3), and 14 (Level 2), with differences between pre exploration and post exploration of (d = 6), (d = 6), and (d = 5) respectively. This group improved only on Level 2 questions while it deteriorated on Level 1 and 3 questions.

GE performance on the OMKT. As shown in Table 10 (above) and Figure 15 (below), the GE group did best on Questions 6, and 9 (all Level 1) and least well on Questions 1, 3 (both Level 2), and 10 (Level 3) on the pretest. After their instructional exploration for the simulation, students did best on Questions 6 and 9, 12 and least well on Question 1. Most improvement was seen on Questions 3, 10, and 12. Questions 3 (Level 2) and 10 (Level 3) ask about changes in variables when giving blood as in question 3 or after giving diuretics as in question 10 and 12 (Level 2) asks about the relationship between SaO2, hemoglobin and arterial oxygen saturation. Most degradation was seen on Questions 8 (Level 1), and 11 (Level 3), with differences between pre exploration and post exploration of (d = 5), and (d = 4) respectively. This group improved the most on Level 2 questions while it deteriorated on Level 1 questions.

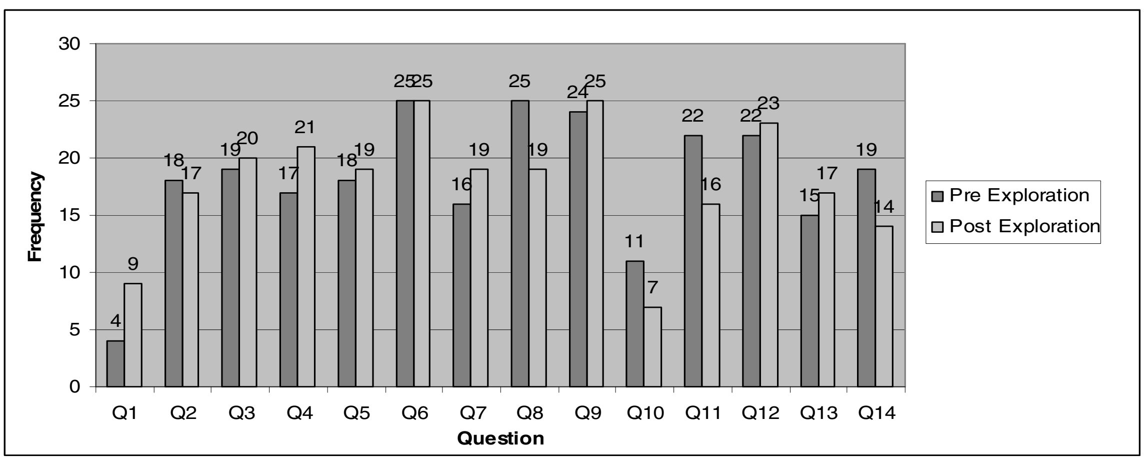

FIGURE 14. *Frequency of correct responses to OMKT questions by FE group (n = 26)*

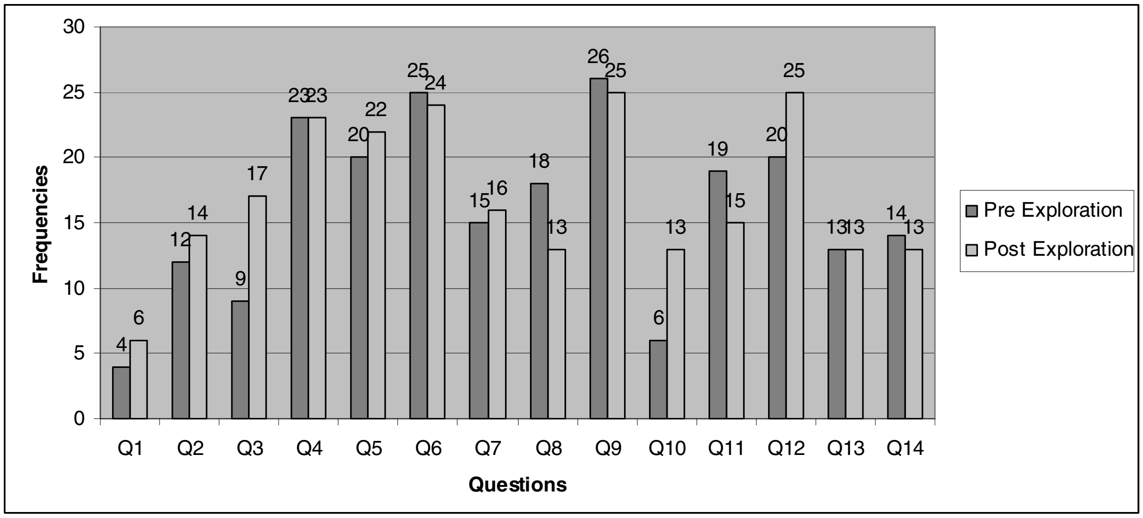

FIGURE 15. *Frequency of correct responses to OMKT questions by GE group (n = 26)*

Case Scenario performance. Students were asked to use the available drugs to treat two clinical problems. The same problems were used in the pre and posttest conditions. Each scenario ran for 10 minutes. Students were expected to bring eight variables (PAWP, MAP, SVR, HR, CO, Hgb, SaO2, and DO2) to within the normal, target range by the end of the 10 minutes. Because the computer failed to record the full 10 minutes of data for all participants, a new cutoff point was adopted (9:50) which allowed me to collect complete and equivalent data for all participants. Since there is some fluctuation in the simulation values from second to second, I used the average of the five values closest to the completion time (9:50).

The mean number of variables within normal range at the conclusion of each scenario is shown by exploration group and pre and posttest conditions in Table 11. Inspection of Table 11 reveals that, for Scenario 1, the mean number of variables corrected by the FE group in the pretest condition was 3.23 (*SE* = 0.31, Range 1 - 7) and in the posttest condition, 2.77 (*SE* = 0.17, Range 1 - 4). The mean number of variables corrected by the GE group in the pretest condition was 3.00 (*SE* = 0.24, Range 1 - 5) and, in the posttest condition, 3.12 (*SE* = 0.18, Range 1 - 5). An independent*t* -test using the *d* scores showed no significant difference between the exploration groups, $t_{50} = -1.42$, $p>0.05$.

For Scenario 2, the mean number of variables corrected by the FE group in the pretest condition was 4.03 (*SE* = 0.26, Range 1 - 7) and, in the posttest condition, 4.54 (*SE = 0.22,* Range 2 - 7). The mean number of variables corrected by the GE group in the pretest condition was 4.19 (*SE* = 0.20, Range 2 - 6) and, in the posttest condition, 3.85 (*SE* = 0.23, Range 2 - 6). An independent groups *t*-test using the *d* scores showed no significant difference between the groups, $t_{50} = 2.00$, $p>0.05$.

TABLE 11. *Mean number of variables in target range in the pre- and posttest conditions by scenario and exploratory group*

	Exploratory Group			
	Free (*n* = 26)		Guided (*n* = 26)	
	Pre	Post	Pre	Post
	M (SE)	*M (SE)*	*M (SE)*	*M (SE)*
Scenario 1	3.23 (0.31)	2.77 (0.17)	3.00 (0.24)	3.12 (0.18)
Scenario 2	4.03 (0.26)	4.54 (0.22)	4.19 (0.20)	3.85 (0.23)
Scenario 3 (Transfer)	[a]	4.15 (0.30)	[a]	4.27 (0.26)

[a] No record in the pre exploration because this is transfer case.

Table 12 displays the mean number of variables corrected by each exploratory group for each scenario. According to table 12, in Scenario 1, only one variable, SaO_2, was corrected by more than half the group; this is true for both Free and GE groups. This suggests that the task was very difficult for them. Heart rate was corrected on the pretest by over 50% of the FE group and less than 50% on the posttest, while the GE group corrected HR by less than 50% of on the pretest and more than 65 % on the posttest. None of the students in either group corrected either DO_2 or SVR on the posttest, although a single student did so in each group on the pretest (with the exception of DO_2 and the Free Exploratory group).

In Scenario 2, SaO_2 was the only variable corrected by more than 75% of the students on both pre and posttest trials—and this was true of both exploratory groups. The groups differed on two variables particularly: SVR was controlled by 9 of the FE group on the pretest and 15 on the posttest. In contrast, SVR was controlled by 13 of the GE group on the pretest and only 6 on the posttest. A similar pattern exists for cardiac output (CO). Eleven of the FE group controlled CO on the pretest and 15 on the posttest. In contrast, 13 of the GE group controlled CO on the pretest and 9 on the posttest. This might be due to the fact that many students in the GE group did not have enough time to correct those two variables during their exploratory practice.

According to my experiment observation notes, many students at the FE group reported that they finished their exploration within 22 - 27 minutes. The opposite was true for the GE group. The majority of them did not have enough time to finish all the required tasks (such as increasing SVR and DO_2 to the target value). Interestingly, some students in the GE group worked with more than one variable at a time. For example, some of them were working to increase (or decrease) Hgb and HR at the same time, as evidenced by their notes in which they indicated that they were using a drug to accomplish two tasks at once. Many of the GE group preferred to start tasks that they were familiar with, such as increasing Hgb. Some of the GE group started to work on some tasks such as increasing or decreasing CO, then moved on to another task before completing that one. Students had difficulty working with this task, which might explain why the GE group controlled this variable worse on the posttest in both case scenarios. Some GE students found it difficult to wait until the target range dictated by the task was reached; and some of them spent too much time controlling a single variable. I observed that the groups' strategies differed. The FE group would give a certain drug and then observe the changes that occurred, while the GE group gave more than one drug at a time and observed if this would help to achieve the task goal.

TABLE 12. *Frequency with which individual variables were corrected to normal by scenario, exploratory group, and trial*

	Scenario 1				Scenario 2				Scenario 3 (Transfer)			
	Free		Guided		Free		Guided		Free		Guided	
	n = 26		*n* = 26		*n* = 26		*n* = 26		*n* = 26		*n* = 26	
Variables	pre	Post	pre	post	Pre	Post	Pre	Post	pre	post	pre	Post
PAWP	6	4	6	6	6	7	2	4	-	6	-	4
MAP	6	4	6	1	23[a]	24[a]	18[a]	20[a]	-	17[a]	-	16[a]
SVR	1	0	1	0	9	15	13	6	-	10	-	7
HR	15	11	11	17	8	6	8	9	-	8	-	13
CO	12	7	9	7	11	15	13	9	-	13[a]	-	13[a]

Hgb	25[a]	23[a]	25[a]	22[a]	25[a]	26[a]	26[a]	24[a]	-	26[a]	-	26[a]
SaO2	19	22	19	23	22	21	25	24	-	19	-	26
DO2	0	0	1	0	2	3	2	4	-	8	-	6

[a] Variables were in normal range when the case started
- Case was only given in the post exploration thus no pre-exploration values

Outlier. An outlier was detected when transferring the d-values to z-scores (Fig. 16). The outlier showed up in the total group initially, and then was isolated to the free exploration group (Fig. 17). I tried to overcome this problem by transforming the values by using their square roots, but this did not help with the overall z-scores. Then I decided to temporarily delete the case and assess the impact on the free exploration group. A *t*-test was done excluding this case revealed no significant differences on the overall learning outcome between free and guided exploration groups, $t_{49} = -.58$, $p>0.05$. In addition, the t-test did not show significant mean differences between the OMKT, Case 1, and Case 2 ($t_{49} = -1.43$, $p>0.05$, $t_{49} = -1.02$, $p>0.05$, $t_{49} = -1.64$, $p>0.05$) respectively.

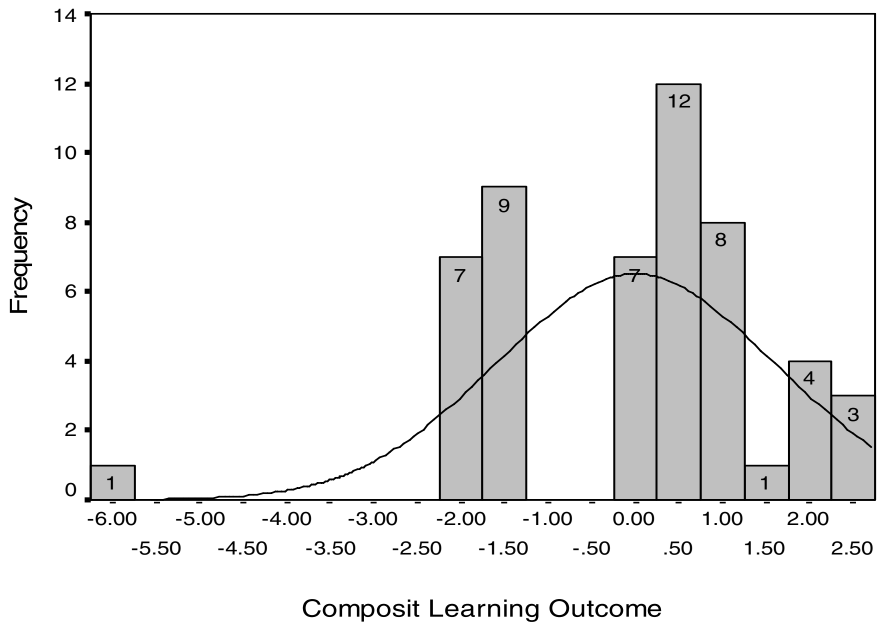

FIGURE 16. *Outlier present within the composite variable*

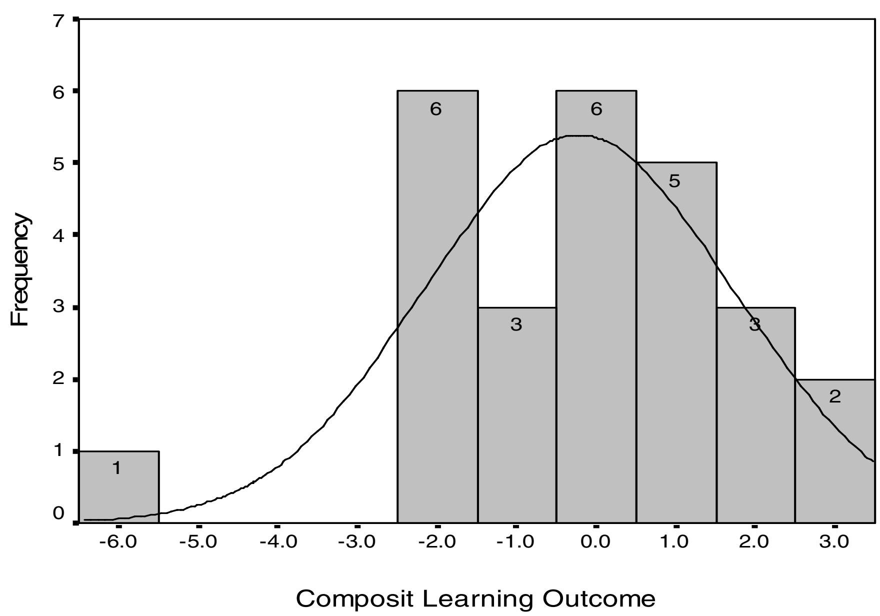

FIGURE 17. *Outlier in the Free Exploration group for the composite variable*

Research Question 3

The third research question asked whether there is a differential effect of FE vs. GE on students' abilities to transfer to novel situations the oxygenation management principles learned while using the oxygenation management instructional computer simulation. Knowledge transfer was measured by students' performance when they viewed a previously unseen case scenario post exploration. Table 11 (above) reveals that the mean number of variables corrected for the transfer scenario were 4.15 (*SE* = 0.30) for the FE group and 4.27 (*SE* = 0.26) for the GE group. An independent groups *t*-test confirmed that these means were not significantly different ($t_{50} = -.29$, $p > 0.05$).

As shown in Table 12 (above), students' performance on Scenario 3 is very interesting in that students in both groups controlled the higher order variables DO_2 and SaO_2 better than in the previous scenarios. Their performance on this case is consistent with the goal of the simulation, which is managing relationships among variables that help get oxygen to the cell. More students seem to have paid attention to SVR, which might be an indication that the students may have learned though using the simulation what drugs might control it.

Further Analysis

A bivariate correlation was run to determine whether there were any significant correlations between students' computer usage and their overall performance. The results showed no significant correlation. Moreover, there was no significant correlation between their computer usage and the difference scores on the OMKT, Scenario 1, Scenario 2, and Scenario 3.

Table 13 shows the mean number of drugs given in each scenario on the pre and post test by exploratory group. The mean number of drugs increased slightly on the post test in all but one case. The means were higher than the means of drugs given by novice doctors and novice critical care nurses on the same scenarios in another research study (Effken, 2004). An independent group's *t*-test was run to determine whether the number of drugs was significantly different post exploration between the groups. Results showed no significant differences between groups on Scenarios 1 (t_{50} = -1.78, p>0.05), 2 (t_{50} = 0.32, p>0.05), or 3 (t_{50} = -.40, p>0.05).

TABLE 13. *Mean number of drugs used by each scenario, exploratory group, and trial*

	Exploratory Group			
	Free		Guided	
	Pre	Post	Pre	Post
Cases	M (*SD*)	M (*SD*)	M (*SD*)	M (*SD*)
Case Scenario 1	7.12 (1.4)	7.19 (1.13)	7.12 (1.4)	7.65 (0.69)
Case Scenario 2	6.42 (1.2)	6.08 (1.35)	5.73 (1.08)	5.96 (1.24)
Case Scenario 3 (Transfer)		5.8 (1.44)		5.96 (1.31)

Conclusion

This chapter described the results of the data analysis. A description of the sample was provided, followed by the results of data analysis to answer the three research questions.

CHAPTER FIVE

Discussion

Introduction

This chapter will present the general discussion of the results, its implications, limitations, and future research.

The purpose of this research was to measure nursing students' learning outcomes after using an oxygen management computer display under two exploratory conditions: guided and free exploration. This discussion will mainly follow Jenkins (1979) Tetrahedron Model (Figure 16). In his Tetrahedron Model, Jenkins argues that learning and memory depend on four components: (a) the nature of the learners (in this study, nursing students' knowledge and computer experience), (b) orienting tasks (in this study, the type of exploration instructions), (c) the kinds of materials used (here, the computer display), and (d) criterial tasks (here, students' performance on the OMKT and Scenarios). Jenkins' model describes the interactions among the four components interacting. This study focused on six of those interactions:

1) Subjects and criterial tasks. This describes the interaction between the students prior knowledge and characteristics and their performance on the OMKT and Scenarios;
2) Material and criterial tasks. This describes how much the computer simulation increased the knowledge of students, as measured by the OMKT and the clinical scenarios;
3) Orienting task and criterial task. This describes the interrelationship between

the type of exploration and performance;

4) Subjects and orienting tasks. This describes the relationship among students' characteristics and their exploration;

5) Orienting task and material interaction. This describes the how the exploration style interacts with the computer simulation; and

6) Subjects and materials. This describes how student characteristics might interact with the exploration strategies.

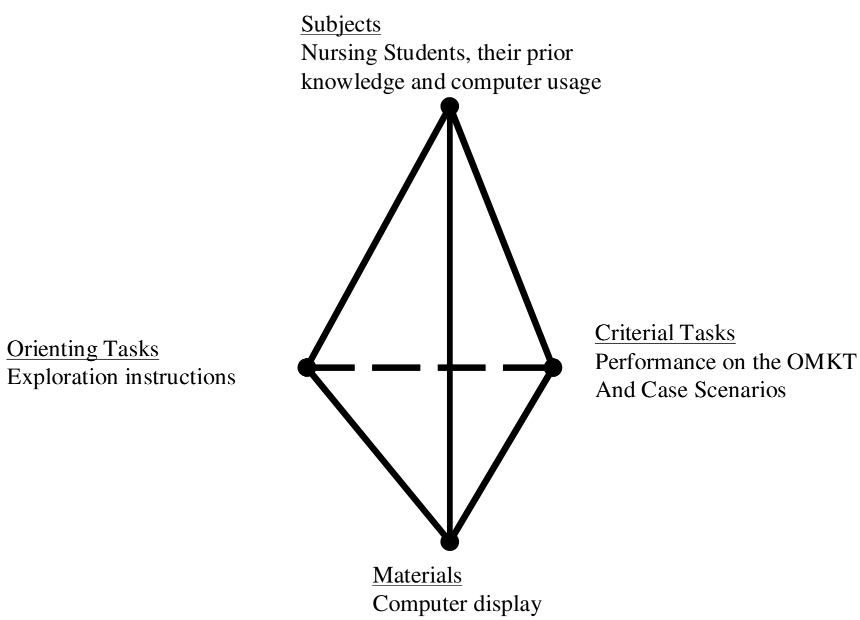

FIGURE 18. *The Theorist Tetrahedron*

Subjects and criterial tasks

The students, who were either in or had just finished a critical care course, were randomly assigned into Free and GE Groups. The Free and GE Groups were similar in terms of their age, and use of all computer applications except Internet and computer simulations. The FE group used the Internet significantly more than the GE group; while the GE groups used computer simulations significantly more than the FE group. Neither group spent much time playing computer games, which is consistent with the literature on female students (e.g., Eglesz et al., 2005). It is noteworthy that the FE group scored significantly higher on the OMKT pretest than did the GE group.

In terms of knowledge outcomes, there were no significant differences between the groups' knowledge outcomes, which are different from the results reported by Mitchell et al. (2005) in which learners with lower domain knowledge showed greater improvement in learning. This was not noticeable in this study because the GE group did not show significant improvement in knowledge although they had lower scores on the OMKT pretest.

Materials and criterial tasks

The goal of this research was to test two hypotheses: 1) The instructional simulation will increase students' general knowledge of oxygen management, as evidenced by significantly higher mean scores on the posttests than on the pretests, and 2) the GE group's learning outcomes will improve more than the FE group. Results indicated that, when all students were included, there was no significant improvement in their oxygen management scores on the OMKT or clinical scenarios from pre to posttest. This means that the computer simulation did not improve students' oxygen management knowledge as expected.

Orienting tasks and criterial tasks

Similarly, the results did not reveal any significant differences in learning outcomes between the Free and GE groups. Thus the results cannot inform us about what kind of exploration might be better for learning with computer simulations.

Although the overall results were not statistically significant for either the OKMT or clinical scenarios, still there is some evidence to suggest that students did learn something from working with the computer simulation. For example, the FE group more frequently answered questions 1 (Level 2), 4 (Level 1), and 7 (Level 3) correctly on the posttest and the GE group was more likely to answer questions 3 (Level 2), 10 (Level 3) and 12 (Level 2) correctly on the posttest. Thus, when the FE group interacted with the simulation, the students learned more related to some questions at all three levels while GE group learned something related to questions at only two levels. This difference might suggest that each type of exploration might be useful for learning different kinds of things. However, the reason for this remains unclear and awaits further research.

All students were able to maintain SaO_2 at high levels, which is a higher order goal of oxygenation management. Moreover, FE students were able to improve their control of variables such as SVR and CO in Scenario 2 and of SVR and CO in Scenario 3 (Transfer). GE students improved their control of SVR in Scenario 3 (Transfer) and of HR in Scenarios 2 and 3 (Transfer). This suggests that they had learned to handle the basic task, at least for these variables. Thus, even though this simulation was not built for educational purposes, it still helped students learn something about oxygenation management. This is consistent with Kashihara et al. (2002) and Issenberg et al’s (1999) conclusions that simulations have proven to be effective in medical education for learning anatomical structure, as well as for improving diagnosis and treatment skills.

Subjects and orienting tasks

Based on my observations of students as they explored, it was apparent to me that each group had adopted a different exploratory strategy. Students in the FE group typically administered each drug separately and then observed changes occur within and among variables. By contrast, students in the GE group first identified the desired goal, and then tried giving drugs that they suspected could achieve that goal. This strategy might have required them to tap into their prior knowledge, formulate different hypothesis and explore each hypothesis then interpret the result, which may have reinforced that knowledge. This might support Kulger et al's (1991) idea that, with each step closer to the goal, the information must become ever more specific, thereby, tightening the reins on how the action path unfolds, until ultimately, at the amount of accomplishment, the path becomes uniquely defined. Thus the students were trying each drug that might help them to achieve one goal until they could figure out the suitable drug.

Orienting tasks and materials

One might hypothesize that the computer simulation used in this research is more suitable for FE than for GE because in the display there are many variables that are interrelated and it is difficult to restrict students to correcting a single variable and essentially ignoring the others. In fact, this task may not be ecologically (or at least clinically) valid. The instructional simulation was developed using ecological interface design (EID) techniques. EID emphasizes a perception/action approach to ecological affordances that attempts to show, in the display, the constraints that are inherent in the clinical case (e.g., pressure = f (flow, resistance)). If the display is working as intended, students should be influenced by the constraints of the display, (i.e., the way the variables are presented.) That this might have been the case is evidenced by the fact that some students in the GE group attempted to correct more than one variable at a time. This also might be why I had to direct many students repeatedly to follow the exploration guidelines in the instructions and not to do more than one task at a time. This might be due to two reasons: 1) Trudel and Payne (1995) suggested that one of the remaining gaps in exploratory learning is to get students to accept the tasks. This clearly was evident in the GE group, 2). Because EID attempts to integrate data elements by making relationships apparent, it may better support FE. However, it is unclear whether FE better facilitates learning with such simulations. Some have argued that computer simulations need to have features and characteristics that support exploration (Kashihara, 2002; Oostendorp & Mul, 1999; Soto, 1999). I would suggest that simulations need to have features and characteristics that support each type of exploration (free vs. guided). Based on Jenkins (1979) arguments, there may be no inherently better type of exploration, but there may need to be a match, or fit, between the material to be taught and the type of exploration.

Subjects and material

Interestingly, the majority of students in the GE group chose as their first exploratory task increasing Hgb to 15. This might be due to their familiarity with this task. De Jong and Van Joolingen (1998) have reported that some learners tend to avoid testing hypotheses that have a high chance of being rejected and instead focus on testing those that have a high likelihood of success.

Implications

This research has two implications: 1) This research will encourage researchers to probe more into the best way to learn to use computer simulations based on ecological interface theory (Vicente,1992) especially they are being used in medical and nursing fields (Vicente, 2002, Christoferson et al., 1996, 1997); 2) The research can inform simulation designers, that when planning to prepare teaching materials for simulations, it is essential to consider the theory that underpins the simulation. For example the simulation used for this study is built based on the ecological psychology theory; therefore, it is essential to consider the components of this theory when developing the instructional guidance to get better learning outcomes.

Limitations

This study has several limitations:

1- One of the major limitations in this study was the dubtful reliability of the OMKT.

2- In this study, the time constraints imposed by a two-hour experiment were a serious limitation. It is likely that this amount of time is not enough for students to learn to use the simulation and apply their knowledge effectively. Christofferson et al. (1996) emphasized this point when they conducted their longitudinal study to study the influence of interface designs on deep learning outcomes and it took a very long time (6 months) for students to learn to use the complex simulation effectively.

3- Another limitation is the way I measured display scenarios. Rather than using the many variables that are available in each case scenario, I limited the number of variables measured.

4- The value for CVP in the display is abnormally high (8-14 mm Hg). The usual norm is 2-6 mm Hg.

5- The time delay in the display might influence the students' performance and made the tasks more difficult, the delayed feedback drugs take effect at different rates, and different variables respond slower or faster.

6- The complexity of the scenarios used here has been found in previous studies to be difficulty for even experts.

7- While it was useful to see if students could learn anything from it in a short period of time, this simulation was not designed as an instructional tool.

8- This study is underpowered to detect possible effects.

Future Research

Secondary data analysis considering all the display variables is suggested. In, addition, it would be important to compare students' performance at 5 minutes and then 10 minutes of their working with the display. This would give more insight into the students' overall performance. In addition, I accepted as "learning" only improvement in scores, but it is plausible that lowered scores also represent learning and the secondary analysis might take this into account.

Because exploration is a process of experimenting, stating a hypothesis, and interpreting the results of the experiments, thinking aloud technique might unveil many uncovered issues related to this research. In addition, I would consider changing the instructions (define free and guided exploration differently) to be more compatible with the display. This too will provide more information about what might help learners learn with this display. In addition, studies of complex simulations such as that used in this study may require a longitudinal study with repeated measures. Thus it is essential to overcome the time constraint in terms of learning the display.

To understand more fully the effect of FE and GE on students' learning outcomes with instructional simulations, it is important first to determine whether the simulation can be used effectively under both types of exploration. Another future study suggested is to determine which is more efficient, Free or GE, when using another computer simulation.

Even though this simulation was not designed as an instructional tool, it still would be interesting to test learning outcomes in terms of intuitive knowledge gained when working with the simulation. Such testing is called an Intuitive Knowledge Test or a "What if?" Test. This test could show if this simulation increases students' intuitive knowledge. Swaak, Van Joolingen, and De Jong (1998) reported that in simulation based learning, students gain more intuitive knowledge.

It was noticeable in this research that some students preferred free exploration even though they were assigned to the guided exploration group. Thus it would be interesting to know what learner characteristics make them prefer guided exploration or free exploration as a learning strategy when they are using a computer simulation.

In the literature there is still an overlap between the concepts of Discovery and Exploration. Thus I would suggest future concept analysis for the terms Free Exploration, Guided Exploratory, Free Discovery, and Guided Discovery. In my opinion, the term Discovery Learning would better be used in educational domains because it reflects more learning at the end. By contrast, exploration does not impose an end on the learner. For example exploring is a process but discovering is an outcome and we are looking for outcomes.

Conclusion

In this research students who were enrolled in or had completed a critical care class were randomly assigned into free or guided exploration conditions to explore an oxygen management computer simulation. Oxygenation management knowledge was measured via two means: scores on the OKMT test and scores on computer generated clinical scenarios. Results indicated that the students somehow learned from the simulation but there were no differences between exploration groups. Exploration can be defined by the researcher in terms of how much instruction can be given to students when they are doing their exploration, thus free and guided terms are dependent on how the researcher conceptualizes them in the research. It is hypothesized that the major reason for the lack of difference observed between groups was that the way guided exploration was defined was inconsistent with the features of the simulation itself.

APPENDIX A

RECRUITMENT LETTER

Dear Nursing Student:

I am conducting a research study entitled **Impact of Free vs. Guided Exploratory Learning via Interactive Computer Simulation on Students' Learning.** The overall aim of the research is to discover how students learn most efficiently through computer simulations. You are being invited to participate in this research because you are a student enrolled in a critical care course and the simulation attempts to teach content that is consistent with materials in this course. That is why you have received this invitation. The experiment will take less than 2 hours at a research room in the College of Nursing and you will be compensated for your participation ($10 worth phone card). Your grades will not be affected by participation.

If you choose to participate, you will be asked to do the following:

- Complete a brief pre-test of your knowledge of oxygen management.
- Solve two clinical problems using the computer simulation.
- Explore the computer simulation in more detail.
- Solve three additional case scenarios using the computer simulation.
- Complete a brief posttest of your knowledge of critical care.

If you are interested in participating in the study, please list your name, phone number and email on the Signup Sheet or you may contact me by phone or email:

Suzan Ahmad, RN, MS
Telephone: (520)219-0554
Cell: (480)242-8192
Email: sahmad@nursing.arizona.edu

If you sign up to participate in this study, I will contact you to set up a time that is convenient to you.

Sincerely,

Suzan Ahmad, RN, MS, Nursing Doctoral Student

SIGNUP SHEET

Impact of Free vs. Guided Exploratory Learning via Interactive Computer Simulation on Students' Learning

No.	Name	Telephone No.	E-mail

APPENDIX B

SUBJECTS DISCLAIMER FORM

Title of the Project: Impact of Free vs. Guided Exploratory Learning via Interactive Computer Simulation on Students' Learning

You are being invited to voluntarily participate in the above-titled research study. The purpose of the study is to examine the learning outcomes of nursing students when using an interactive computer simulation. You are eligible to participate because you are nursing student enrolled in a critical care course or just finished critical care course.

If you agree to participate, your participation will involve an experiment that will take place in one session for 2 hours. During the experiment you will be asked to do the following:

- Complete a brief pre-test of your knowledge of oxygen management.
- Solve two clinical problems using the computer simulation.
- Explore the computer simulation in more detail.
- Solve three additional case scenarios using the computer simulation.
- Complete a brief posttest of your knowledge of critical care.

You may choose not to answer some or all of the questions. Any questions you have will be answered and you may withdraw from the study at any time. There are no known risks from your participation and no direct benefit from your participation is expected. You are assured that your participation will not affect your grades. There is no cost to you except for your time and you will receive $ 10 worth prepaid phone card for your participation.

Only the principal investigator will have access to the name and the information that you provide. In order to maintain your confidentiality, your name will not be revealed in any reports that result from this project. Your de-identified data will be locked in a cabinet in a secure place.

You can obtain further information from the principal investigator, Suzan Ahmad, RN, Doctoral Nursing Student, at (520) 219-0554. If you have questions concerning your rights as a research subject, you may call the University of Arizona Human Subjects Protection Program office at (520) 626-6721.

By participating in this study, you are giving permission for the investigator to use your information for research purposes.

Thank you.
Suzan Ahmad, RN, Doctoral Nursing Student
College of Nursing, University of Arizona
Home (520) 219-0554, Cell (480)242-8192
E-mail: sahmad@nursing.srizona.edu

APPENDIX C

OXYGEN MANAGEMENT KNOWLEDGE TEST (OMKT)

The purpose of this questionnaire is to know some information about you and your computer usage and to assess your knowledge of critical care.

Date: -------------------   ID #:--------------------

Part 1: Biographical Information:

I- For the following questions some questions will require you to put (×) in the category that belongs to you and other questions you need to write the response in the dotted area:

1) Age: <20
   (a) 21-25
   (b) 26-30
   (c) 31-35
   (d) 36-40
   (e) 41-45
   (f) 46-50
   (g) >51

2) Sex: M F

3) How much time do you spend per day using a computer?

   i. 1-3 hours
   ii. 4-7 hours
   iii. 8-11 hours
   iv. 12-15 hours

4) How many hours of those are for school purposes: -----------

5) What % of your daily use of the computer would you assign to the following programs:

6) Microsoft Office:

   1. Word: -----------------% of daily use

   2. Excel: -----------------% of daily use

   3. Power Point: -----------------% of daily use

4. Access: -----------------% of daily use

7) Internet: -----------------% of daily use

8) E-mails ----------------% of daily use

9) Computer Games: -----------------% of daily use

10) Have you ever used a computer simulation during your study (a computer program that gives an illusion of reality): ☐ Yes ☐ No

Part 2: Test questions:

II- For each multiple-choice question, please circle the letter of the correct answer. A table showing the norms for the variables used in the questions can be found on the last page.

Questions

Sally a 29 years old female who was admitted to the ER after sustaining a gunshot wound to her abdomen. Your quick review of her flowchart reveals the following data: Hgb = 10.1 g/dl, CVP = 6 mmHg, PAWP = 8 mmHg, CO = 6 L, CI = 3.5L/m², SVR = 1027, SVO2 = 74%:

1- Based on the values above what would you expect to see in the physician's initial orders for Sally?

a- Blood transfusion.
b- Fluid replacement.
c- Oxygen
d- An Inotrope

2- Suppose Dr. Mark ordered an Inotrope for Sally. Once you have started the Inotrope, which of the following change would you expect to find?

a- Increased CVP.
b- Decreased HR.
c- Increased CO.
d- Decreased Hgb

3- Suppose Dr. Mark ordered packed red blood cells for Sally. Once the transfusion is complete, which of the following changes would you expect to see?

a- Increased CO and SVR.
b- Increase CO, CVP, and decrease DO_2.
c- Decreased CVP, PAWP, CO, and SVR.
d- Increased CVP, DO2, and PAWP

4- Sally's Hgb has dropped to 8.2 g/dl. Which of the following changes would you anticipate next?

a- DO2 will increase.
b- HR will not change
c- CO will decrease
d- Oxygen content will decrease.

5- Dr. Mark decided to order a vasodilator for Sally. Once the vasodilator is running, you would expect to see which of the following changes:

a- Decreased SV, CVP, PAWP, and SVR.
b- Decreased HR, CO, and increased SVR.
c- Increased HR and CO
d- Decreased Hgb and increased DO2

Sarah, a 61 year old female, was admitted to the CCU with Congestive Heart Failure (CHF). A pulmonary artery catheter was inserted and you now have the following data: MAP = 78 mm Hg, PAWP = 25 mm Hg, CVP = 20 mm Hg, CO = 2.5 L/min, CI= 1.4, SVR= 1856 dynes/sec/cm-5, SaO2=88%, SVO= 55%

6- You know that the major determinants of CO are:

a- PAWP and SVR
b- SV and HR
c- PAWP and HR
d- PAWP, SVR, and HR

7- Sarah's heart rate is now 50 beats/min. As you call Dr. Nancy, you anticipate that she will order:

a- Betablockers and Vasopressors
b- Fluids and Oxygen
c- Blood and Diuretics
d- Inotrope, Diuretics and Vasodilators

8- Sarah's heart rate has dropped. What other changes would you anticipate as a result?

a- CO will increase
b- CO will decrease
c- SV will increase
d- SVR will increase

9- Sarah's cardiac output is falling. You expect that her oxygen delivery will:

a- Decrease then will increase
b- increase
c- decrease
d- not change

10- Dr. Nancy ordered a diuretic for Sarah. As you prepare to give this, you anticipate that the diuretic will:

a- increase Sarah's CO and HR
b- increase Sarah's Hgb, and DO2, and decrease CVP, and PAWP
c- decrease Sarah's CVP, PAWP and increase her SVR and MAP
d- greatly decrease Sarah's Hgb, HR and DO2

11- Nurse Emma was caring for Sarah when she remembered reading in her book the other day about Extraction Ratio (ER); you will know that the ER is defined as:

a- The ratio of SaO2 & Hgb (SaO2/Hgb).
b- The ratio of CaO2 & Hgb (CaO2/Hgb).
c- The ratio of CO & CI (CO/CI).
d- The ratio of O2 uptake to O2 delivery (VO2/DO2).

12- Sarah's CaO2=18 ml/dl, as an ICU nurse you know that CaO2 is:

a- The product of arterial oxygen saturation and hemoglobin.
b- The sum of CVP and PAWP
c- The product of SVR and MAP
d- The ratio of CO to ER.

13- The main goal of oxygenation management is to:

a- Manage the functions of oxygen and hemodynamics in the body.
b- Manage the medications that treat major oxygenation and hemodynamic problems in the body.
c- Manage the major Oxygen values that need to be investigated for ICU patients and know their normal values.
d- Manage relationships among variables that help to get oxygen to the cell and treat related problems.

14- Sarah's SVR is rising; you know that an increased SVR will lead to:

a- increased CO
b- increased MAP
c- increased CVP
d- decreased CO

Table of Normal Values

	Variable	Normal Values
Mean Central Venous Pressure	CVP	8-14mm Hg
Mean Pulmonary Artery Wedge Pressure	PAWP	8-14 mm Hg
Mean Arterial Pressure	MAP	70-105 mm Hg
Systemic Venous resistance	SVR	800-1200 dynes/sec/cm-5
Heart Rate	HR	60-80/min
Stroke Volume	SV	60 – 100 ml/beat
Cardiac Output	CO	4.0 -6.0 L/min
Cardiac Index	CI	2.5 – 4.5 L/min/m^2
Extraction Ratio	ER	22-28 %
Whole Blood Hemoglobin Concentration	Hgb	10-17 g/dl
Oxygen Content of Mixed venous Blood	CVO2	12-15 %
Mixed-Venous Hemoglobin Saturation	SVO2	65 – 75 %
Oxygen Content of Arterial Blood	CaO2	17-20ml/dl
Arterial Oxygen Saturation	SaO2	94-100 %
Oxygen Uptake	VO2	200-250 ml/min
Oxygen Delivered	DO2	950-1150 ml/min

Colochesy, J. M., Breu, C., Cardin, S., Whittaker, A.A., & Rudy, E.B. (1996). *Critical Care Nursing*. (2nd Ed). Philadelphia: W.B. Saunders Company.

APPENDIX D

LETTER ADDRESSED TO THE CONTENT VALIDITY EXPERT PANEL

Dear Evaluator:

The following is the Oxygen Management Knowledge Test (OMKT). The test is a 15-item experimenter-designed instrument that measures students' oxygen management knowledge before and after working with the oxygenation management instructional computer simulation. The OMKT contains display-sensitive questions that measure the students' knowledge about oxygen management related to the display as well as their prior knowledge about oxygenation management in the human body. Read each item and based on your experience of working in critical care course and with this level students, use the ordinal scale below to decide if each item relates to the display as well as to the color code of the test questions ranges.

Your participation will add great input to this research. Thank you and looking forward to hear from you soon.

Sincerely,

Suzan Ahmad, RN, Doctoral Student

OXYGEN MANAGEMENT KNOWLEDGE TEST

Test questions range from:

Average students can answer the question without doing the simulation but can be reinforced with the experience with the simulation

Good students can answer the questions and the display will reinforce it.

Not taught or known but learned through the simulation

Scale for rating the items:

1= irrelevant item to the color code
2= unable to assess relevance without item revision
3= relevant but need minor alteration
4= extremely relevant

For each multiple-choice question, please circle the letter of the correct answer. A table showing the norms for the variables used in the questions can be found on the last page.

Questions	1	2	3	4
Sally a 29 year old female who was admitted to the ER after sustaining a gunshot wound to her abdomen. Your quick review of her flowchart reveals the following data: Hgb = 10.1 g/dl, CVP = 6 mmHg, PAWP = 8 mmHg, CO = 6 L, CI = 3.5L/m², SVR = 1027, SVO2 = 74%:				
1- Based on the values above what would you expect to see in the physician's initial orders for Sally? a- Blood transfusion. b- Fluid replacement. c- Oxygen d- An Inotrope				
2- Suppose Dr. Mark ordered an Inotrope for Sally. Once you have started the Inotrope, which of the following change would you expect to find? a- Increased Central Venous Pressure (CVP) b- Decreased heart rate (HR). c- Increased cardiac output (CO) d- Decreased hemoglobin (Hgb)				
3- Suppose Dr. Mark ordered packed red blood cells for Sally. Once the transfusion is complete, which of the following changes would you expect to see? a- Increased cardiac output (CO) and increased systemic vascular resistance (SVR) b- Decreased cardiac output (CO) decreased central venous pressure (CVP) and decreased oxygen delivery (DO_2). c- Decreased central venous pressure (CVP), decreased wedge pressure (PAWP), decreased cardiac output (CO), and decreased systemic vascular resistance (SVR) d- Increased CVP, DO2, and PAWP				

4- Sally's Hgb has dropped to 8.2 g/dl. Which of the following changes would you anticipate next? a- DO2 will increase. b- HR will not change c- CO will decrease d- Oxygen content will decrease.				
5- Dr. Mark decided to order a vasodilator for Sally. Once the vasodilator is running, you would expect to see which of the following changes: a- Decreased SV, CVP, PAWP, and SVR. b- Decreased HR, CO, and increased SVR. c- Increased HR and CO d- Decreased Hgb and increased DO2				
Sarah, a 61 year old female, was admitted to the CCU with Congestive Heart Failure (CHF). A pulmonary artery catheter was inserted and you now have the following data: MAP = 78 mm Hg, PAWP = 25 mm Hg, CVP = 20 mm Hg, CO = 2.5 L/min, CI= 1.4, SVR= 1856 dynes/sec/cm-5, SaO2=88%, SVO2= 55%				
6- You know that the major determinants of CO are: a- PAWP and SVR b- SV and HR c- PAWP and HR d- PAWP, SVR, and HR				
7- Sarah's heart rate is now 50 beats/min. As you call Dr. Nancy, you anticipate that she will order: a- Betablockers and Vasopressors b- Fluids and Oxygen c- Blood and Diuretics d- Inotrope, Diuretics and Vasodilators				
8- Sarah's heart rate has dropped. What other changes would you anticipate as a result? a- CO will increase b- CO will decrease c- SV will increase d- SVR will increase				
9- Sarah's cardiac output is falling. You expect that her oxygen delivery will: a- Decrease then will increase b- increase c- decrease d- not change				
10- Dr. Nancy ordered a diuretic for Sarah. As you prepare to give this, you anticipate that the diuretic will: a- increase Sarah's CO and HR b- increase Sarah's Hgb, and DO2, and decrease CVP, and PAWP c- decrease Sarah's CVP, PAWP and increase her SVR and MAP d- greatly decrease Sarah's Hgb, HR and DO2				

11- Nurse Emma was caring for Sarah when she remembered reading in her book the other day about Extraction Ratio (ER); you will know that the ER is defined as: a- The ratio of SaO_2 & Hgb (SaO_2/Hgb). b- The ratio of CaO_2 & Hgb (CaO_2/Hgb). c- The ratio of CO & CI (CO/CI). d- The ratio of O_2 uptake to O_2 delivery (VO_2/DO_2).				
12- Sarah's CaO_2=18 ml/dl, as an ICU nurse you know that CaO_2 is: a- The product of arterial oxygen saturation and hemoglobin. b- The sum of CVP and PAWP c- The product of SVR and MAP d- The ratio of CO to ER.				
3- The main goal of oxygenation management is to: a- Manage the functions of oxygen and hemodynamics in the body. b- Manage the medications that treat major oxygenation and hemodynamic problems in the body. c- Manage the major Oxygen values that need to be investigated for ICU patients and know their normal values. d- Manage relationships among variables that help to get oxygen to the cell and treat related problems.				
14- In oxygenation management, we try to balance: a- Hemoglobin and level and the saturation of arterial oxygen. b- Oxygen consumption and oxygen delivery in the body. c- The differences between CVO_2 & CaO_2. d- Pressure level variables in the body				
15- Sarah's SVR is rising; you know that an increased SVR will lead to: a- increased CO b- increased MAP c- increased CVP d- decreased CO				

Table of Normal Values

	Variable	Normal Values
Mean Central Venous Pressure	CVP	8-14mm Hg
Mean Pulmonary Artery Wedge Pressure	PAWP	8-14 mm Hg
Mean Arterial Pressure	MAP	70-105 mm Hg
Systemic Venous resistance	SVR	800-1200 dynes/sec/cm-5
Heart Rate	HR	60-80/min
Stroke Volume	SV	60 – 100 ml/beat
Cardiac Output	CO	4.0 -6.0 L/min
Cardiac Index	CI	2.5 – 4.5 L/min/m^2
Extraction Ratio	ER	22-28 %
Whole Blood Hemoglobin Concentration	Hgb	10-17 g/dl
Oxygen Content of Mixed venous Blood	CVO2	12-15 %
Mixed-Venous Hemoglobin Saturation	SVO2	65 – 75 %
Oxygen Content of Arterial Blood	CaO2	17-20ml/dl
Arterial Oxygen Saturation	SaO2	94-100 %
Oxygen Uptake	VO2	200-250 ml/min
Oxygen Delivered	DO2	950-1150 ml/min

Comments and suggestions:

Your opinion about keeping the variables in an abbreviation format or write down the full word for each variable:

REVISED OMKT (BY THE EXPERT PANEL)

OXYGEN MANAGEMENT KNOWLEDGE TEST

Test questions range from:

Average students can answer the question without doing the simulation but can be reinforced with the experience with the simulation

Good students can answer the questions and the display will reinforce it.

Not taught or known but learned through the simulation

For each multiple-choice question, please circle the letter of the correct answer. A table showing the norms for the variables used in the questions can be found on the last page.

Questions

Sally a 29 years old female who was admitted to the ER after sustaining a gunshot wound to her abdomen. Your quick review of her flowchart reveals the following data: Hgb = 10.1 g/dl, CVP = 6 mmHg, PAWP = 8 mmHg, CO = 6 L, CI = 3.5L/m², SVR = 1027, SVO2 = 74%:

1- Based on the values above what would you expect to see in the physician's initial orders for Sally?
  a- Blood transfusion.
  b- Fluid replacement.
  c- Oxygen
  d- An Inotrope

2- Suppose Dr. Mark ordered an Inotrope for Sally. Once you have started the Inotrope, which of the following change would you expect to find?
  a- Increased Central Venous Pressure (CVP)
  b- Decreased heart rate (HR).
  c- Increased cardiac output (CO)
  d- Decreased hemoglobin (Hgb)

3- Suppose Dr. Mark ordered packed red blood cells for Sally. Once the transfusion is complete, which of the following changes would you expect to see?
  a- Increased cardiac output (CO) and increased systemic vascular resistance (SVR)
  b- Decreased cardiac output (CO) decreased central venous pressure (CVP) and decreased oxygen delivery (DO_2).
  c- Decreased central venous pressure (CVP), decreased wedge pressure (PAWP), decreased cardiac output (CO), and decreased systemic vascular resistance (SVR)
  d- Increased CVP, DO2, and PAWP

4- Sally's Hgb has dropped to 8.2 g/dl. Which of the following changes would you anticipate next?

a- DO2 will increase.
b- HR will not change
c- CO will decrease
d- Oxygen content will decrease.

5- Dr. Mark decided to order a vasodilator for Sally. Once the vasodilatoris running, you would expect to see which of the following changes:

a- Decreased SV, CVP, PAWP, and SVR.
b- Decreased HR, CO, and increased SVR.
c- Increased HR and CO
d- Decreased Hgb and increased DO2

Sarah, a 61 year old female, was admitted to the CCU with Congestive Heart Failure (CHF). A pulmonary artery catheter was inserted and you now have the following data: MAP = 78 mm Hg, PAWP = 25 mm Hg, CVP = 20 mm Hg, CO = 2.5 L/min, CI= 1.4, SVR= 1856 dynes/sec/cm-5, SaO2=88%, SVO2= 55%

6- You know that the major determinants of CO are:

a- PAWP and SVR
b- SV and HR
c- PAWP and HR
d- PAWP, SVR, and HR

7- Sarah's heart rate is now 50 beats/min. As you call Dr. Nancy, you anticipate that she will order:

a- Betablockers and Vasopressors
b- Fluids and Oxygen
c- Blood and Diuretics
d- Inotrope, Diuretics and Vasodilators

8- Sarah's heart rate has dropped. What other changes would you anticipate as a result?

a- CO will increase
b- CO will decrease
c- SV will increase
d- SVR will increase

9- Sarah's cardiac output is falling. You expect that her oxygen delivery will:

a- Decrease then will increase
b- increase
c- decrease
d- not change

10- Dr. Nancy ordered a diuretic for Sarah. As you prepare to give this, you anticipate that the diuretic will:

a- increase Sarah's CO and HR
b- increase Sarah's Hgb, and DO2, and decrease CVP, and PAWP
c- decrease Sarah's CVP, PAWP and increase her SVR and MAP
d- greatly decrease Sarah's Hgb, HR and DO2

11- Nurse Emma was caring for Sarah when she remembered reading in her book the other day about Extraction Ratio (ER); you will know that the ER is defined as:

a- The ratio of SaO2 & Hgb (SaO2/Hgb).
b- The ratio of CaO2 & Hgb (CaO2/Hgb).
c- The ratio of CO & CI (CO/CI).
d- The ratio of O2 uptake to O2 delivery (VO2/DO2).

12- Sarah's CaO2=18 ml/dl, as an ICU nurse you know that CaO2 is:

a- The product of arterial oxygen saturation and hemoglobin.
b- The sum of CVP and PAWP
c- The product of SVR and MAP
d- The ratio of CO to ER.

13- The main goal of oxygenation management is to:

a- Manage the functions of oxygen and hemodynamics in the body.
b- Manage the medications that treat major oxygenation and hemodynamic problems in the body.
c- Manage the major Oxygen values that need to be investigated for ICU patients and know their normal values.
d- Manage relationships among variables that help to get oxygen to the cell and treat related problems.

14- Sarah's SVR is rising; you know that an increased SVR will lead to:

a- increased CO
b- increased MAP
c- increased CVP
d- decreased CO

APPENDIX E

ORIENTATION USING MINIMAL INSTRUCTIONS

1- Take 15 minutes to orient yourself to the computer display (icons indicating mean arterial pressure, etc. and drugs).

2- Press the left mouse button to activate the drugs; press the button again to turn the drug off.

3- Green bars indicate the normal range of the variable.

4- If you wish, you can see the normal value for a variable by moving the mouse over the variable.

5- After you have familiarized yourself with the display, I will ask you to use the treatment options to correct patient problems.

6- When each case starts:

   a. Read the short patient history at the bottom of the screen.

   b. Look at the main part of the display and try to identify the patient's problem then use the drugs to correct the problem you identified. An optimal treatment will bring all the values shown into the green range.

You'll have 10 minutes to identify each problem and correct it.

APPENDIX F

CASE SCENARIO INSTRUCTIONS

Date---------------------- St. ID: --------------

For the case scenarios, please try to identify and correct the patients' problem/s and return the values shown in the display to the normal ranges. You have 10 minutes for each problem.

APPENDIX G

GUIDED EXPLORATION INSTRUCTIONS

You will have 30 minutes to explore the computer simulation. As part of your exploration, use the available treatment options to:

1- Decrease the CO to 4 L/min

2- Increase Hgb to 15 g/dl

3- Decrease the HR to 55/min

4- Increase the CVP to 14mmHg

5- Increase the SVR to 1400

6- Increase the CaO2 to 22ml/dl

7- Increase CO to 7 L/min

8- Decrease the Hgb to 10 g/dl

9- Increase the HR to 85/min

10- Decrease the SVR to 900

11- Increase the DO2 to 1500 ml/min

12- Decrease the CVP to 9 mmHg

During your exploration, try to discover how each drug works on the variables shown (e.g., CO or MAP) as well as the various relationships among the variables shown. Use this time to learn as much as you can before you take the posttest.

APPENDIX H

FREE EXPLORATION INSTRUCTIONS

You will have 30 minutes to explore the computer simulation. During your exploration, try to discover how each drug works on the variables shown (e.g., CO or MAP), as well as the various relationships among the variables shown. Use this time to learn as much as you can before you take the posttest.

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