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# APPLICATION OF THE LEARNING CYCLE IN MEDICAL EDUCATION

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APPLICATION OF THE LEARNING CYCLE IN MEDICAL EDUCATION

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF INSTRUCTIONAL LEADERSHIP
AND ACADEMIC CURRICULUM

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# DEDICATION

This dissertation is dedicated to my sparkling, loving and supportive wife, Annette L. Shukry, my loving, caring, and devoted parents, Mahasen Jazmati and Taoufik Shukry, and my smart, exuberant, charming and kind children, Lina and Omar Shukry. Their constant love and caring are every reason for where I am and what I am. My gratitude and my love to them are beyond words.

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Mohanad Shukry, MD

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## ABSTRACT

This study was designed to compare factual knowledge retention and clinical skills outcomes of two different teaching designs: inquiry via the learning cycle and exposition via power point presentation. This research was guided by the following questions:

- How do senior medical students, who are taught by the learning cycle (inquiry students) compare to medical students taught by power point presentation (exposition students) when managing a crisis of malignant hyperthermia assessed by medical fidelity human simulator one month following the teaching?
- How do inquiry students compare to exposition students on retention of factual knowledge one month following the teaching assessed by multiple-choice test?
- Is there a relationship between students' performance during simulation and on a multiple-choice test one month following teaching?

The research method employed was quantitative data sources, including three multiple-choice tests and a scoring system for a management of high fidelity medical simulation crisis related to the subject taught.

Major findings of the study include:

- Clinical skills score of students who were taught by the learning cycle were not statistically significantly different when compared with students in the exposition teaching.

- Students who were taught by the learning cycle had statistically significant higher knowledge retention a month later.
- Clinical skills improved with increased medical knowledge, and that was more significant in students who were exposed to exposition teaching.

Although this is the first study to report on the application of the learning cycle in medical education, the results of the study is encouraging and the learning cycle could improve medical students’ learning.

## Chapter I

## Introduction

Two contrasting teaching procedures are frequently compared in science education: inquiry and exposition (Berg, Bergendahl, Lundberg, & Tibell, 2003; Johnson & Lawson, 1998; Karakoc & Simsek, 2004; Marek, Eubank, & Gallaher, 1990; Marek & Laubach, 2007). Students experiencing inquiry courses use higher cognitive skills as they gain greater conceptual understandings. Conceptual understanding occurs as students are gathering data and discussing facts, concepts, laws, principles and theories. On the other hand, students experiencing exposition are not involved in the processes of science, such as observing, model building, measuring, and theorizing. These passive learners are primarily receiving information through lectures.

Medical education curricula have shifted toward student-centered methodologies (inquiry) and away from only teacher-centered methodologies (expository). Problem based learning, for example, was developed in medical education in the early 1970s (Johnson & Finucane, 2000). Problem based learning has widespread application in the first two years of medical science curricula where it replaces the traditional lecture based approach. Although some case discussion and group learning occurs during clinical rotations (third and fourth year medical students), most of classroom medical education is still carried out through lectures and with minimal active participation among students (exposition).

The learning cycle is an inquiry teaching procedure that is designed to allow students' participation in the kind of thinking constructivists describe as essential to learning and cognitive development (Henson, 2003; Vygotsky, 1978). Rooted in Piaget's theory of intellectual development, the learning cycle phases were derived from Piaget's mental functioning processes (*exploration* correlates with assimilation, *explanation* with accommodation, and *expansion* with organization) (Marek, 2009; Marek & Cavallo, 1997). During exploration, the teacher provides learners with developmentally appropriate experiences related to the content to be learned. This phase allows learners to mentally process observations and experiences as they collect data (assimilation). After exploration, the teacher guides students in the development of the science concept in the learning cycle phase known as explanation. The teacher promotes a discussion period in which learners share their observations (data) with their classmates. This discussion and sharing of data causes the students to feel uncomfortable with the lack of explanation to the new phenomenon or situation (disequilibration). The teacher guides students to link their experiences and data to derive the relevant scientific concept and terminology (accommodation). After this phase, learners engage in additional activities in which they apply their newly developed knowledge to novel situations in the learning cycle phase known as expansion. This third phase is designed to cause learners to use the mental function known as organization (Marek & Cavallo, 1997).

The learning cycle paradigm has been used in science classrooms for over five decades with its beginnings in elementary schools and eventually applied at the secondary schools and college levels. The learning cycle, by its design, is consistent with the nature of science and promotes critical thinking through inquiry, collaborative grouping, and the construction of new concepts. Although problem based learning has been applied in medical education, learning cycle per se has never been reported in medical education.

Medical fidelity simulation has been increasingly implemented in medical education as an educational and competency assessment tool (Henrichs et al., 2009; Murray et al., 2007). Advantages of medical simulations include (Lake, 2005) (a) active learning process, (b) nonthreatening environment to patients, (c) ability to repeat performance until mastery, (d) experience in crisis situations seen infrequently, and (e) as a competency assessment tool. Simulation can also be used in assessing competences acquired from different teaching procedures. For this research, simulation will be used in assessing competencies acquired from different teaching procedures.

**Purpose of the Study**

This study is designed to compare factual knowledge retention and clinical skills outcomes of two different teaching designs: inquiry via the learning cycle and exposition via power point presentation. The learning cycle has not been implemented in medical education before, but problem based learning has been used and compared to the traditional lecture based practices. The major focus in studies of the effectiveness of problem based learning has been on students' knowledge base, assessed by multiple-choice examinations, and not the application of this knowledge (Blake, Hosokawa, & Riley, 2000; Ripkey, Swanson, & Case, 1998). Any teaching procedure (inquiry or exposition) should affect not only factual knowledge, but also clinical knowledge; the way students apply the knowledge during medical tasks. Some research showed that different teaching methodologies (inquiry or exposition) have the same effects on factual knowledge, measured by multiple-choice test (Albanese, 2000; Lycke, Grottum, & Stronmso, 2006). This study is different from previous studies by the way knowledge acquired from either teaching procedure (inquiry or exposition) is measured and assessed. Clinical knowledge and skills acquired from either teaching practice will be measured by how learners recognize and manage a malignant hyperthermia crisis in a medical fidelity simulation one month following the teaching procedures. A simulated operating room with a mannequin, which serves as a patient presenting with malignant hyperthermia crisis, will be used to test the learner's response to such a crisis. This safe and controlled environment is currently the best available setting for testing crisis management of students. Additionally, a multiple-choice test will assess the retention of factual knowledge one month later.

**Research Questions**

This research is guided by the following questions:

- How do senior medical students, who are taught by the learning cycle (inquiry students) compare to medical students taught by power point presentation (exposition students) when managing a crisis of malignant hyperthermia assessed by medical fidelity human simulator one month following the teaching?
- How do inquiry students compare to exposition students on retention of factual knowledge one month following the teaching assessed by multiple-choice test?
- Is there a relationship between students' performance during simulation and on a multiple-choice test one month following teaching?

## Significance of the Study

To improve teaching practices in medical schools, learning theories for adults must be applied. It is empirically clear that rote knowledge (memorization) is quickly forgotten, and meaningful knowledge (understanding) tends to be retained longer and applied or practiced on a higher level (Baxter & Elder, 1996; Mayer, 2002). Applied learning theory in medical education should help physicians apply the appropriate knowledge to benefit their patients. To test the effectiveness of the learning cycle on long term knowledge application, a human fidelity simulator will be used to give medical students the opportunity to apply acquired knowledge. The results of this research may help medical faculty improve their teaching practices since 27% of medical faculty focus on having students learn and apply knowledge and skills to accomplish clinical tasks (Williams & Klamen, 2006).

## Definitions of Terms

**Learning cycle.** An inquiry constructivist teaching procedure that allows students to manipulate materials and generate data that they analyze to construct concept understandings. A learning cycle for the concept of malignant hyperthermia has been developed and used by the investigator for several years to teach senior medical students and postgraduate residents.

**Malignant hyperthermia.** A genetic disease that can be triggered by an anesthetic and lead to death if not treated promptly. Despite the availability of a drug that can reverse the crisis, multiple deaths still occur annually in the US. Although the disease is different from an anaphylactic shock, it has a similar course of events.

**Power point presentation.** An exposition teaching method where the instructor presents knowledge to students on slides projected on a board. For few minutes at the end, students are usually allowed to ask questions to the presenters. A group discussion does not normally occur in this format. This format is very common in medical education.

**High fidelity simulator.** A high fidelity simulation is a computer controlled mannequin that can demonstrate many signs and symptoms of a human patient disease process. The mannequin can be placed in a simulated operating room that includes all the monitors and also humans acting as operating room staff. Many programmed crises can be manifested by the mannequin, including malignant hyperthermia crises. A simulator will be used in this study to assess medical students' management of a crisis of malignant hyperthermia. Video camera recording of the crisis allows for an observer to assess the student's management of the crisis.

## Chapter II

## Theoretical Foundation

This chapter focuses on three central premises (a) medical education, (b) structured inquiry via the learning cycle, and (c) role of simulation in medical education. Medical education is subdivided into six categories (a) complexity of medical education, (b) cognitive flexibility theory, (c) outcome-based or competency-based education, (d) inquiry vs. exposition learning, (e) problem based learning, and (f) overview of the University of Oklahoma College of Medicine curriculum. The learning cycle section is subdivided into four categories (a) history of the learning cycle, (b) the learning cycle teaching procedure, (c) Piaget's & Vygotsky's theoretical underpinning to the learning cycle, and (d) cognitive and motivational variables. The simulation section is subdivided into five categories (a) history of mannequin simulation, (b) simulators in anesthesia, (c) current uses of simulation, (d) advantages of medical simulation, and (e) simulation in medical education.

### Medical Education

The current blueprint for medical education in North America was articulated in 1910 by Abraham Flexner in his report, *Medical Education in the United States and Canada*, a comprehensive survey of medical education prepared on behalf of The Carnegie Foundation for the Advancement of Teaching and at the request of the American Medical Association's Council on Medical Education (Flexner, 1910). The basic features of medical education outlined by Flexner remain in place today: a university-based education consisting of two years of scientific foundations and two years of practical experience in clinical settings. Recently, The Carnegie Foundation for the Advancement of Teaching undertook an investigation of medical education and a research team embarked on an examination into the status of medical education (Cooke, Irby, & O'Brien, 2010). Over a three-year period, the research team reviewed the literature and conducted site visits to 14 medical schools and medical centers. Data were collected through 140 structured interviews, 50 focus groups, 200 observations and documents. Both qualitative and quantitative analyses were employed. The Carnegie researchers found medical education lacking in many important regards. They found that medical training is inflexible, excessively long, and not learner centered. They also found that clinical education is overly focused on inpatient clinical experience, supervised by clinical faculty who have less and less time to teach and who have ceded much of their teaching responsibilities to residents, and is situated in hospitals with marginal capacity to support their teaching mission. They observed poor connections between formal knowledge and experiential learning. Learners have inadequate opportunities to work with patients over time and to observe the course of illness and recovery; students and residents often poorly understand non-clinical physician roles. Most importantly, the team observed that medical education does not adequately make use of the learning sciences (epistemology).

**Complexity of medical education.** Medical education for health-related professions represents a major category of adult training and is one of the most complicated educations. Medical knowledge is enormous and constantly changing and physicians must acquire and remember a tremendous number of details, making memory processes critical. Understanding and managing diseases (medicine) are complicated processes that form conceptual complexity and case-to-case irregularity in knowledge domain, thus referred to as ill-structuredness. Additionally, medical education extends over the lifetime of the physicians, who must be self-directed in their learning activities and capable of relating new information to their own needs and experiences. For these reasons, theories of adult learning that emphasize self-directed and experiential learning are highly pertinent. Furthermore, theories of instruction that are based upon self-study or use of media are also significant to medical education. Cognitive flexibility theory, which emphasizes a case study approach involving context-dependent and realistic situations, applies directly to medical education.

Cognitive flexibility thinking and teaching allows for shifting from constructive orientation that emphasizes retrieval from memory of intact preexisting knowledge to an alternative constructivist stance which stresses the flexible reassembly of preexisting knowledge to adaptively fit the needs of new situation. For example, managing a disease such as malignant hyperthermia requires connecting hundreds of variables. Understanding the pathology and the cellular level of the disease explains why an episode of malignant hyperthermia presents in many different ways. The variation of presentations makes the diagnosis difficult as many of the presenting symptoms are common for other diseases that may occur in relationship to surgeries and anesthesia. The rarity of the disease adds to the complexity of diagnosing it, but the deathly outcome for failing to diagnose the disease in a timely manner adds to the seriousness of it. Following the diagnosis, the physician will have to know the treatments including managing a crisis. Previous experiences with crisis management have to be transferred to the situation at hands as not all crises are the same. Additionally, prioritizing management steps and using resources appropriately is crucial to the treatment and positive outcome. Counseling a patient and family on what to do following the safe outcome is also part of management. Without teaching cognitive flexibility, it will be impossible to teach the management of malignant hyperthermia knowing that a physician may spend all his/her carrier without seeing the disease once. Take this into account with thousands of other diseases and the complexity and ill-structuredness of medicine become obvious.

Ill-structured domain such as medicine must not be confused with *complexity* (Spiro & DeSchryver, 2009). Complexity alone does not make a domain ill-structured; in fact, many well-structured domains are complex. In ill-structured domain such as medicine, we cannot have a prepackaged prescription of how to think or act. We also cannot have a prepared schema that can be used for whatever the situation at hand may be as those situations may vary completely. Rather, in ill-structured domain, the schema of the moment should be formulated from different pieces of knowledge and experiences that were acquired at different times and situations. This can be acquired by creating as many variables and experiences during the learning process so learners can build the network of knowledge with the flexibility of using different pieces of this network for different future situations. This seems to be working in medicine over the many years medicine has been taught. In today's medical education, medical students acquire much of the "introductory" knowledge during the first two years of medical school. During these two years, students expand on their previous knowledge of chemistry, biology, anatomy, and physiology. They also learn basic or introductory application of this new knowledge into some clinical scenarios. However during third and fourth year of medical school, students expand on this knowledge and apply much of it in clinical scenarios in different ways. During the years of residency, or post-graduate education, (multiple years of training following medical school) and with much available content knowledge, physicians can apply this knowledge on real cases with many variables. Although each disease could be the same, each patient is different and different content knowledge needs to be applied to different patients or problem. Following the many years of residency, physicians should be more exposed to almost all variables and should have built a wide network of knowledge that they can apply to more complicated scenarios in the future.

Medical educators often deliver complex material in a format that does not allow the positive learning engagement recommended by cognitive researchers and theorists. Cognitive researchers believe that intentional engagement and active learning pedagogies change the nature of learning, while simultaneously improving knowledge gain and recall abilities. Engaged students find the work more interesting and thereby put more effort into it. Certain cognitive processes and skills such as decision-making, reasoning, and problem-solving are critical in medical practice. Problem-solving, in particular, has been the basic pedagogy for many medical curricula (Taylor & Miflin, 2008). Additionally, many aspects of medicine, such as anesthesiology and surgery, require high levels of sensory-motor ability.

Due to the complexity of medical education, medical schools have yet to find pedagogical practice that can be successful in medical education. The goals and objectives of medical students' education have been outlined by the Association of American Medical Colleges (1998) as to produce physicians who are altruistic, knowledgeable, skillful, and dutiful. Most structured medical education now focuses on knowledge and skills, while altruism and dutifulness are ostensibly satisfied by appropriate selection of medical students and role modeling by medical teachers.

**Cognitive flexibility theory.** Cognitive flexibility is the human ability to adapt cognitive processing strategy to face a new or unexpected condition. Cognitive flexibility theory (CFT) is a continuum of the constructivist theory of learning. CFT is a theory of learning and instruction that was developed to address four main goals: (a) helping learners to learn important but difficult subject matter, (b) fostering adaptive flexible use of knowledge in real-world settings, (c) changing underlying ways of thinking, (d) developing hypermedia learning environments to promote complex learning and flexible knowledge application (Sprio, Collin, Thota, & Feltovich, 2003).

For constructivists, knowledge is not simply handed down from teachers to students. Rather, students are co-participants in the construction of meaning (Dimitriadis & Kamberelis, 2006). One of the main constructivist theorists, Jerome Bruner, believes that students should be encouraged to construct their own knowledge and build upon what they already learned. He argues that instructions should be designed to encourage the learner to go beyond the given information (Bruner, 1996). CFT can also be related to the genetic epistemology theory of Piaget, who posited that students develop cognitively when they are presented with new situations that require them to adapt previously learned materials (Bybee & Sund, 1982). While CFT is built on many of the same principles as other constructivist theories, it was developed to be especially useful when applied in complex, ill-structured domains with multivariable and higher-level learning, such as the teaching/learning of medicine. In other words, the theory was developed to allow the application of different types of knowledge to a variety of dynamic situations.

In well-structured domains, concepts can be, matter of fact should be, directly instructed, fully explained, and simply supported. However, this cannot be done in ill-structure domain. Spiro believes that there is no alternative to constructivist approach in learning, instruction, knowledge application, and mental representation in ill-structured domain (Spiro & DeSchryver, 2009). Although using constructivism through CFT has not yet proved to fully work in ill-structure domain, Spiro believes that we should continue on using it. This is due to the fact that we know that direct instructional guidance does not work in ill-structured domain (Spiro & DeSchryver, 2009). It is the particular way that CFT instructions, and the associated guidance tailored to the need of learning in ill-structure domain that distinguishes it in fundamental ways from direct instructions. CFT based systems facilitates a nonlinear web of knowledge that resist the oversimplification of knowledge. This web of knowledge insures the connections of different pieces of knowledge to support maximal adaptive flexibility in the later-situation assembly of knowledge and experiences to suit the needs of a new problem-solving event.

Coulson, Feltovich, and Spiro (1997) studied the application of cognitive flexibility in medicine, specifically in the way physicians analyze and treat a very common disease, hypertension. They argued that in using the standard hypertension treatment algorithm, in which hypertension pathology and etiology are very simplified, physicians mistreat 50% of the cases.  However, if physicians use cognitive flexibility to take into account all the variables and factors as well as the inherent complexity of hypertension, physicians could treat the disease and control blood pressure faster and more reliably.

The goals of medical education are clearly those of advanced knowledge acquisition. New medical students have already been introduced to many of the subject areas within the biological sciences that they will learn in medical school. However, during medical school and life-long learning, physicians need to master these concepts and have the ability to apply the knowledge from formal instruction to real world cases. The complexity of medical domain and the many variables of medical cases make the medical field an ill-structured domain. Due to these complexities, medical educators have been very busy structuring an outcome-based curricula that teach medical students the attributes and competencies that are expected of physicians (Harden, 2007).

**Outcome-based or competency-based education.** Outcome-based education emphasizes learner and program outcomes, not the pathway and processes to attain them. Calls for competency-based approach to educate professionals go back decades ago (Carraccio, Wolfsthal, Englander, Ferentz, & Martin, 2002). Traditional criteria curriculum is organized around knowledge objectives that focus on instructional process regardless of the outcome of the process. On the other hand, outcome-based education structures its curricula around the outcome while the process is secondary (Harden, 1999). Some of the rationales for a competency-based medical education are (Frank et al., 2010) (a) focus on curricular outcomes, (b) emphasis on abilities (competencies are the organizing principle of curricula), (c) de-emphasis of time-based training, and (d) promotion of learner-centeredness. As medical education evolves to focus on competencies, it is important to define those competencies. It is assumed so far that those competencies will include knowledge, skills, and attitude (Molenaar et al., 2009). On the other hand, competency-based medical education has been criticized for being reductionistic, that is, for focusing on atomistic skills and failing to capture the essence of professional activities as manifested by complex and integrated capabilities (Swing, 2010).

**Inquiry vs. exposition learning.** Contemporary views on learning conceive that one constructs knowledge based on previously held beliefs and experience. In this sense, inquiry learning is metacognitive, giving the individual a picture of how she/he learns (Graffin, 2007). As in many other disciplines, a growing literature in medical education praises the benefits of inquiry versus exposition learning (Carline, 1989; Richardson & Brige, 1995). The difference between inquiry and exposition is not just observable, but is also ideological. While passive learning assumes that knowledge can be transferred from one person to another, active learning presupposes that all knowledge is constructed by the learner. Each offers a very different epistemological underpinning. Passive learning perceives knowledge as a commodity, whereas active learning perceives knowledge as experience created by the individuals' meaning making processes (Maclellan, 2005).

For learning to be active, learners not only need to be doing something but also need to reflect on what they are doing. Active learning is learner-centered, where an individual's needs are more important than those of the group. Active learning pedagogies change the teacher-learner relationship to a learner-learner relationship.

Active learning is within Piaget's taxonomies, among other taxomonies. Active learning combines engagement and observation with reflective experiences.

Passive learning as a method fails to connect students directly with the knowledge and skills they need to learn. Passive learning occurs when students read an assigned article, chapter, or book; when they watch a film; when they attend a lecture. Active learning occurs when each of those activities is combined with engagement, observation and reflection.

**Problem based learning.** Following the introduction of problem based learning (PBL) to medical curricula in the 1970s (Johnson & Finucane, 2000), the majority of medical schools worldwide began to adapt more active learning strategies (inquiry) over what was considered the traditional passive method (exposition) (Norman & Schmidt, 1992). This movement created a body of literature that describes the potential benefits of PBL curricula compared to traditional learning. However, navigating this body of literature is not an easy task. Generally, the end results of studies on PBL are inconsistent and the sample size of some makes it difficult to arrive at conclusive evidence. Additionally, review articles on the subject produced conflicting results and some skepticism regarding the effectiveness of PBL.

Dochy et al. (2003) published a meta-analysis of 43 studies to evaluate PBL effects on knowledge and skills. The review was not restricted to medical education, but included all forms of tertiary education. The analysis showed moderately significant effects on practice skills favoring PBL. Although deemed small and not of practical significance, the authors found scores on knowledge tests to be lower in the non PBL group. While the appropriateness of combining these data in a meta-analysis is questionable due to substantial heterogeneity across studies, the analysis provided some insight into potential effect modifiers. These exploratory analyses, which were based on a small number of studies, suggested that study design, students' level of expertise, retention period, and assessment methods may explain variability in effect estimates. The authors cite their main limitation as the compromised internal validity of the primary research studies.

Koh et al. (2008) conducted a systematic review that evaluated PBL on 37 outcomes of physician competency (identified by the authors) post-graduation. The review was methodologically rigorous in that it comprised a comprehensive and/or systematic approach to searching, study selection, data extraction, and quality assessment. The authors identified 13 unique relevant studies although 4 only provided self-reported data which the authors acknowledge as being prone to inaccuracy. The analysis yielded significant results supporting PBL for 7 of the 37 competencies; diagnostic skills or accuracy, communication skills, and possession of medical knowledge are among these 7 competencies. The authors pointed out a number of limitations of their review, some of which stem from the nature of the literature, in particular, the challenge of disentangling the effects of PBL from other curricular changes.

Hartling et al. (2010) conducted a systematic review of PBL in undergraduate, pre-clinical medical education between 1985 and 2007. A review of 30 unique studies demonstrated that knowledge acquisition measured by exam scores was the most frequent outcome reported. They concluded that PBL does not impact knowledge acquisition, and evidence for other outcomes does not provide unequivocal support for enhanced learning.

Although the superiority of inquiry curricula has been demonstrated, a concurrent literature is growing to discuss the lack of pedagogical change in medical education (Hurst, 2004; Rudland & Rennie, 2003). In 2003, a web-based questionnaire to medical schools education deans documented that 70% of the 123 medical schools in the US used PBL in the preclinical years (Kinkade, 2005). Of schools using PBL, 45% used it for fewer than 10% of their formal teaching, while 60% used it for more than half of their formal teaching. Of the 30% of schools not using PBL, 22% had used it in the past, and 2% had plans to incorporate it in the future.

Due to their lack of pedagogical understandings, teachers in medical schools generally teach as they were taught in undergraduate and graduate schools. Although medical faculty were able to keep up with the rapidly changing science of medicine in the last few decades, the same cannot be said about medical teaching. Medical faculty understand the complexity of scientific changes; for example, if a scientific research uncovers a function or treatment, medical faculty are eager to apply it to their patients. On the other hand, pedagogical changes are not a function of medical education, due to medical faculty's lack of pedagogical preparation and understanding. This could be due to medical teachers' simplistic understanding that to be a good educator, one only needs to have exceptional grasp of the material. Today, teaching in medical classroom remains lecture driven, with little engagement between students and faculty (Graffam, 2007).

**Overview of the University of Oklahoma College of Medicine curriculum.** The four-year MD curriculum at the University of Oklahoma College of Medicine is divided into two phases: the pre-clinical curriculum, which consists of the first and second years, and the clinical curriculum, which consists of the third and fourth years. The medical school curriculum includes both required courses and elective opportunities. Many courses are team-taught under the leadership of course directors. And the courses are graded both by traditional letter grades and honors/pass/fail grades.

The preclinical curriculum is organs-systems based. The basic sciences curriculum begins with foundation courses, followed by organ-systems courses, and culminates with a capstone course. There are many opportunities for self-directed learning throughout the first and second year. The preclinical curriculum courses include: three foundational courses, numerous systems courses, a clinical medicine course, and finally the capstone course. Students have an opportunity to participate in the enrichment program which consists of elective courses offered during the preclinical curriculum. In the enrichment program, students take two courses from the following areas: medical humanities, clinical learning, and research. At the conclusion of the basic sciences curriculum, students take a capstone course, which is a ten-week course that is designed to reinforce, apply, and synthesize basic science concepts taught during the systems courses. This capstone course is also designed to introduce concepts of evidence-based medicine, and to facilitate the transition to the third year.

The first year curriculum includes forty weeks of coursework. It begins with a one-week prologue course, and then transitions into three foundation courses, including molecular and cellular systems, disease diagnosis and therapy, and the human structure. Students take four systems based courses during the spring semester. During the afternoon, students take clinical medicine, “patients, physicians, and society”, and the enrichment track. The second year curriculum consists of 35 weeks. Students take the remaining 3 systems based courses, the clinical medicine II course, the “patients, physicians, and society” course, and enrichment courses if they’re enrolled in it. The second year ends with a ten-week capstone course.

The College of Medicine uses a variety of instructional approaches during the preclinical curriculum. These include: lectures, small group sessions, team based learning, clinical preceptor experiences, anatomy dissections, and independent study. During a typical day, students may have some combination of lectures, team based learning, independent study, anatomy dissection, or small group discussion.

In contrast, the clinical years curriculum is experiential, immersive, and participatory. There are few lectures in the clinical curriculum. The clinical years consist of a series of discipline based clerkships, electives, and selectives. Students work in the outpatient environment, and in inpatient settings. Additionally, the college of medicine has a rich online curriculum resource called Hippocrates that is designed to supplement the traditional curriculum.

The third year consists of a variety of clinical clerkships that range from four to eight weeks in length. During the third and fourth year students must take five 2-week selectives from a variety of areas including: dermatology, emergency medicine, anesthesiology, neurosurgery, and pathology. During the fourth year students take a four week geriatrics clerkship, a four week ambulatory medicine clerkship and a four week rural preceptorship, and 22 weeks of electives. The College of Medicine uses a hybrid grading system. During the pre-clinical curriculum, an honors pass-fail system is used. During the clinical curriculum, a standard letter grade system is used within a 4.0 GPA system.

Regarding assessment: pre-clinical students are assessed via one or more multiple-choice tests per course. Students may also undergo clinical skills assessments and they may be asked to complete assignments or participate in an audience response system exercise. During the clinical curriculum, students are assessed via written and oral exams and are asked to complete patient write ups. Faculty and residents rate student performance on every clerkship. Across the third and fourth year, students are asked to participate in clinical skills assessments.

**The Learning Cycle**

The learning cycle is a teaching procedure that structures inquiry and transpires in several sequential phases. A learning cycle moves the learners through a scientific investigation by encouraging them first to explore materials, then construct a concept, and finally apply or extend the concept to other situations (Marek, 2008).The best description of the learning cycle is an essay by Ann M. L. Cavallo:

> The learning cycle is best described as a philosophy of science teaching and learning, focusing attention on the students and their learning processes. Importantly, the learning cycle is the means to achieve the primary educational purpose of promoting a *thinking*, scientifically well-prepared citizenry that is so critically needed in today's world. (Marek, 2009, p.151)

**History of the learning cycle.** Robert Karplus, a physicist at the University of California Berkelry, is credited for seminal work on structure inquiry, which later became known as the learning cycle. This approach to science began in the late 1950s (Marek, 2009). Together with J. Myron Atkins, Karplus created a theory of "Guided Discovery" which is based around students learning based on their own observations (similar to the scientific method).  The 1970s mark the first time the term "learning cycle" appeared in the literature. The 1970s also brought different other type of inquiry programs for science to numerous school districts.

During the 1980s, John W. Renner and Michael Abraham identified the relationship between the three phases of the learning cycle (exploration, explanation, and expansion) and the three elements of Piaget's model of mental function (assimilation, accommodation, and organization). They found through a study conducted in high school chemistry classes that the sequence of the cycle phases was important to students learning, but noted that they could be reordered under certain conditions. Towards the end of the decade, modified names for the learning cycle were proposed.

The 1990s made additional changes to the learning cycle in the form of new steps added in a more alliterative fashion: engagement, exploration, explanation, elaboration, and evaluation. This is the so-called *5e* learning cycle. Research focus also shifted from the students' involvement in the learning cycle to the teachers' understanding of it. The greater the understanding of the learning cycle by teachers translated into better implementation of the learning cycle as it was designed.

**The learning cycle teaching procedure.** Learning cycles consist of three phases: exploration, explanation, and expansion. During *exploration*, collaborative learner groups engage in an activity and general data collection using scientific processes (assimilation). The exploration phase is designed to stimulate learners' interest by producing some degree of disequilibration. The outcome of the learning cycle (science concept) is not disclosed to the learners beforehand. During the exploration phase, the teacher acts as a facilitator, providing materials and directions, and guiding the physical process of the experiment. The outcome of the exploration phase is typically a set of data for the learners to analyze and interpret in the next phase.

In *explanation* phase, learner groups present their data for class analysis and discussion. During this process, the teacher guides the learners' analysis of the data by questioning them in both groups and whole class discussion (Marek & Cavallo, 1997). Finally, as a class, the learners, using their own words, develop an explanation, or the concept of the learning cycles and therefore re-equilibrate. After the class has constructed the concept (accommodation), the teacher, if appropriate, may introduce any scientific terms related to the concept. Naming these terms culminates the second phase of the learning cycle.

The *expansion* or application phase allows students opportunities to use the science concept in different contexts (organization). The purpose of this phase is to extend or expand learners' understanding of the concept and help them understand its application to other situations. The application may utilize additional experiments, demonstrations, reading, videos, computer programs, and discussions to help learners expand their understanding of the concept. The use of the concept in the application phase completes the cyclical process, and often leads to new explorations (learning cycles). Learning cycles are often viewed as spirals, as application activities lead to more topics to be explored and explained while building more complex concepts upon the foundation of simpler ones.

**Piaget's & Vygotsky's theoretical underpinning of the learning cycle.** The theory of cognition upon which the learning cycle is based is a model of intellectual development advanced by Piaget. Jean Piaget (1896-1980) was a developmental psychologist, best known for his structuralist theory of cognitive development, in which development is organized into a series of sequential and invariant stages. Piaget became very interested in philosophy, especially logic. He blended this with his interest in science and began searching for biological explanations of cognition. Piaget decided to develop philosophy/biology of life and life forms, the centerpiece of which was the idea that all forms of life (organic, mental, and social) are organized as "totalities" that are greater than the sum of their parts, and that these totalities impose the organizing structure of the parts.

Reacting to a long legacy dominated by behaviorist learning theories, Piaget proposed a dynamic, cognitive model of learning that became known later as constructivism. In constructivism, learning is conceived to be a holistic, "bottom-up" process enacted by an *active learner*. In contrast to behaviorist learning theories, Piaget proposed several new and radical themes: the individual learner is an active constructor of knowledge; developmental process must precede learning through instruction; and language is an epiphenomenon of thought and not constitutive of thought. Piaget called the knowledge and skills possessed by individuals “schemas”, and he explained how they got reorganized with the concepts of assimilation, disequilibrium, equilibrium, accommodation, and organization.

Piaget claimed that individuals learn primarily through their own categories of thought while they attempt to organize the world around them. To eventually arrive at adult-like forms of understanding- or, in Piagetian terms, objective knowledge- individuals activity proceed through a spiral of stages in which they develop different hypotheses based on their experience and incorporate these hypotheses into different naïve theories for understanding and explaining the world around them. Instead, individuals’ epistemologies about the world are continually transformed as they act in and on the world and reflect on the nature and effects of their actions.

It is important to note that although originally based on Piagetian theory, the learning cycle also embodies other constructivist paradigms or learning and development such as social constructivist theory by Vygotsky and meaningful learning theory by Ausubel (Marek, Gerber, & Cavallo, 1999). Vygotsky maintained that “learning is a necessary and universal aspect of the process of developing culturally organized, specifically human, psychological functions.” (Vygotsky, 1978). In other words, learning is what leads to the development of higher order thinking. As a constructivist, Vygotsky repeatedly stressed the importance of past experiences and prior knowledge in making sense of new situations or present experiences. According to Vygotsky’s theory, social learning leads to future development, which represents a huge difference from Piaget who believes that development is a prerequisite to learning (Bybee & Sund, 1982). Vygotsky believes that learning and development are always within two planes: social and psychological. Learning is first situated in an interpsychological plane between the learner and knowing others. However, in later stage learning moves into another intrapsychological plane through a process called “internalization.” Internalization is the reconstruction of external operation so they transform from being a social phenomena to being part of the learner’s interpersonal mental functioning. Learning is specific to the culture and society as the tools of learning, such as language and signs, differ from culture to culture. Vygotsky maintained that language plays a central role in cognitive development. He argued that language was the tool for determining the ways an individual learns "how" to think. That is because complex concepts are conveyed to the individual through words. Learning, according to Vygotsky, always involves some type of external experience being transformed into internal processes through the use of language. Additionally, speech and language are the primary tools used to communicate with others, promoting learning. This is in a way similar to Piaget who emphasized the role of experiences on assimilation of knowledge.

Vygotsky's concept of the Zone of Proximal Development (ZPD) is perhaps what he is known for most. He proposed that an essential feature of learning is to create the ZPD; that is, learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers (Gredler & Shields, 2008). Once these processes are internalized, they become part of the child’s independent developmental achievement. In other way, ZPD is “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (Vygotsky, 1978). In theory, as long as a person has access to a more capable peer, any problem can be solved. According to Piaget, learning is what results from both mental and physical maturation plus experience (Bybee & Sund, 1982). In contrast to Piaget who believes that development preceded learning; Vygotsky observed that learning processes lead development (Gredler & Shields, 2008). According to Vygotsky the two primary means of learning occur through social interaction and language. Language greatly enhances humans' ability to engage in social interactions and share their experiences. Vygotsky maintained that learning occurs just above the student's current level of competence. Furthermore ZPD is dynamic and fluid space within which individuals move about as the content, learning contexts, and learner characteristics change (Dimitriadis & Kamberelis, 2006).

***Mental functioning.*** According to Piaget, learning occurs primarily through self-regulation. It involves a series of active constructions and adjustments on the part of the individual in response to external perturbances. These constructions and adjustments are both retroactive (loop systems or feedback) and anticipatory. Together they form a permanent system of compensations, always seeking equilibrium. The compensations are accounted for primarily by assimilation and accommodation. *Assimilation* is a matter of making a new object or experience fit into an old schema. This new object causes a disturbance or disequilibrium that forces the mind to equilibrate. *Equilibrium* is typically motivated by the experience of *disequilibrium*, the uncomfortable sense that one’s experience is at odds with one’s capacity to understand

and explain it. *Accommodation* is a matter of making an old schema fit a new object. For example, teaching medical students about malignant hyperthermia as a disease could be achieved by connecting the pathology of the disease to an earlier concept the learners know, muscle fiber contraction (force). This concept is familiar to all medical students through earlier biology and physiology classes. A review of intracellular action of a fiber contraction and the role of calcium regulation in organized fiber contraction places the subject in the learners' ZPD. Introducing the concept of a genetic malfunction that cuases massive release of calcium under certain circumstances will cause the learners to cognitively disequilibrate and force them to equilibrate by assimilation. Students will then accommodate by connecting the effects of increased intracellular calcium release and the clinical symptoms of malignant hyperthermia: increased muscular contraction causes rigidity and increased heat production, massive lactate release causes acidosis, increased oxygen consumption manifests as blood oxygen desaturation, and increased carbon dioxide production forces the body to remove it manifesting by increased carbon dioxide elimination by the lungs. Learning about malignant hyperthermia causes the learners to go through multiple loops and feedbacks while disequilibrating and equilibrating multiple times; a formal learner should be able to do that.

***Developmental stages.*** Even though Piaget claimed that children are active participants in the creation of knowledge, he also claimed that they progress through distinct development stages, each with its own specific kind of knowledge and ways of organizing that knowledge, as well as specific behavioral characteristics. The first, the *sensorimotor stage*, occurs roughly between birth and two years of age. During this stage, children explore things that can be seen, felt, and touched through their senses. Their knowledge during this stage is largely immediate, sensory, and motor. The next stage, the *preoperational*, occurs roughly between the ages of two and seven years. During this stage, children's thinking is more intuitive and concrete than logical and abstract. One of the best-known examples of preoperational children's centrism is their inability mentally to conserve number, length, and solid or liquid amounts. The third stage, *concrete operations*, emerges roughly between the ages of seven and up. During this stage, children begin to apply logical operations to concrete problems. Children are rather skilled at thinking logically, but only in the context of specific, concrete situations. They have difficulty thinking abstractly and forming generalizations based on particular experiences. They also develop the concept of "Reversibility", "Classification" and "Serration". The fourth stage, *formal operations*, emerges roughly around ages of eleven and up. During this stage, children develop the ability to view problems from multiple perspectives, to think abstractly, to form and test hypotheses intentionally, to generalize from the particular to the abstract, to engage in logical (deductive) reasoning, and to develop ideals. Although Piaget posited that these four stages are sequentially invariant, he also acknowledged that the ages when children pass through different stages are approximate, and that children sometimes move back and forth between stages during transitional developmental periods.

Piaget argued that language does not facilitate cognitive development, and that cognition can develop normally without language acting as a mediational means. Additionally, he thought that although language is instrumental in sharing of knowledge, it is not a source of knowledge. Instead, for Piaget, thought development precedes language development. Language is simply a reflection of the thought. This claim seems rooted in Piaget's instance that the individual learner is a little scientist, constantly constructing and reconstructing theories about the world and how it works. This perspective is controversial and was strongly opposed by Vygotsky and his followers. From this perspective, socialization and teaching is effective only after children have moved beyond syncretic thought and egocentric speech.

Vygotsky promoted the development of higher level thinking and problem solving in education (Gredler & Shields, 2008). If situations are designed to have learners utilize critical thinking skills, their thought processes are being challenged and new knowledge gained. The knowledge achieved through experience also serves as a foundation for the behaviors of every individual. Vygotsky believes in the "More Knowledgeable Other" (MKO). The MKO is anyone who has a better understanding or a higher ability level than the learner, particularly in regards to a specific task, concept or process. The MKO could be thought of as a teacher or an older adult; however, this is not always the case. Other possibilities for the MKO could be a peer, a sibling, a younger person, or even a computer. This is similar to what Bruner thinks and believes (Bruner, 1996). The key to MKO is that they must have more knowledge about the topic being learned than the learner does. Teachers or more capable peers can raise the student's competence through the ZPD. Vygotsky's findings suggest methodological procedures for the classroom where the ideal role of the teacher is that of providing scaffolding to assist students on tasks within their ZPD. During scaffolding the first step is to build interest and engage the learner. Once the learner is actively participating, the given task should be simplified by breaking it into smaller subtasks. During this task, the teacher needs to keep the learner focused, while concentrating on the most important ideas of the assignment. One of the most integral steps in scaffolding consists of keeping the learner from becoming frustrated. The final task associated with scaffolding involves the teacher modeling possible ways of completing tasks, which the learner can then imitate and eventually internalize. It seems that what Vygotsky is calling *internalization* is close to Piaget's idea of *assimilation*. Students need to work together to construct their learning, teach each other so to speak, in a socio-cultural environment.

**Cognitive and motivational variables.** In addition to research supporting the effectiveness of the learning cycle in facilitating a better understanding of scientific concepts and processes, the role of cognitive variables on science achievement has also been investigated (Cavallo, 1996; Johnson & Lawson, 1998; Lawson & Thompson, 1988). Among cognitive variables, *reasoning ability* has received the most attention. The ability to reason formally is the strongest predictor of meaningful understanding of scientific concepts. Lawson and Thompson (1988) demonstrated that high-formal learners who no longer require concrete objects make rational judgments and are capable of hypothetical and deductive reasoning, performed better than did low-formal learners. High-formal learners are able to understand both concrete and formal concepts. They have developed sound understanding of abstract concepts. Such learners are capable of looking for relations, generating and testing alternative solutions to problems, and drawing conclusions by applying rules and principles. Low-formal learners on the other hand are concrete reasoners who are unable to develop sound understanding of abstract concepts. They are able to understand only concrete concepts. Low-formal learners have not fully developed formal thought yet. Lawson and Renner (1975) reported that interpreting and solving genetics problems requires formal-level operations such as probabilistic, combinational, and proportional reasoning that is in line with Piaget's developmental theory. It is assumed in this research that all medical students are formal thinkers and thus can handle teaching of more than one concept at a time. This is very important to medical educators as most of the teaching that we do depends on formal learners who can move among concepts smoothly.

**Simulation for Assessment of Learning in Medicine**

Simulation in medical education is a growing enterprise that facilitates learning for individuals and multidisciplinary teams in hospital and school environments. Simulators range from task trainers, to medium fidelity life size and human appearing mannequins, to high fidelity mannequins that project physiological signals and respond to pharmacological interventions in a realistic looking healthcare setting. Training has a wide range of applications, from basic to advanced technical skills acquisition, to interpersonal factors such as communication and teamwork, to assessing the learners in a safe environment. This training can be provided through the use of high-fidelity simulation as well as other methods such as standardized patient scenarios and task trainers. Dr. David Gaba (2007) defined simulation as "a technique-not a technology-to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner." (p. 126).

Learning from error is a new concept that has been applied in medical teaching in the last few decades. This method of teaching was not applicable years ago as medical errors may lead to fatal consequences to patients. However, with the invention of human simulators learning by error is easily and safely applicable. This gives medical teachers better chance at focusing on challenging, open-ended investigations without the fear of harming a patient. The negative emotions generated from bad outcomes as a result of mistakes made during simulation can lead to better decision making in real clinical situations (Okuda et al., 2009). As complex skills are constructed from fundamental component skills, the proficient performance of complex skills is achieved by refining and integrating the component skills during repeated performance in a realistic context that is accompanied by feedback on performance. This is precisely what simulation learning can provide.

Despite advances in simulator development, even high-fidelity simulators are imperfect. Although simulation has come a long way in replicating human likeness, there remains a degree of low face-validity, or realism. Some trainees, for example, know that the simulator is not a “real patient,” and so may behave differently than they might in “real” situations. Future developments in simulator technology will likely help to improve the fidelity of training scenarios, which will in turn, improve the assessment of trainee performance.

**History of mannequin simulation.** Simulators in healthcare date back to the 1960’s with the development of Resusci-Anne for the purpose of teaching and demonstrating mouth to mouth resuscitation (Cooper & Taqueti, 2008; Cumin & Merry, 2007; Grenvik & Schaefer, 2004).

***Early mannequin simulators.*** The earliest medical simulator is *Resusci-Anne*. The first version of Resusci-Anne simulated airway obstruction and allowed the user to adjust the airway by hyperextending the neck and forward thrusting the chin to aid mouth to mouth resuscitation. Not long after its development, and following the realism of the benefits of external chest compression during cardiac arrest, Resusci-Anne was updated to include a spring in the chest to allow the simulation of chest compressions.

Another historical mannequin simulator that also has its origins in the 1960s is *Harvey*, a mannequin designed to model 27 different cardiac conditions (Gordon, 1974). Harvey could demonstrate blood pressure, jugular venous pulses, arterial pulses, precordial impulses and auscultatory events (Cooper & Taqueti, 2008). Throughout the decades Harvey has been the center of many studies that explored the efficacy of simulation in medical education. A study by The National Heart, Lung, and Blood Institute showed that fourth year medical students trained with Harvey performed better than their colleagues trained with live patients only (Ewy, Felner, & Juul, 1987). For these high performing students, training with Harvey had improved their confidence and cardiology assessment skills. Harvey has also been utilized as a tool to test the cardiology exam and diagnostic skills of medical professionals.

**Simulators in anesthesia.** Simulators have long been used for purposes of developing anesthesia related skills. For example, *Sim One.* is a computer controlled high-fidelity simulator developed for training and testing experiments. Additionally, Dr. David Gaba (1988) developed the simulator known as *CASE* – Comprehensive Anesthesia Simulator Environment to investigate human performance in anesthesia.

CASE relied on the ability of a computer to run simulated blood pressure values and later displayed physiological cardiac signals in a realistic operating room environment. With the ability to simulate a number of critical events, a new curriculum entitled Anesthesia Crisis Resource Management (ACRM) was born (Holzman et al., 1995).

At the same time of CASE's development, *GAS*. - Gainesville Anesthesia Simulator was developed and originally used to simulate and diagnose faults within an anesthesia machine (Cooper & Taqueti, 2008). Combining the apparatus with a simulated lung model, GAS is a complete mannequin simulator that enabled users to diagnose critical anesthesia events. GAS later became a licensed product of Medical Education Technologies Inc. which now makes *HPS* (Human Patient Simulator) and *PediaSIM*. The creation of such high fidelity patient simulators provided an avenue for medical personnel to learn psychomotor and cognitive skill in a realistic patient setting.

**Current uses of simulation.** Medical simulation, in general, has been used to (a) practice complex medical procedures and critical events, (b) promote rehearsal of clinical and nonclinical skills such as communication, (c) introduce new equipment/technology, (d) train teams and individuals, (e) experiment with novel interventions, and (f) assess performance (Bradly, 2006). In anesthesia, simulation can be used to provide training in crisis management, new technologies or equipment, cognitive skills such as decision-making, technical skills such as airway management, behavioral skills such as communication, teamwork, and leadership. Additionally, simulation can be used for competency assessments for physicians credentialing and board examinations.

**Advantages of medical simulation.** There are a number of reasons for using simulation in health care environments. Primarily, use of simulation provides zero risk to patients as errors may be obtained and corrected without consequences. Simulation also allows for the presentation of a wide variety of scenarios, including less frequent but still critical events. Additionally, simulation provides flexible, job-specific training and learning that can be tailored to a participant's skill level and/or learning style. Unlike patients, simulators do not become embarrassed or stressed, are available at any time to fit curriculum needs, and have predictable behavior. Thus, training does not have to be delayed due to "real patient" variables. In addition, simulators: can be programmed to simulate selected conditions, findings, situations and complications; allow standardized experience for all trainees; can be used repeatedly with fidelity and reproducibility (Issenberg et al., 1999).

**Simulation in medical education.** In a systematic review of 670 peer-reviewed journal articles related to high fidelity medical simulation in a range of disciplines, including anesthesia, clear evidence was found that repetitive practice involving medical simulation is associated with improved learner outcomes (McGaghie, Issenberg, Petrusa, & Scalese, 2006). Furthermore, it was identified that a dose-response relationship, such that more practice, yielded better results for all levels of learners, including students, residents, and attending physicians.

***Undergraduate medical education.*** Teaching through the use of simulation could be superior to typical problem based learning for undergraduate learning. In science, mannequins are used to teach physiology, while human actors are very effective in teaching multiple different disciplines including neuroscience. Simulation can also help to ease the transition from study into clinical clerkships; for example, the cardiology patient simulator replicates 30 different cardiac conditions. Additionally, virtual reality simulation can be used to aid students in learning through simulated surgeries (Okuda et al., 2009). Morgan and Cleave-Hogg (2000) demonstrated that simulation is a reliable assessment method for medical students' performance.

***Graduate medical education.*** Simulation can be used to teach adverse reactions to anesthesiology in a way that legal and safety concern prevent in real-life situations. For training in obstetrics, motorized muscles allow a mannequin to "give birth" to a mannequin "baby". Valuable emergency medicine skills are being transmitted through the use of simulation, as well as crew resource management skills. Critical care training, such as central line placement, can be taught through the use of simulated practice (Okuda et al., 2009).

***Board certification and credentialing, and medical-legal applications.*** Computer-based simulation of patients is used in several countries' examination processes. The US and Canada use simulation to add additional levels of evaluation. The American Board of Anesthesiology is preparing to use simulation in the evaluation for board certifications. Simulation has also been effective as a tool in cases of malpractice. Some insurance companies have been offering incentives to anesthesiologists who participate in simulations for crisis resource management. Simulation may also have implications if used as evidence in the courtroom for malpractice cases.

***Competency assessment.*** Simulations can be used to assess the competency of a physician and are capable of distinguishing between a novice resident and a more experienced one. The use of an anesthesia simulator offers a number of advantages over traditional assessment methods. First of all, simulation allows for multidisciplinary learning: nurses, pharmacists, medical students, residents, fellows, and physicians. Secondly, scenarios can be standardized so that multiple teams of learners can be trained in the same way, which is especially helpful for assessment and credentialing. By standardizing the scenarios, having the observers view the same events, and scripting the responses to the problems, differences attributed to the "patient," the candidates, or the conduct of the examination are eliminated (Devitt, Kurrek, & Cohen, 1997).

Malignant hyperthermia scenarios have been used frequently to assess anesthesiologists (Boulet, Murray, Kras, & Woodhouse, 2008; Henrichs et al., 2009; Murray et al., 2007). Standards for management of malignant hyperthermia mannequin-based scenario are established using aggregate expert judgments of physicians' audio-video performances (Boulet et al., 2008). A scenario of malignant hyperthermia, among other conditions, provides a great assessment opportunity in anesthesiology as the management of malignant hyperthermia is emergent with a set of agreed upon steps to recognize and treat.

# Chapter III

## Research Methodology

This study is designed to compare factual knowledge retention and clinical skills outcomes of medical students following their experience in one of two different teaching designs: inquiry via the learning cycle and exposition via power point presentation. Clinical knowledge and skills acquired from either teaching practice was measured by how learners recognized and managed a malignant hyperthermia crisis in a medical fidelity simulation one month following the experimental teaching procedures. Factual knowledge acquired and retained was compared using a multiple-choice test immediately following the teaching procedure and one month later. Additionally, correlation between factual knowledge (performance on multiple-choice test) and clinical skills (simulation) was studied. A quantitative analysis was used to compare the difference between the two groups.

### Description of Participants

Following The University of Oklahoma Health Sciences Center Institutional Review Board approval, third and fourth year medical students (MSIII and MSIV, respectively) enrolled in the College of Medicine at the University of Oklahoma were asked to participate in this study. The current demographics of medical students in the College of Medicine is 48% females and 77% whites. The only exclusion criteria that was used is refusal to participate in the study.

**Recruitment.** In July of 2011, an email was sent out to all MSIII & MSIV (250 students) at College of Medicine at the University of Oklahoma inviting them to participate in the study. The process was repeated 3 times after that on a weekly basis.

Only 22 students agreed to participate and 5 of them did not show up to the class session for which they signed up. A recruitment email was then distributed to all MSII (136 students) and only 7 agreed to participate. Following that, and to increase students' participation, students who were rotating in Anesthesiology or Surgery were personally recruited by the investigator on a monthly basis. A $25 gift card was offered to each student at the completion of the study to compensate for their time. Additionally, students were informed that performance assessment generated from participating in the study will not be used in any of their medical school evaluation.

**Randomization**

Research Randomizer software (http://www.randomizer.org/) was used for randomization. The software assigned each student either the number 1 (inquiry) or the number 2 (exposition).

**Inquiry group (I).** Students who were randomly assigned the number 1 were taught about malignant hyperthermia using a learning cycle the investigator developed and used previously (Appendix B).

**Exposition group (E).** Students who were randomly assigned the number 2 were taught about malignant hyperthermia using a slide presentation the investigator developed and used previously (Appendix C).

**Teaching Procedures**

Students were taught by the same instructor in different groups. All teaching for inquiry and exposition occurred in the lecture room at the University of Oklahoma Clinical Skills Education & Testing Center. The instructor and the group met for one hour. All content taught were similar between the two groups but the teaching practices were different.

**Inquiry teaching.** During one hour, the instructor followed the lesson plan on malignant hyperthermia. See Appendix B.

**Exposition teaching.** During one hour, the instructor followed a slide presentation format. Following the slide presentation, a 5 minutes period was allowed for students to ask questions and participate. See Appendix C.

To ensure parallel of teaching content between inquiry and exposition before enrolling medical students into the study, pre-experiment teaching procedures were conducted and videotaped one time (one inquiry and one exposition) with MSI who were not recruited for the study. Two anesthesiologist raters watched the videotapes and used a checklist of the items the students will be assessed with (simulation and multiple-choice tests) as teaching rubric. Each item was scored as covered or not (Appendix D). Both raters reported that 8 out of 22 items on the checklist were not covered during both teaching procedures. The items were written down and added to the content of the teaching procedures as notes to be covered by the instructor.

Additionally, all teaching procedures were captured on vediotapes and the anesthesiologist raters randomly selected one videotape from each actual teaching group and used the same above prescribed checklist to ensure similarity of teaching content between inquiry and exposition teaching.

**Assessment Procedures**

Human Fidelity Simulation has been used extensively to assess management of a malignant hyperthermia crisis (Boulet et al., 2008; Henrichs, et al., 2009; Murray et al., 2007). However, results from a study by Morgan, Cleave-Hogg, Guest, and Herold (2001) indicated that a complex multitask simulator scenario could be somewhat challenging at the undergraduate level. Thus, performance template of the current study involves a single patient management problem only, giving the students opportunity to focus their problem solving abilities. As per our interest is the long term effects of the teaching procedures, the assessment process took place approximately one month following the experimental teaching procedures.

**Orientation to simulation.** The students as a group were introduced to the simulator mannequin and the monitors in the simulation room. The mannequin was in a state of awake and spontaneously breathing. This gave the students the chance to observe the monitors with normal vital signs (blood pressure, oxygen saturation, and electrocardiogram). The investigator allowed the students during that time to ask questions regarding simulation, but not regarding malignant hyperthermia. Then the student group witnessed the investigator demonstrate management of a scenario of bronchospasm. This gave the students a chance to see the mannequin reacting to a crisis where oxygen saturation decreased slowly and intra-thoracic pressures increased accompanied by wheezing in the chest. These symptoms improved and returned to normal when the investigator administered epinephrine intravenously. The students were also oriented to the anesthesia machine and the ventilator. They were shown how to read the vital signs on the monitors, and were shown where the emergency drugs and ambu-bag are.

Then the students were asked to return to the class room. They were given the following instructions: (a) please remember to communicate with the personnel in the control room if anything does not make sense to you, and (b) please think out loud during the assessment so we can guide you if needed. One student will be randomly picked to be assessed next and so forth.

**Anaphylaxis scenario.** Each student was assessed separately by being asked to go to the simulation mannequin room. The anaphylaxis scenario served to familiarize the student with the environment, and was done without the student knowledge beforehand. This scenario was not videotaped or rated. A printed handout sheet of information containing the pertinent history, physical exam, and laboratory findings was given to the student. Following checking the student's preparedness and all equipment, the mannequin simulated a patient under general anesthesia for a leg surgery. The monitors showed normal vital signs with a patient under general anesthesia. The student was then asked by the surgeon actor in the simulation room to administer 2 ml of a muscle relaxant intravenously. Thirty seconds following the administration of muscle relaxant, the mannequin manifested with anaphylaxis symptoms. These symptoms included: increase heart rate, decreased blood pressure, increased intra-thoracic pressure and chest wheezing. This scenario was terminated three minutes later regardless of the student's management.

Next, the student was asked to wait in the hallway while the investigator and one assistant set up the simulator for the actual assessment. This set-up included 3 main steps: (a) a scenario of malignant hyperthermia was reloaded on the computer that controls the mannequin, (b) two ceiling video cameras that record the action of the student were positioned to capture the student during the assessment, and (c) the audio that connects the control room with the mannequin room was checked for functionality. The controlling computer is located in the control room that connects to the mannequin room through a one-way mirror.

**Malignant hyperthermia scenario.** The student was asked to enter the simulation room to care for a different patient. A printed handout sheet of information containing the pertinent history, physical exam, and laboratory findings was given to the student. Following checking the student's and equipments' preparedness, the mannequin simulated a patient under general anesthesia for an elbow surgery. A minute later, the student was asked by the acting surgeon to administer a muscle relaxant (succinylcholine). A minute later, the mannequin presented with manifestation of malignant hyperthermia episode. This included: increased end-tidal carbon dioxide, increased blood pressure, increased heart rate with arrhythmias, and slow increased in temperature. The student's management was captured using the video cameras. The experiment ended in five minutes and the student was asked to leave the simulation center. Students who have been exposed to teaching or assessment were asked to not share their experience with any other students participating in the study.

**Standardized performance evaluation.** Each student was asked to sign a consent form to be videotaped and the tape to be analyzed. Two microphones were suspended from the ceiling to capture audio during the scenario. Each malignant hyperthermia performance was videotaped and recorded on a three-box screen that included two separate video views of the student and the mannequin. The third box of the three-box video recording displayed the simultaneous full display of patient vital signs (electrocardiogram, pulse oximetry, temperature, and blood pressure). Below the

3 boxes, identifying information such as the date and student ID are displayed. This part of the screen was also used to add information to clarify participant actions during the scenario (Figure I).

**Figure I.** A sample shot of the video recording screen.


Similar to other studies on simulation (Morgan et al., 2001), the general approach to scoring the scenario included two analytic methods (checklist and essential action) and a single global rating scale. For the analytic scoring, two trained anesthesiologists scored each student's performance separately using a detailed checklist of diagnostic and therapeutic actions and an abbreviated checklist system that consists of three essential actions for the scenario. In a previous study, a list of technical actions and point values for a malignant hyperthermia scenario were created and used (Gaba et al., 1998). The checklist scoring system included two essential actions and 33 possible actions totaling 95 points, and each action was weighted based on its importance with respect to overall patient care. The checklist action used in this study is a modification of the checklist action used by Gaba et al. In our checklist, we have deleted some of the actions used be Gaba et al. as we concluded that these actions are above and beyond the expectations of a medical student. Our checklist scoring system included three essential actions and 12 possible actions totaling 50 points (Table I). A subject who misses one essential action or more by the two raters was considered “fail”, while a subject who performed all three essential actions was considered a “pass” and received an extra point on the total clinical skills score. All videos of “fail” students were reviewed by a third anesthesiologist rater to confirm the deficiency. The rater anesthesiologists also provided a single global rating of the performance on a scale of 0-10, where zero is very bad and 10 is excellent. The anesthesiologists were blinded to students’ assignment groups (inquiry or exposition).

**Table I.** Checklist Scoring System for malignant hyperthermia scenario.

| **Action** | **Point Value** |
|---|---|
| Initiation of MH protocol | |
| -Diagnoses MH or notify surgeon | EA |
| -Requests MH box | 5 |
| -Calls for help | 5 |
| -Terminates triggering agent within 1 minute | EA |
| Dantrolene administration | |
| -Administers dantrolene within 10 minutes | EA |
| -Administers dantrolene 2.5 mg/kg | 10 |
| Ventilation and oxygenation | |
| -Uses 100% oxygen | 5 |
| -Hyperventilates by ventilator | 5 |
| -Clears triggering agent with high flow | 5 |
| -Disconnects from ventilator and uses Ambu-bag | 5 |
| Requests blood gas or potassium levels | 5 |
| Cooling action of any kind | 5 |

The checklist includes 3 essential actions (EA) and 12 possible actions totaling 50 points.

**Multiple-choice test.** Students in each group were asked to take a 15 minutes/15 item multiple-choice test prior to (pre-test) and immediately following the teaching procedures (post-test). The same test was repeated prior to the simulation assessment one month later (post/post-test). See Appendix E.

**Statistical Methods**

Data were analyzed using SPSS® Software Version 18.1. A *p*-value lower than 0.05 was used as an indication of significant difference between the two groups. Demographic data including age, days between lecture and simulation, post-high school education, number of months in medical school, gender, and medical school class were collected and compared using an independent sample *t* test. Medical knowledge as assessed by the multiple choice test scores for pre, post, and post-post teaching method were compared using an independent sample *t* test to test the null hypothesis that there is no differences in scores between the two groups. A paired-samples *t* test was used to evaluate the effects of the teaching methods on the students' test scores (difference between pre and post) and their knowledge retention a month later (difference between post and post-post).

Due to difference in the scale of the simulation tests, the following algorithm was used to calculate the final clinical skill scores; the quartiles for the average scores of the two raters for checklist, global rating, and essential action were calculated for all students. Students who performed in the first quartile on each category were assigned 1 point; students who performed in the second quartile were assigned 2 points; students who performed in the third quartile were assigned 3 points; and students who performed in the forth quartile were assigned 4 points. Additionally, students who performed all 3 essential actions were considered a "pass" and were assigned an extra point. The points from the 3 simulation categories and the "pass" point were added together for each student and were considered a clinical skills score that ranges from 0 to 13. Independent-samples *t* test was used to test the null hypothesis that there is no difference in clinical skills between the two groups.

Pearson correlation coefficient was used to test correlations between clinical skills, knowledge retention (scores difference between post and post-post), medical knowledge (post-post score), days following lecture, period of enrollment in medical school (months), post-high school education (years), knowledge improvement (scores difference between pre and post-post), and age.

**Risks and Benefits to Participants**

Minimal risks to subjects included: (a) total time spent in participating in the study, which was 3-4 hours (Table II), (b) experiencing simulation and testing that could cause anxiety to some students, (c) potential anxiety for students who are planning to apply into Anesthesiology and are afraid that the experience will influence any of the program's future opinion about them. On the other hand, there were many benefits to the students participating: (a) increasing the amount of knowledge from teaching, (b) experiencing simulation session and learning from it, (c) and monitorial benefit.

**Table II.** Timeline for conduction of investigation.

| **Time (minutes)** | **Process** |
|---|---|
| 15 | Multiple-choice pre-test |
| 60 | Learning procedure |
| 15 | Multiple-choice post-test |
| 10 | Introduction to simulator |
| 15 | Multiple-choice post/post-test |
| 5 | Bronchospasm scenario |
| 5 | Set up for a student |
| 5 | Anaphylaxis scenario |
| 5 | Set up for real assessment |
| 5 | Malignant hyperthermia scenario |

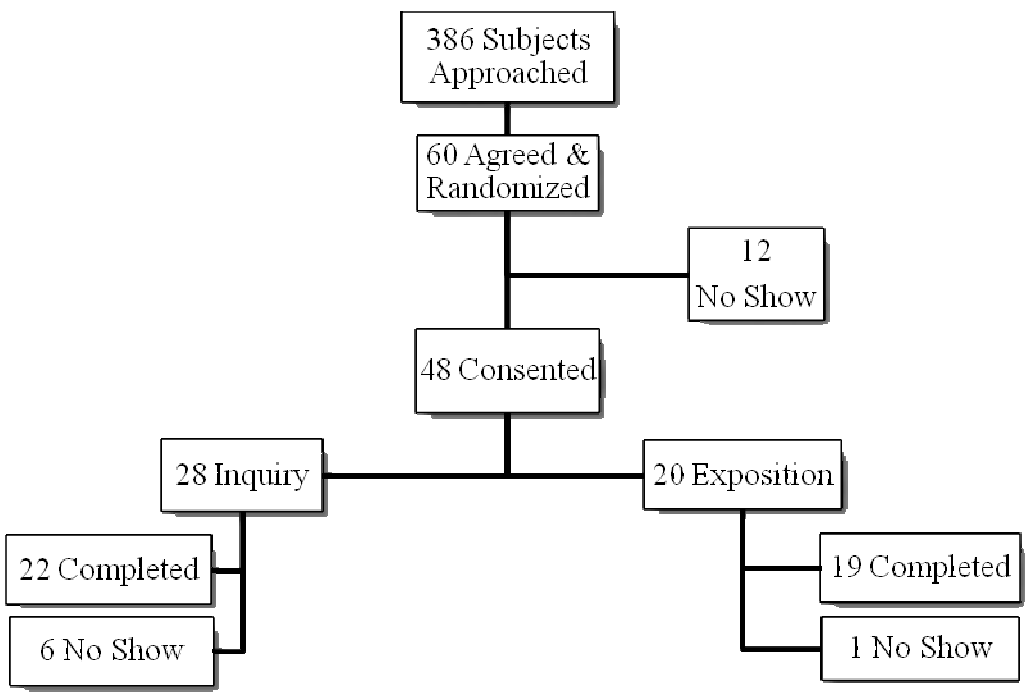
# Chapter IV

## Results & Interpretation

### Recruitment

By the end of the academic year (July of 2012), 60 students agreed verbally or by email to participate in the study and were randomized. Forty eight attended the teaching session and signed the consent form. From the 48 students, 28 were randomized into the inquiry group (I) and 20 into the exposition group (E). Seven of the students who attended a teaching session (6 I and 1 E) did not show up to the simulation session a month later and multiple attempts to coordinate with them for a makeup sessions failed (Figure II).

**Figure II.** Recruitment and flow of participants.




Groups were not significantly different in age (*M* = 26, SD = 3.0 years in I, and *M* = 27.4, SD = 4.5 years in E), post-high school education (*M* = 6.6, SD = 1.4 years in I, and $M$ = 7.2, SD = 2.2 years in E), time enrolled in medical school ($M$ = 31.4, SD = 9.1 months in I, and $M$ = 31.5, SD = 7.7 months in E), gender (15 female and 13 male in I, 13 female and 7 male in E), and class (5 MSII, 16 MSIII, 7 MSIV for I, 2 MSII, 12 MSIII, 6 MSIV for E). Demographics of participants are reported in table III.

**Table III.** Demographics of participants.

| | | Inquiry | Exposition | *p* |
|---|---|---|---|---|
| **Age in years** (Mean ± SD) | | 26.0 ± 3.0 | 27.4 ± 4.5 | 0.23 |
| **Days between lecture and simulation** (Mean ± SD) | | 31.0 ± 4.4 | 37.4 ± 2.6 | 0.00* |
| **Years post-high school education** (Mean ± SD) | | 6.6 ± 1.4 | 7.2 ± 2.2 | 0.26 |
| **Months enrolled in medical school** (Mean ± SD) | | 31.4 ± 9.1 | 31.5 ± 7.7 | 0.98 |
| **Gender** (female/male) | | 15/13 | 13/7 | 0.63 |
| **Class** | **MSII** | 5 | 2 | |
| | **MSIII** | 16 | 12 | 0.28 |
| | **MSIV** | 7 | 6 | |

* $p < .05$.

## Teaching Procedures

Five inquiry teaching sessions were conducted for 28 students (4, 6, 4, 5, and 8 students in each session respectively), and 3 exposition teaching sessions were conducted for 20 students (9, 8, and 3 students in each session respectively). The anesthesiologist raters randomly selected one videotape of one inquiry and one exposition teaching procedures. They separately viewed the tapes and used the checklist to ensure similarity of teaching content between inquiry and exposition teaching. Both agreed that the 22 items in the rubric were covered in all teaching sessions.

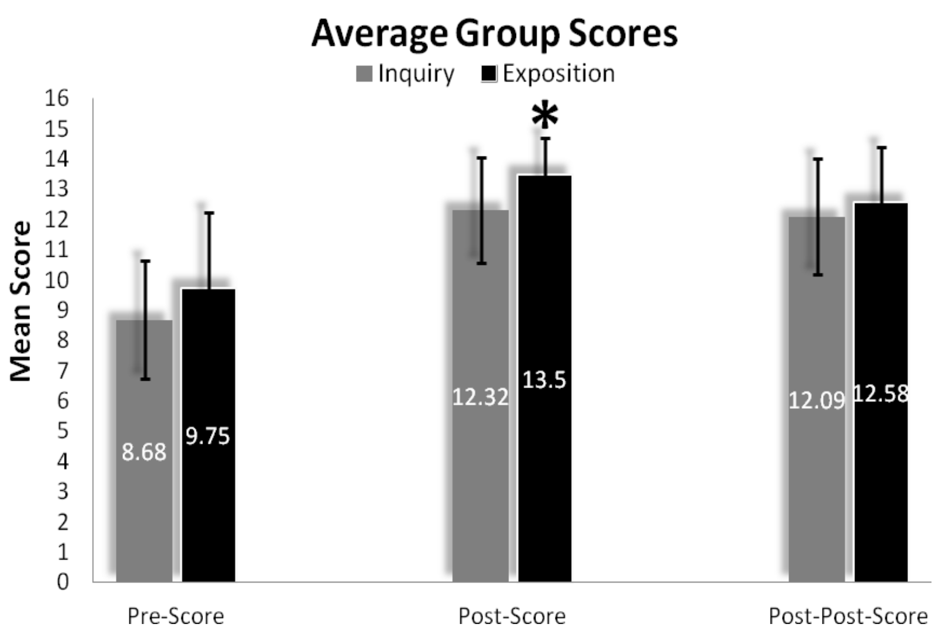
### Simulation Sessions

Thirty students were able to attend 4 weekends' simulation sessions, and 11 students had to have makeup sessions that totaled 9 different sessions due to scheduling issues. Seven students never showed up to any simulation session despite all attempts to coordinate with them. Although all attempts were made to have the simulation session in exactly 30 days, students' schedule and holidays interfered. Students in E group had a significantly longer time between teaching session and simulation ($M$ = 31, SD = 4.4 days in I, and $M$ = 37.4, SD = 2.6 days in E, $p$ = 0.00).

### Medical Knowledge (multiple-choice test)

Mean scores for pre-test, post-test, and post-post-test were higher in the E group (Figure III). Clinical skills scores and post-post scores were not available for those 7 students who did not show up to the simulations session.

**Figure III.** Comparison of mean scores in multiple-choice tests in both groups.




* $p < .05$.

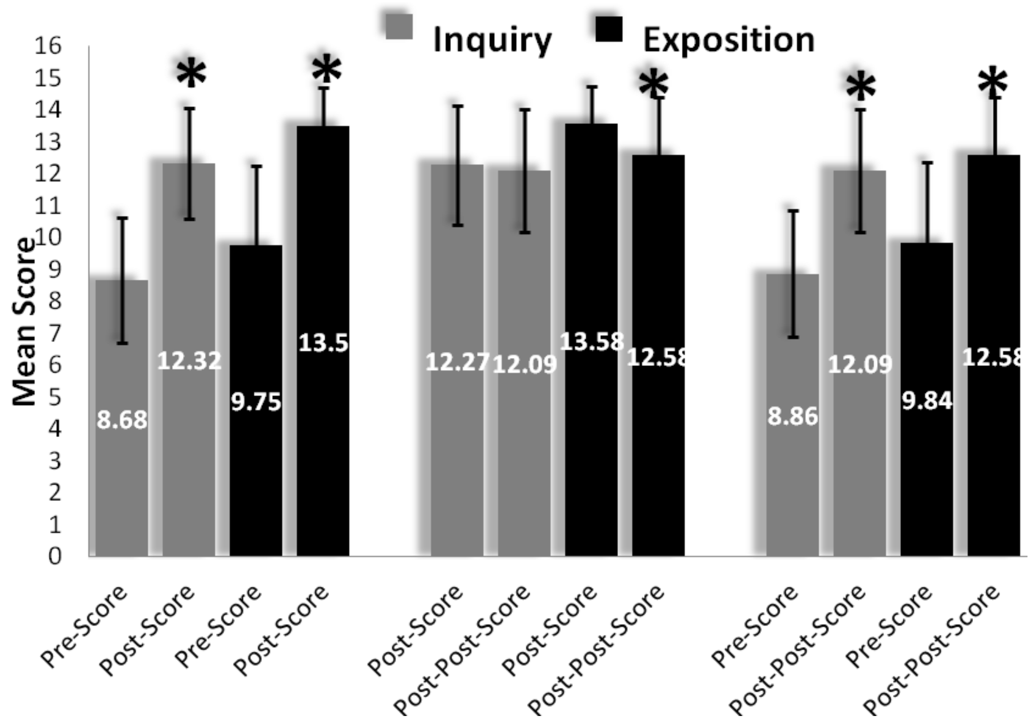
An independent sample *t*-test was conducted on the test scores of the two groups to evaluate whether their means were significantly different from each other and alpha was set at .05. Mean scores of pre-test were not statistically significantly different between the 2 groups (*M* = 8.68, SD = 1.96 in I, and *M* = 9.75, SD = 2.49 in E). Mean scores of post-post test were also not statistically significantly different between the 2 groups (*M* = 12.09, SD = 1.92 in I, and *M* = 12.56, SD = 1.80 in E). However, the post-scores were significantly higher in E group with *p* value of .012 (*M* = 12.32, SD = 1.74 in I, and *M* = 13.50, SD = 1.19 in E) (Table IV).

**Table IV.** Comparison of mean scores in multiple-choice tests in both groups.

| | *p* | Mean Difference | 95% Confidence Interval of the Difference | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Pre-Score (equal variance) | .102 | -1.07 | -2.37 | .22 |
| Post-Score (equal variance) | **.012** | -1.18 | -2.09 | -.27 |
| Post-Post-Score (equal variance) | .410 | -.49 | -1.67 | .70 |

A paired-samples *t* test was conducted to evaluate the difference in the effects of the teaching practices on the students' knowledge improvement (pre to post) and their knowledge retention a month later (post to post-post) (Figure IV). Students' score in both groups improved significantly from pre to post (*M* = 3.64, SD = 2.26 in I, and *M* = 3.75, SD = 2.29 in E) and from pre to post-post (*M* = 3.28, SD = 2.47 in I, *M* = 2.74, SD = 2.58 in E). However, their scores decreased from post to post-post (*M* = -0.18, SD = 2.04 in I, *M* = -1.00, SD = 1.20 in E). Although the decrease in scores was not significant in group I; it was significant in the group E with *p* value of 0.02 (Table V). This indicates that students who were exposed to inquiry teaching had a statistically significantly better knowledge retention a month later compared to students who were exposed to exposition teaching.

**Figure IV.** Mean paired scores for all three multiple choice tests.




* $p < .05$.

**Table V.** Comparison of mean paired scores for all three multiple-choice tests.

**Paired Test**

| Randomization | | | Mean | 95% Confidence Interval | | *p* |
|---|---|---|---|---|---|---|
| | | | | Lower | Upper | |
| I | Pair 1 | Post Score – Pre Score (Knowledge Improvement) | 3.64 | 2.76 | 4.52 | .000 |
| | Pair 2 | Post Post Score – Post Score (Knowledge Retention) | -.18 | -1.09 | .72 | .680 |
| | Pair 3 | Post Post Score – Pre Score | 3.28 | 2.13 | 4.32 | .000 |
| E | Pair 1 | Post Score – Pre Score (Knowledge Improvement) | 3.75 | 2.68 | 4.82 | .000 |
| | Pair 2 | Post Post Score – Post Score (Knowledge Retention) | -1.00 | -1.58 | -.42 | **.002** |
| | Pair 3 | Post Post Score – Pre Score | 2.74 | 1.50 | 3.97 | .000 |

**Clinical Skills (simulation)**

Although the exposition group had higher scores on simulation measurements, the difference was not statistically significant (Table VI). Clinical skills scores were (*M* = 7.45, SD = 3.63 in I, and *M* = 9.05, SD = 3.34 in E). Average raters scores for checklist was (*M* = 20.91, SD = 12.4 in I, and *M* = 25.79, SD = 13.62 in E), for global scores was (*M* = 6.14, SD = 2.18 in I, and *M* = 6.89, SD = 3.32 in E), and for essential action was (*M* = 2.48, SD = 0.52 in I, and *M* = 2.74, SD = 0.42 in E). See results in table VII.

**Table VI.** Difference of clinical skills between the 2 groups.

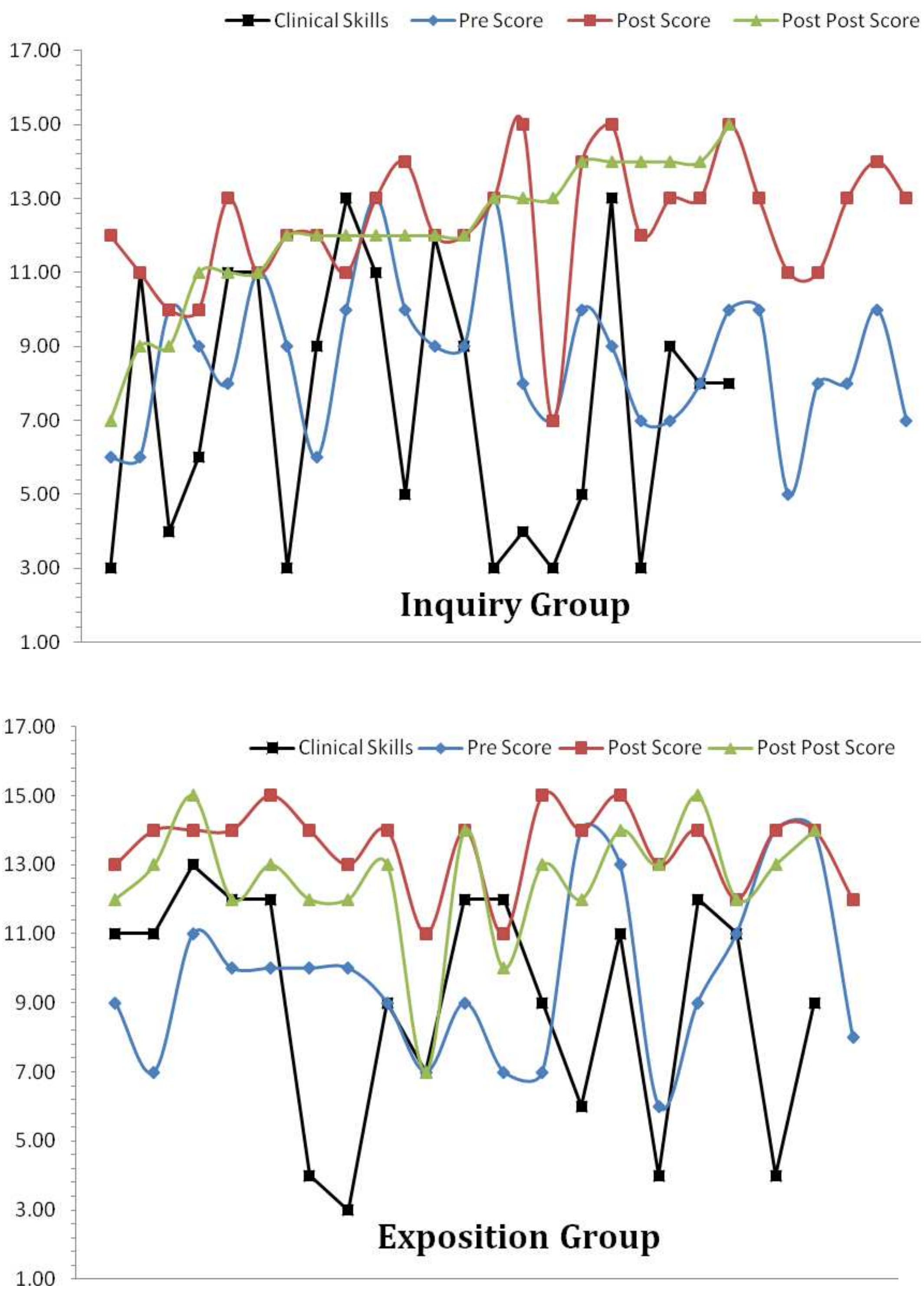
| | *p* | Mean Difference | 95% Confidence Interval of the Difference | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Clinical Skills (Equal variances) | .153 | -1.60 | -3.81678 | .62061 |
| Checklist Score (Equal variances) | .238 | -4.88 | -13.1181 | 3.3573 |
| Global Score (Equal variances) | .288 | -.76 | -2.1835 | .6668 |
| EA Score (Equal variances) | .091 | -.26 | -.52258 | .04344 |

**Table VII.** Comparison of clinical skills between the 2 groups.

| | Randomization | N | Mean | Std. Deviation |
|---|---|---|---|---|
| Clinical Skills | I | 22 | 7.4545 | 3.63485 |
| | E | 19 | 9.0526 | 3.34122 |
| Checklist Ave | I | 22 | 20.909 | 12.4534 |
| | E | 19 | 25.789 | 13.6181 |
| Global Ave | I | 22 | 6.136 | 2.1832 |
| | E | 19 | 6.895 | 2.3249 |
| EA Ave | I | 22 | 2.4773 | .52275 |
| | E | 19 | 2.7368 | .42060 |

Figure V shows scores of clinical skills and pre, post, post-post test in each student separated by group.

**Figure V.** Scores of clinical skills, pre-test, post-test, and post-post-test in each student separated by group.



## Correlations

**Clinical skills and medical knowledge.** All 41 students scores had a Pearson correlation of 0.168 ($p = 0.29$), which is positive, but a weak effect. When the same correlation was calculated for the separate groups, it was weaker in I (0.048 & $p = 0.83$) compared to E (0.271 & $p = 0.26$). None of the above had any statistical significance. A linear regression analysis was conducted to evaluate the prediction of medical knowledge on clinical skills in all 41 students. The scatterplot for the two variables, as shown in figure VI, indicates that the increase in medical knowledge improves clinical performance. This is more predictable in group E than I (Figure VII).

**Figure VI.** Scatterplot depicting the relationship between medical knowledge and clinical skills.

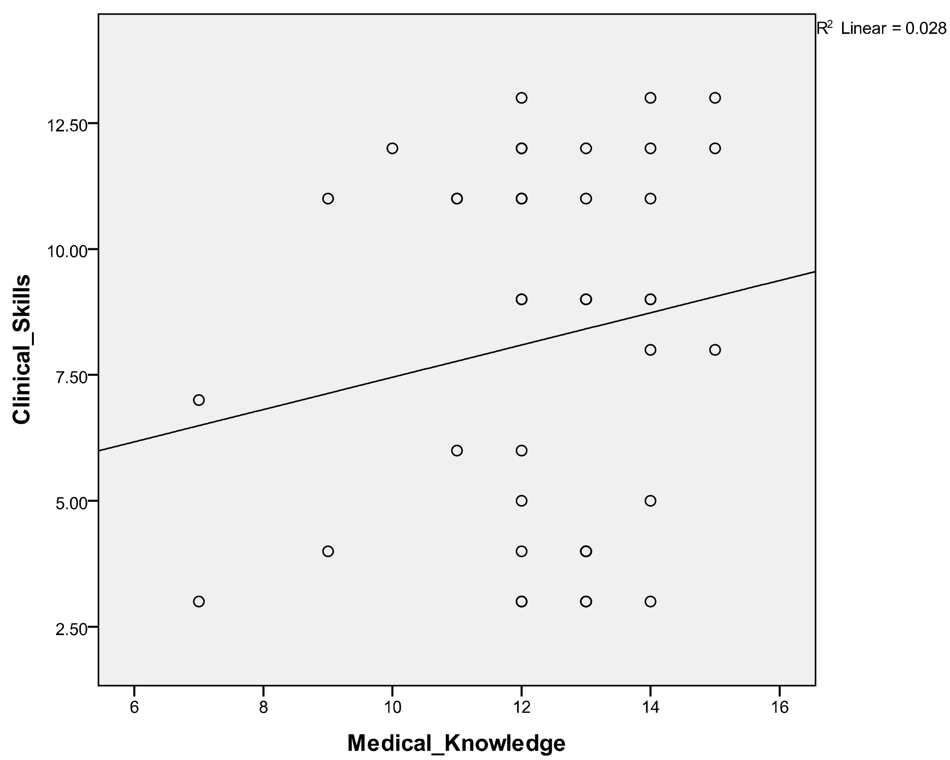
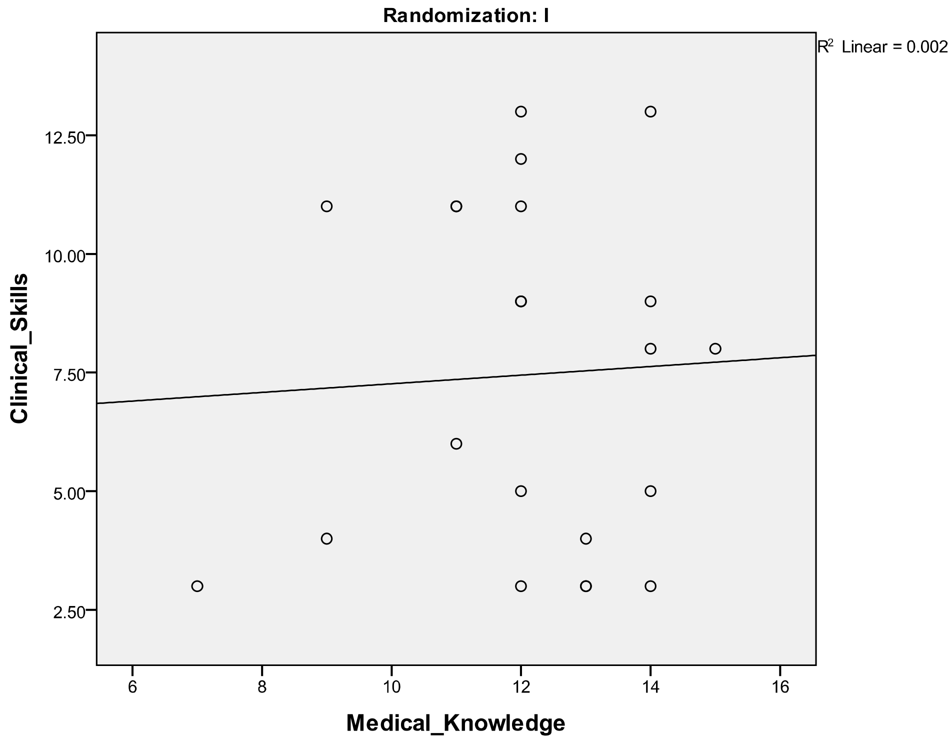
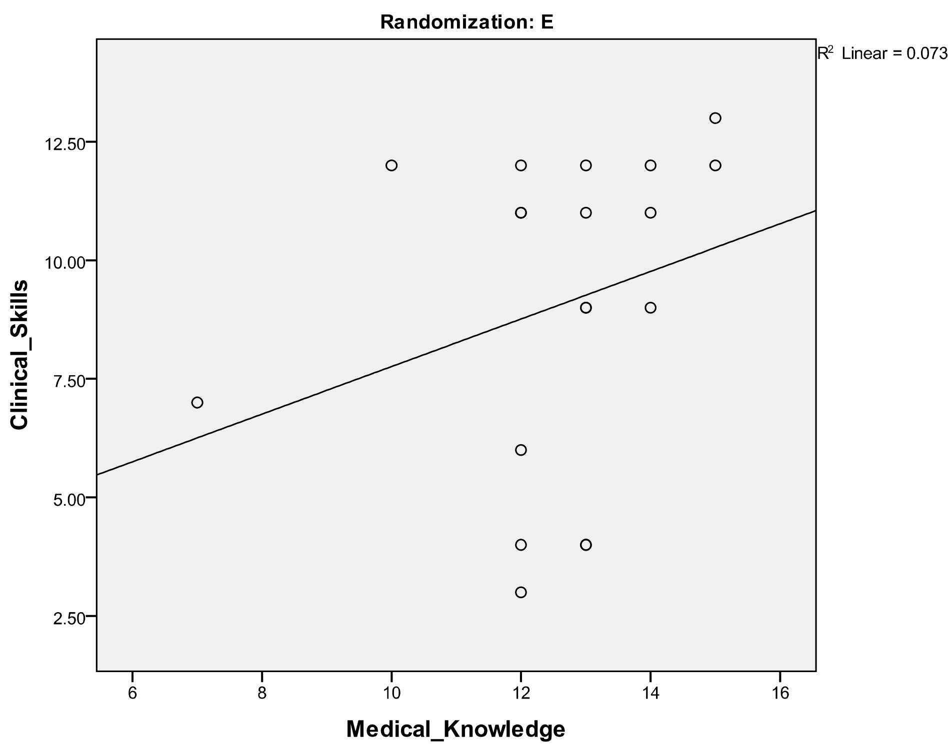


**Figure VII.** Scatterplot depicting the relationship between medical knowledge and clinical skills in Inquiry and Exposition groups.



A multiple regression analysis was conducted to evaluate how well medical knowledge predicted clinical performance. The predictors were age, months in medical school, and medical knowledge. Table VIII presents indices to indicate the relative strength of the individual predictors. In group E, medical knowledge, when controlling for age and months in medical school, had a positive, strong correlation with clinical performance that is statistically significant ($p = 0.035$); this was not true for group I as the correlation between medical knowledge and clinical performance stayed the same when controlling for age and medical months. On the other hand, medical months correlated negatively with clinical performance in both groups when controlling for other factors. This negative correlation was statistically significant in group E when controlling for age and medical knowledge ($p = 0.047$).

**Table VIII.** The bivariate and partial correlation of the predictors with clinical skills.

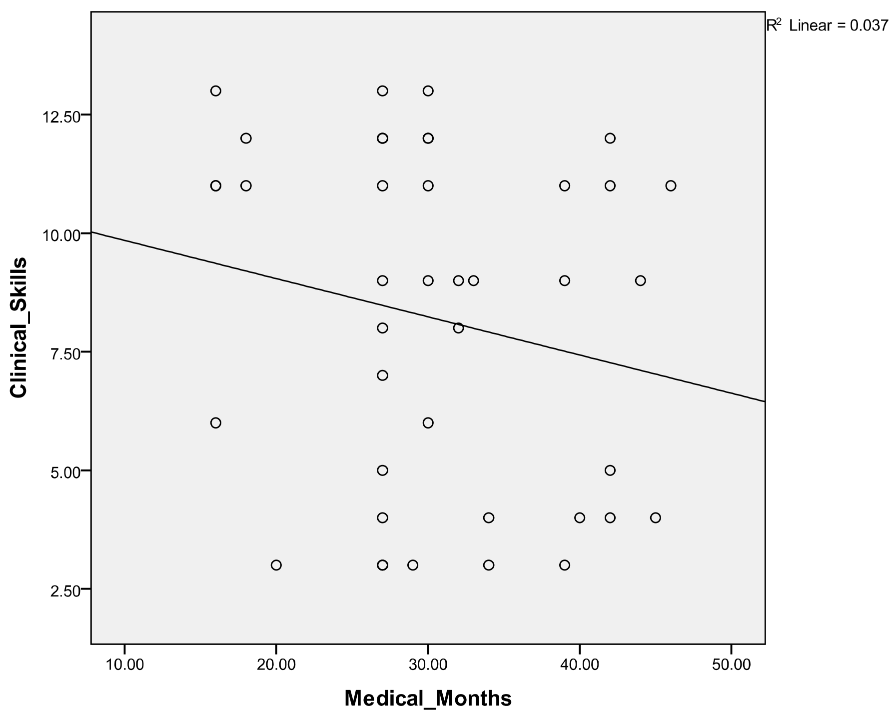
| Predictors | | Correlation between each predictor and clinical performance | Correlation between each predictor and clinical performance controlling for all other predictors |
|---|---|---|---|
| I | Age | -0.18 | -0.14 |
| | Medical Months | -0.21 | -0.21 |
| | Medical Knowledge | 0.05 | 0.05 |
| E | Age | 0.16 | 0.37 |
| | Medical Months | -0.24 | -0.50* |
| | Medical Knowledge | 0.27 | 0.51* |

* $p < .05$.

**Medical knowledge and period of enrollment in medical school**. All 41 students scores had a Pearson correlation of 0.348 ($p = 0.026$), which is positive and statistically significant, but a weak effect. When the same correlation was calculated for the separate groups, it was weaker in I (0.279 & $p$ = 0.21) compared to E (0.427 & $p$ = 0.068). This suggests that medical knowledge improves with time spent in medical school, which is not surprising.

**Clinical skills and period of enrollment in medical school**. All 41 students scores had a Pearson correlation of -0.193 ($p$ = 0.226), which is negative and statistically insignificant, but a weak effect (Figure VIII). When the same correlation was calculated for the separate groups, it was the same for both (-0.211 in I with $p$ of 0.347 compared to -0.241 in E with $p$ of 0.320). This is surprising as we expect clinical performance to improve with increased months in medical school.

**Figure VIII.** Scatterplot depicting the relationship between medical months and clinical skills in all students.



**Medical knowledge and knowledge retention**. All 41 students scores had a Pearson correlation of 0.542 ($p$ = 0.000), which is positive, statistically significant, and a strong effect. When the same correlation was calculated for the separate groups, it was weaker in I (0.547 & $p$ = 0.008) compared to E (0.768 & $p$ = 0.000). This suggests that knowledge retention improves with increasing medical knowledge.

**Knowledge improvement and knowledge retention**. All 41 students scores had a Pearson correlation of -0.341 ($p$ = 0.029), which is negative, statistically significant, and a weak effect. When the same correlation was calculated for the separate groups, it was stronger in I (-0.483 & $p$ = 0.023) compared to E (-0.079 & $p$ = 0.749). This suggests that knowledge retention decreases if knowledge improvement was high, especially in group I.

**Knowledge retention and days following lecture**. All 41 students scores had a Pearson correlation of -0.013 ($p$ = 0.934), which is negative, statistically insignificant, and a very weak effect. When the same correlation was calculated for the separate groups, it was positive in I (0.297 & $p$ = 0.179) compared to E (-0.036 & $p$ = 0.884). This suggests that knowledge retention decreases as time passes by, although the decrease is more significant in the group E.

**Knowledge retention and post high school education**. All 41 students scores had a Pearson correlation of -0.223 ($p$ = 0.162), which is negative, statistically insignificant, and a weak effect. When the same correlation was calculated for the separate groups, it was the same in I compared to E (-0.206 in I with $p$ of 0.359 compared to -0.212 in E with $p$ of 0.384). These results mirror the correlation of **knowledge retention and age** which is statistically significant (-0.324 in all 41 students with *p* of 0.039, -0.347 in I with *p* of 0.113 compared to -0.263 in E with *p* of 0.276). This suggests that knowledge retention decreases in older students or with more years of schooling. On the other hand, **knowledge improvement and post high school education** in all 41 students scores had a Pearson correlation of 0.237 ($p$ = 0.105), which is positive, statistically insignificant, and a weak effect. When the same correlation was calculated for the separate groups, it was weaker in I (-0.010 & $p$ = 0.958) compared to E (0.435 & $p$ = 0.055). This suggests that increase in knowledge (amount of learning) may be more significant in students who had more schooling.

## Chapter V

## Discussion

As stated previously, the purpose of this study was to compare knowledge retention and clinical skills outcomes of medical students following their experience in one of two different teaching procedures: inquiry via the learning cycle and exposition via power point presentation. Additionally, correlation between factual knowledge (performance on multiple-choice test) and clinical skills (simulation) was studied.

### Knowledge Retention

Both teaching procedures improved students' knowledge, but students who were exposed to inquiry teaching had better knowledge retention a month later compared to students in exposition group who had a statistically significantly decrease of more than one point in their scores (Figure IV on page 54). Unfortunately, and due to scheduling and recruiting reasons, the average time between the two tests was 6 days longer for students in the exposition group, and that could have negatively affected their knowledge retention compared to the inquiry group. However, there were no correlation between knowledge retention and number of days between the tests in all students. This makes us believe that inquiry teaching may have a true better knowledge retention effects compared to exposition teaching. Interestingly, the more senior the students were in medical school, the more knowledge retention they had. We can hypothesize, and based on zone of proximal development theory of Vygotsky, that senior students can retain useful medical knowledge longer as they are more likely to have had previous knowledge or experiences that they can connect with, compared to junior students.

Two of the most important educational goals are to promote *retention* and to promote *transfer* which, when it occurs, indicates meaningful learning. *Retention* is the ability to remember material at some later time in much the same way it was presented during instruction. *Transfer* is the ability to use what was learned to solve new problems, answer new questions, or facilitate learning new subject matter (Mayer & Wittrock, 1996). When the objective of instruction is to promote retention of the presented material in much the same form in which it was taught, the relevant process category is *Remember*. Training in medicine requires the memorization of tremendous amount of facts, theories, and skills. Remembering involves retrieving relevant knowledge from long-term memory. It is only when the memory is engaged in the learning process that the brain is really challenged and this could explain the superiority of inquiry teaching over exposition teaching. Remembering knowledge is essential for meaningful learning and problem solving when that knowledge is used in more complex tasks, and any teaching procedure that improves remembering and knowledge retention should theoretically improve problem solving.

**Clinical Skills**

Students who were exposed to exposition design had slightly higher scores on all simulation measures of clinical skills, but this was not statistically significant. One possible explanation for these results is simply that the variation attributable to factors controlled in the study-subjects and content-was small, leading to a high proportion of variance due to random variations. This circumstance could arise if the students in the study were relatively homogeneous in ability, so that there was no observable variation between subjects, or if the simulation case was chosen in such a way that the range of observed performance was very similar. The solution of a single patient problem would derive not from a general problem-solving process utilizing a logically consistent knowledge base, but from a pattern-matching process against experiences in memory. Other than controlling for months spent in medical school, years of education, and teaching procedures, it was very difficult to control for the previous experiences of all students especially in the third year of medical school. Medical students have different clinical rotations in different order during the academic year with random nature of adverse patient events and vagaries of clinical exposure. Since the development of student experiences is dependent on the type of diseases or problems they were exposed to during any certain rotation, we can expect some variations in certain skills needed to solve a clinical simulated problem such as the one we used in this study. One way of controlling for this variation is to perform the simulation test on all students on the last day of $4^{th}$ year to guarantee some homogeneity among students; this, however, is very difficult to achieve in reality.

Reliability and validity of assessing with simulation can be a delicate task. Unlike many performance-based assessments in clinical medicine, where fairly generic skills are being measured (e.g., history taking), the management of patients by anesthesiologists can be very task-specific. For performance-based assessments such as the one we used, there has been a heavy emphasis on content related issues. To support the content validity of our assessment, our simulated scenarios were modeled and scripted based on our actual practice characteristics, including the type of patients that are normally seen in our setting. With respect to rubrics, special care was taken to define the specific skill sets and measures that were developed to reflect evidence-based perspective. Finally, the encounters were modeled in realistic ways, using the same equipments that are found in a real operating room. Although raters in general have been identified as a source of variability, their overall impact on reliability, given proper training and well-specified rubrics, tends to be minimal (Boulet & Murray, 2010). Additionally, several studies have examined the level of agreement between judges on an anesthetist's performance in the simulator, and have shown that it is possible to generate reliable scores for a single performance with two to three judges such as we did (Gaba et al., 1998). However, managing a simulated patient that requires making diagnosis, reaching a treatment plan, and communicating that to others can be too much to ask from a medical student. Medical students who develop interest towards critical care, surgery, or anesthesiology may perform better in these settings compared to students who are more interested in being a primary care physician. This could have also added to the variability among the subjects especially among 4$^{th}$ year medical students.

**Correlation of Medical Knowledge and Clinical Skills**

Clinical skills correlated indeed with medical knowledge. When we controlled for age and months in medical school, medical knowledge predicted clinical performance more accurately in group E than group I. This could be due to the fact that 9 students out of 22 who completed simulation session in group I had a clinical score equal to or fewer than 5 out of total score of 13 (Figure V on page 56). In comparison, only 4 students out of 19 in E group had a score equal to or fewer than 5!

The ability to define and manage clinical problems is viewed as central to clinical competence in medicine, and is a pervasive theme in medical educational objective. This ability is usually viewed as a general skill described by a variety of terms (problem-solving, clinical judgment, diagnostic skills, clinical reasoning, or synthesis) which interacts with, but is distinct from knowledge. Norman, Tugwell, Feightner, Muzzin, and Jacoby (1985) conducted a study on thirty medical students where they presented the students with a series of simulated patient problems in which content was systematically varied. The students also had to complete a multiple choice test with questions linked to each diagnosis presented in the clinical problem. The authors found that the performance on problem solving did not correlate with performance on the multiple-choice test. They proved that variability in problem solving scores is related to factors other than content knowledge.  This makes us believe that some other uncontrolled variations could have been attributed to our simulation results beside the teaching procedures.

A subject's score in a simulation examination has a number of sources of variance: the subject him- or herself; the particular case; the judges; and the interaction among all these components. Where the purpose of the assessment is to rank the subjects in order of ability, the subject should be the largest source of variance. The number of simulated cases a subject should undertake before it could be confidently said that the final score truly reflected his or her ability is unknown; nor are the optimum number and arrangement of cases and judges to produce a reliable assessment in the simulator. Weller et al. (2005) determined that 10–15 cases, or 3–4 hours, are required to rank trainees reliably in their ability to manage simulated anesthetic emergencies. However, they discussed in their study limitation that it is difficult to generate large numbers of simulator assessments as, unlike established assessment methods, there is no existing pool of data and obtaining data is time consuming and expensive. Our students managed 3 different simulation scenarios including the scored malignant hyperthermia. The purpose of the 2 scenarios that were not scored or taped was to familiarize the students with simulation and eliminate the unfamiliarity pressure variance. Thus we ended up with only one scenario to reflect clinical skills, which may not necessarily be a 100% reflection of the student's ability.

**Limitation**

This study has limitations in terms of scope and numbers. Including larger numbers of students and more simulation scenarios would generate increasingly reliable estimates of the generalisability coefficient of different test formats. Numbers of students in this study were too small to allow subgroup analysis of performance or correlation with other markers of performance. Face validity of the simulations was supported by trainees' responses to the knowledge test, but other aspects of validity require further study.

All students in our study were very accustomed to learning from power point teaching or lecturing due to their previous experiences in college and medical school, but they may not be familiar with learning in the structure we presented in the learning cycle procedure. One can argue that years of familiarity with lecturing may have favored students in the lecturing group (exposition) over students who were exposed to a different teaching procedure (inquiry). Learning is specific to culture and society as the tools of learning differ and it could be argued that the current learning culture in medical school does not favor learning from learning cycle procedures. By changing their processing strategies and regulation strategies, medical students adapt into different learning patterns depending on the type of curricular they are presented with (Van Der Veken, Valcke, Muijtjens, & Derese, 2008). It will be interesting to study the true effect of the learning cycle curricula when applied over a full semester or a whole year.

**Personal Reflection & Recommendation**

This is the first reported attempt to apply the learning cycle in medical education. Although the traditional teaching of the learning cycle emphasizes the "hands-on" activity, we argue that the same teaching procedure can be applied without necessarily any hands-on activity when it comes to medical students. Medical students are highly intelligent and certainly formal thinkers (earlier unreported work by the authors). Thus, medical students are mentally capable of assimilating, disequilibrating, accommodating and organizing different concepts in shorter period of time without necessitating a "hands-on" activity. The important part of the learning cycle procedure is to be organized in a way that helps the learners reach the concept by assimilating, disequilibrating, accommodating, and then organizing.

Although we did not measure the students' reflection about each teaching procedure, we can confirm from personal discussion with the students and observing them during the teaching procedures that students enjoyed the learning cycle procedure remarkably. The discussion and interaction during the inquiry teaching was very stimulating and enjoyable. However, we believe that students in exposition teaching may have received more sum of information in the same hour compared to students in inquiry teaching. Realistically, educators have limited amount of time and they can deliver more information (knowledge) in a unit of time lecturing than they can do in any inquiry setting. However, our purpose is to change medical education to focus more on the end results of teaching, applying knowledge into clinical scenario and problem solving, than focusing on knowledge tests only. We are encouraged that simulation is playing a greater role in evaluating medical learners including physicians in practice. However, we also need to switch our teaching procedures to match the desired end results of knowledge application.

As this was the first time the learning cycle was applied in medical education and for future studies on this subject we recommend the following:

- Recruit at least one instructor for each teaching procedure. This should decrease the instructional bias in teaching.
- Match the assessment tool to the content/concept taught knowing that a content/concept is different than a skill. This may not be easy in medical education as it is very difficult to test for one concept only.

**Conclusion**

Medical education curricula have shifted toward student-centered methodologies (inquiry) and away from only teacher-centered methodologies (expository). Students experiencing inquiry courses use higher cognitive skills as they gain greater conceptual understandings. Although some case discussion and group learning occurs during clinical rotations (third and fourth year medical students), most of classroom medical education is still carried out through lectures and with minimal active participation among students (exposition). The learning cycle is an inquiry teaching procedure that is designed to allow students' participation in the kind of thinking constructivists describe as essential to learning and cognitive development

(Henson, 2003; Vygotsky, 1978). The learning cycle, by its design, is consistent with the nature of science and promotes critical thinking through inquiry, collaborative grouping, and the construction of new concepts. This study demonstrates that the learning cycle can be successfully applied in medical education. It also demonstrates that applying the learning cycle can improve students' knowledge retention a month later without affecting their clinical skills assessed by simulation. This is encouraging, as we believe that if a quarterly or yearly curriculum were designed around the learning cycle, students will adapt different learning strategies that will increase the benefits of applying this learning procedure.

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# APPENDICES

Appendix A

Approved Prospectus

## Chapter I

## Introduction

Two contrasting teaching procedures are frequently compared in science education: inquiry and exposition (Berg, Bergendahl, Lundberg, & Tibell, 2003; Johnson & Lawson, 1998; Karakoc & Simsek, 2004; Marek, Eubank, & Gallaher, 1990; Marek & Laubach, 2007). Students experiencing inquiry courses use higher cognitive skills as they gain greater conceptual understandings. Conceptual understanding occurs as students are gathering data and discussing facts, concepts, laws, principles and theories. On the other hand, students experiencing exposition are not involved in the processes of science, such as observing, model building, measuring, and theorizing. These passive learners are primarily receiving information through lectures.

Medical education curricula have shifted toward student-centered methodologies (inquiry) and away from only teacher-centered methodologies (expository). Problem based learning, for example, was developed in medical education in the early 1970s (Johnson & Finucane, 2000). Problem based learning has widespread application in the first two years of medical science curricula where it replaces the traditional lecture based approach. Although some case discussion and group learning occurs during clinical rotations (third and fourth year medical students), most of classroom medical education is still carried out through lectures and with minimal active participation among students (exposition).

The learning cycle is an inquiry teaching procedure that is designed to allow students' participation in the kind of thinking constructivists describe as essential to learning and cognitive development (Henson, 2003; Vygotsky, 1978). Rooted in Piaget's theory of intellectual development, the learning cycle phases were derived from Piaget's mental functioning processes (*exploration* correlates with assimilation, *explanation* with accommodation, and *expansion* with organization) (Marek, 2009; Marek & Cavallo, 1997). During exploration, the teacher provides learners with developmentally appropriate experiences related to the content to be learned. This phase allows learners to mentally process observations and experiences as they collect data (assimilation). After exploration, the teacher guides students in the development of the science concept in the learning cycle phase known as explanation. The teacher promotes a discussion period in which learners share their observations (data) with their classmates. The teacher guides students to link their experiences and data to derive the relevant scientific concept and terminology (accommodation). After this phase, learners engage in additional activities in which they apply their newly developed knowledge to novel situations in the learning cycle phase known as expansion. This third phase is designed to cause learners to use the mental function known as organization (Marek & Cavallo, 1997).

The learning cycle paradigm has been used in science classrooms for over five decades with its beginnings in elementary schools and eventually applied at the secondary schools and college levels. The learning cycle, by its design, is consistent with the nature of science and promotes critical thinking through inquiry, collaborative grouping, and the construction of new concepts. Although problem based learning has been applied in medical education, learning cycle per se has never been reported in medical education.

Medical fidelity simulation has been increasingly implemented in medical education as an educational and competency assessment tool (Henrichs et al., 2009; Murray et al., 2007). Advantages of medical simulations include (Lake, 2005) (a) active learning process, (b) nonthreatening environment to patients, (c) ability to repeat performance until mastery, (d) experience in crisis situations seen infrequently, and (e) as a competency assessment tool. Simulation can also be used in assessing competences acquired from different teaching procedures. For this research, simulation will be used in assessing competencies acquired from different teaching procedures.

**Purpose of the Study**

This study is designed to compare factual knowledge retention and clinical skills outcomes of two different teaching designs: inquiry via the learning cycle and exposition via power point presentation. The learning cycle has not been implemented in medical education before, but problem based learning has been used and compared to the traditional lecture-based practices. The major focus in studies of the effectiveness of problem-based learning has been on students' knowledge base, assessed by multiple-choice examinations, and not the application of this knowledge (Blake, Hosokawa, & Riley, 2000; Ripkey, Swanson, & Case, 1998). Any teaching procedure (inquiry or exposition) should affect not only factual knowledge, but also clinical knowledge; the way students apply the knowledge during medical tasks. Some research showed that different teaching methodologies (inquiry or exposition) have the same effects on factual knowledge, measured by multiple-choice test (Albanese, 2000; Lycke, Grottum, & Stronmso, 2006). This study is different from previous studies by the way knowledge acquired from either teaching procedure (inquiry or exposition) is measured and assessed. Clinical knowledge and skills acquired from either teaching practice will be measured by how learners recognize and manage a malignant hyperthermia crisis in a medical fidelity simulation one month following the teaching procedures. A simulated operating room with a mannequin, which serves as a patient presenting with malignant hyperthermia crisis, will be used to test the learner's response to such a crisis. This safe and controlled environment is currently the best available setting for testing crisis management of students. Additionally, a multiple-choice test will assess the retention of factual knowledge one month later.

**Research Questions**

This research is guided by the following questions:

- How do senior medical students, who are taught by the learning cycle (inquiry students) compare to medical students taught by power point presentation (exposition students) when managing a crisis of malignant hyperthermia assessed by medical fidelity human simulator one month following the teaching?
- How do inquiry students compare to exposition students on retention of factual knowledge one month following the teaching assessed by multiple-choice questions test?
- Is there a relationship between students' performance during simulation and on a multiple-choice questions test one month following teaching?

## Significance of the Study

To improve teaching practices in medical schools, learning theories for adults must be applied. It is empirically clear that rote knowledge (memorization) is quickly forgotten, and meaningful knowledge (understanding) tends to be retained longer and applied or practiced on a higher level (Baxter & Elder, 1996; Mayer, 2002). Applied learning theory in medical education should help physicians apply the appropriate knowledge to benefit their patients. To test the effectiveness of the learning cycle on long term knowledge application, a human fidelity simulator will be used to give medical students the opportunity to practice acquired knowledge. The results of this research may help medical faculty improve their teaching practices since 27% of medical faculty focus on having students learn and apply knowledge and skills to accomplish clinical tasks (Williams & Klamen, 2006).

## Definitions of Terms

**Learning cycle.** An inquiry constructivist teaching procedure that allows students to manipulate materials and generate data that they analyze to construct concept understandings. A learning cycle for the concept of malignant hyperthermia has been developed and used by the investigator for several years to teach senior medical students and postgraduate residents.

**Malignant hyperthermia.** A genetic disease that can be triggered by an anesthetic and lead to death if not treated promptly. Despite the availability of a drug that can reverse the crisis, multiple deaths still occur annually in the US. Although the disease is different from an anaphylactic shock, it has a similar course of events.

**Power point presentation.** An exposition teaching method where the instructor presents knowledge to students on slides projected on a board. For few minutes at the end, students are usually allowed to ask questions to the presenters. A group discussion does not normally occur in this format. This format is very common in medical education.

**High fidelity simulator.** A high fidelity simulation is a computer controlled mannequin that can demonstrate many signs and symptoms of a human patient disease process. The mannequin can be placed in a simulated operating room that includes all the monitors and also humans acting as operating room staff. Many programmed crises can be manifested by the mannequin, including malignant hyperthermia crises. A simulator will be used in this study to assess medical students' management of a crisis of malignant hyperthermia. Video camera recording of the crisis allows for an observer to assess the student's management of the crisis.

# Chapter II

## Theoretical Foundation

This chapter focuses on three central areas (a) medical education, (b) structured inquiry via the learning cycle, and (c) role of simulation in medical education. The medical education section is subdivided into six categories (a) complexity of medical education, (b) cognitive flexibility theory, (c) outcome-based or competency-based education, (d) inquiry vs. exposition learning, (e) problem-based learning, and (f) overview of the Oklahoma University College of Medicine Curriculum. The learning cycle section is subdivided into four categories (a) history of the learning cycle, (b) the learning cycle teaching procedure, (c) Piaget's & Vygotsky's theoretical underpinning to the learning cycle, and (d) cognitive and motivational variables. The simulation section is subdivided into five categories (a) history of mannequin simulation, (b) simulators in anesthesia, (c) current uses of simulation, (d) advantages of medical simulation, and (e) simulation in medical education.

### Medical Education

The current blueprint for medical education in North America was articulated in 1910 by Abraham Flexner in his report, *Medical Education in the United States and Canada*, a comprehensive survey of medical education prepared on behalf of The Carnegie Foundation for the Advancement of Teaching and at the request of the American Medical Association's Council on Medical Education (Flexner, 1910). The basic features of medical education outlined by Flexner remain in place today: a university-based education consisting of two years of scientific foundations and two years of practical experience in clinical settings. Recently, The Carnegie Foundation for the Advancement of Teaching undertook an investigation of medical education and a research team embarked on an examination into the status of medical education (Cooke, Irby, & O'Brien, 2010). Over a three-year period, the research team reviewed the literature and conducted site visits to 14 medical schools and medical centers. Data were collected through 140 structured interviews, 50 focus groups, 200 observations and documents. Both qualitative and quantitative analyses were employed. The Carnegie researchers found medical education lacking in many important regards. They found that medical training is inflexible, excessively long, and not learner centered. They also found that clinical education is overly focused on inpatient clinical experience, supervised by clinical faculty who have less and less time to teach and who have ceded much of their teaching responsibilities to residents, and is situated in hospitals with marginal capacity to support their teaching mission. They observed poor connections between formal knowledge and experiential learning. Learners have inadequate opportunities to work with patients over time and to observe the course of illness and recovery; students and residents often poorly understand non-clinical physician roles. Most importantly, the team observed that medical education does not adequately make use of the learning sciences (epistemology).

**Complexity of medical education.** Medical education for health-related professions represents a major category of adult training and is one of the most complicated educations. Medical knowledge is enormous and constantly changing and physicians must acquire and remember a tremendous number of details, making memory processes critical. Understanding and managing diseases (medicine) are complicated processes that form conceptual complexity and case-to-case irregularity in knowledge domain, thus referred to as ill-structuredness. Additionally, medical education extends over the lifetime of the physicians, who must be self-directed in their learning activities and capable of relating new information to their own needs and experiences. For these reasons, theories of adult learning that emphasize self-directed and experiential learning are highly pertinent. Furthermore, theories of instruction that are based upon self-study or use of media are also significant to medical education. Cognitive flexibility theory, which emphasizes a case study approach involving context-dependent and realistic situations, applies directly to medical education.

Cognitive flexibility thinking and teaching allows for shifting from constructive orientation that emphasizes retrieval from memory of intact preexisting knowledge to an alternative constructivist stance which stresses the flexible reassembly of preexisting knowledge to adaptively fit the needs of new situation. For example, managing a disease such as malignant hyperthermia requires connecting hundreds of variables. Understanding the pathology and the cellular level of the disease explains why an episode of malignant hyperthermia presents in many different ways. The variation of presentations makes the diagnosis difficult as many of the presenting symptoms are common for other diseases that may occur in relationship to surgeries and anesthesia. The rarity of the disease adds to the complexity of diagnosing it, but the deathly outcome for failing to diagnose the disease in a timely manner adds to the seriousness of it. Following the diagnosis, the physician will have to know the treatments including managing a crisis. Previous experiences with crisis management have to be transferred to the situation at hands as not all crises are the same. Additionally, prioritizing management steps and using resources appropriately is crucial to the treatment and positive outcome. Counseling a patient and family on what to do following the safe outcome is also part of management. Without teaching cognitive flexibility, it will be impossible to teach the management of malignant hyperthermia knowing that a physician may spend all his/her carrier without seeing the disease once. Take this into account with thousands of other diseases and the complexity and ill-structuredness of medicine becomes obvious.

Ill structured domain such as medicine must not be confused with *complexity* (Spiro & DeSchryver, 2009). Complexity alone does not make a domain ill-structured; in fact, many well-structured domains are complex. In ill-structured domain such as medicine, we cannot have a prepackaged prescription of how to think or act. We also cannot have a prepared schema that can be used for whatever the situation at hand may be as those situations may vary completely. Rather, in ill-structured domain, the schema of the moment should be formulated from different pieces of knowledge and experiences that were acquired at different times and situations. This can be acquired by creating as many variables and experiences during the learning process so learners can build the network of knowledge with the flexibility of using different pieces of this network for different future situations. This seems to be working in medicine over the many years medicine has been taught. In today's medical education, medical students acquire much of the "introductory" knowledge during the first two years of medical school. During these two years, students expand on their previous knowledge of chemistry, biology, anatomy, and physiology. They also learn basic or introductory application of this new knowledge into some clinical scenarios. However during third and fourth year of medical school, students expand on this knowledge and apply much of it in clinical scenarios in different ways. During the years of residency, or post-graduate education, (multiple years of training following medical school) and with much available content knowledge, physicians can apply this knowledge on real cases with many variables. Although each disease could be the same, each patient is different and different content knowledge needs to be applied to different patients or problem. Following the many years of residency, physicians should be more exposed to almost all variables and should have built a wide network of knowledge that they can apply to more complicated scenarios in the future.

Medical educators often deliver complex material in a format that does not allow the positive learning engagement recommended by cognitive researchers and theorists. Cognitive researchers believe that intentional engagement and active learning pedagogies change the nature of learning, while simultaneously improving knowledge gain and recall abilities. Engaged students find the work more interesting and thereby put more effort into it. Certain cognitive processes and skills such as decision-making, reasoning, and problem-solving are critical in medical practice. Problem-solving, in particular, has been the basic pedagogy for many medical curricula (Taylor & Miflin, 2008). Additionally, many aspects of medicine, such as anesthesiology and surgery, require high levels of sensory-motor ability.

Due to the complexity of medical education, medical schools have yet to find pedagogical practice that can be successful in medical education. The goals and objectives of medical students' education have been outlined by the Association of American Medical Colleges (1998) as to produce physicians who are altruistic, knowledgeable, skillful, and dutiful. Most structured medical education now focuses on knowledge and skills, while altruism and dutifulness are ostensibly satisfied by appropriate selection of medical students and role modeling by medical teachers.

**Cognitive flexibility theory.** Cognitive flexibility is the human ability to adapt cognitive processing strategy to face a new or unexpected condition. Cognitive flexibility theory, or CFT, is a continuum of the constructivist theory of learning. CFT is a theory of learning and instruction that was developed to address four main goals: (a) helping learners to learn important but difficult subject matter, (b) fostering adaptive flexible use of knowledge in real-world settings, (c) changing underlying ways of thinking, (d) developing hypermedia learning environments to promote complex learning and flexible knowledge application (Sprio, Collin, Thota, & Feltovich, 2003).

For constructivists, knowledge is not simply handed down from teachers to students. Rather, students are co-participants in the construction of meaning (Dimitriadis & Kamberelis, 2006). One of the main constructivist theorists, Jerome Bruner, believes that students should be encouraged to construct their own knowledge and build upon what they already learned. He argues that instructions should be designed to encourage the learner to go beyond the given information (Bruner, 1996). CFT can also be related to the genetic epistemology theory of Piaget, who posited that students develop cognitively when they are presented with new situations that require them to adapt previously learned materials (Bybee & Sund, 1982). While CFT is built on many of the same principles as other constructivist theories, it was developed to be especially useful when applied in complex, ill-structured domains with multivariable and higher-level learning, such as the teaching/learning of medicine. In other words, the theory was developed to allow the application of different types of knowledge to a variety of dynamic situations.

In well-structured domains, concepts can be, matter of fact should be, directly instructed, fully explained, and simply supported. However, this cannot be done in ill-structure domain. Spiro believes that there is no alternative to constructivist approach in learning, instruction, knowledge application, and mental representation in ill-structured domain (Spiro & DeSchryver, 2009). Although using constructivism through CFT has not yet proved to fully work in ill-structure domain, Spiro believes that we should continue on using it. This is due to the fact that we know that direct instructional guidance does not work in ill-structured domain (Spiro & DeSchryver, 2009). It is the particular way that CFT instructions, and the associated guidance tailored to the need of learning in ill-structure domain that distinguishes it in fundamental ways from direct instructions. CFT based systems facilitates a nonlinear web of knowledge that resist the oversimplification of knowledge. This web of knowledge insures the connections of different pieces of knowledge to support maximal adaptive flexibility in the later-situation assembly of knowledge and experiences to suit the needs of a new problem-solving event.

Coulson, Feltovich, and Spiro (1997) studied the application of cognitive flexibility in medicine, specifically in the way physicians analyze and treat a very common disease, hypertension. They argued that in using the standard hypertension treatment algorithm, in which hypertension pathology and etiology are very simplified, physicians mistreat 50% of the cases. However, if physicians use cognitive flexibility to take into account all the variables and factors as well as the inherent complexity of hypertension, physicians could treat the disease and control blood pressure faster and more reliably.

The goals of medical education are clearly those of advanced knowledge acquisition. New medical students have already been introduced to many of the subject areas within the biological sciences that they will learn in medical school. However, during medical school and life-long learning, physicians need to master these concepts and have the ability to apply the knowledge from formal instruction to real world cases. The complexity of medical domain and the many variables of medical cases make the medical field an ill-structured domain. Due to these complexities, medical educators have been very busy structuring an outcome-based curricula that teach medical students the attributes and competencies that are expected of physicians (Harden, 2007).

**Outcome-based or competency-based education.** Outcome-based education emphasizes learner and program outcomes, not the pathway and processes to attain them. Calls for competency-based approach to educate professionals go back decades ago (Carraccio, Wolfsthal, Englander, Ferentz, & Martin, 2002). Traditional criteria curriculum is organized around knowledge objectives that focus on instructional process regardless of the outcome of the process. On the other hand, outcome-based education structures its curricula around the outcome while the process is secondary (Harden, 1999). Some of the rationales for a competency-based medical education are (Frank et al., 2010) (a) focus on curricular outcomes, (b) emphasis on abilities (competencies are the organizing principle of curricula), (c) de-emphasis of time-based training, and (d) promotion of learner-centeredness. As medical education evolves to focus on competencies, it is important to define those competencies. It is assumed so far that those competencies will include knowledge, skills, and attitude (Molenaar et al., 2009). On the other hand, c**ompetency-based medical education** has been criticized for being reductionistic, that is, for focusing on atomistic skills and failing to capture the essence of professional activities as manifested by complex and integrated capabilities (Swing, 2010).

**Inquiry vs. exposition learning.** Contemporary views on learning conceive that one constructs knowledge based on previously held beliefs and experience. In this sense, inquiry learning is metacognitive, giving the individual a picture of how she/he learns (Graffin, 2007). As in many other disciplines, a growing literature in medical education praises the benefits of inquiry versus exposition learning (Carline, 1989; Richardson & Brige, 1995). The difference between inquiry and exposition is not just observable, but is also ideological. While passive learning assumes that knowledge can be transferred from one person to another, active learning presupposes that all knowledge is constructed by the learner. Each offers a very different epistemological underpinning. Passive learning perceives knowledge as a commodity, whereas active learning perceives knowledge as experience created by the individuals' meaning making processes (Maclellan, 2005).

For learning to be active, learners not only need to be doing something but also need to reflect on what they are doing. Active learning is learner-centered, where an individual's needs are more important than those of the group. Active learning pedagogies change the teacher-learner relationship to a learner-learner relationship. Active learning is within Piaget's taxonomies, among other taxomonies. Active learning combines engagement and observation with reflective experiences.

Passive learning as a method fails to connect students directly with the knowledge and skills they need to learn. Passive learning occurs when students read an assigned article, chapter, or book; when they watch a film; when they attend a lecture. Active learning occurs when each of those activities is combined with engagement, observation and reflection.

**Problem-based learning.** Following the introduction of problem-based learning (PBL) to medical curricula in the 1970s (Johnson & Finucane, 2000), the majority of medical schools worldwide began to adapt more active learning strategies (inquiry) over what was considered the traditional passive method (exposition) (Norman & Schmidt, 1992). This movement created a body of literature that describes the potential benefits of PBL curricula compared to traditional learning. However, navigating this body of literature is not an easy task. Generally, the end results of studies on PBL are inconsistent and the sample size of some makes it difficult to arrive at conclusive evidence. Additionally, review articles on the subject produced conflicting results and some skepticism regarding the effectiveness of PBL.

Dochy et al. (2003) published a meta-analysis of 43 studies to evaluate PBL effects on knowledge and skills. The review was not restricted to medical education, but included all forms of tertiary education. The analysis showed moderately significant effects on practice skills favoring PBL. Although deemed small and not of practical significance, the authors found scores on knowledge tests to be lower in the non PBL group. While the appropriateness of combining these data in a meta-analysis is questionable due to substantial heterogeneity across studies, the analysis provided some insight into potential effect modifiers. These exploratory analyses, which were based on a small number of studies, suggested that study design, students' level of expertise, retention period, and assessment methods may explain variability in effect estimates. The authors cite their main limitation as the compromised internal validity of the primary research studies.

Koh et al. (2008) conducted a systematic review that evaluated PBL on 37 outcomes of physician competency (identified by the authors) post-graduation. The review was methodologically rigorous in that it comprised a comprehensive and/or systematic approach to searching, study selection, data extraction, and quality assessment. The authors identified 13 unique relevant studies although 4 only provided self-reported data which the authors acknowledge as being prone to inaccuracy. The analysis yielded significant results supporting PBL for 7 of the 37 competencies; diagnostic skills or accuracy, communication skills, and possession of medical knowledge are among these 7 competencies. The authors pointed out a number of limitations of their review, some of which stem from the nature of the literature, in particular, the challenge of disentangling the effects of PBL from other curricular changes.

Hartling et al. (2010) conducted a systematic review of PBL in undergraduate, pre-clinical medical education between 1985 and 2007. A review of 30 unique studies demonstrated that knowledge acquisition measured by exam scores was the most frequent outcome reported. They concluded that PBL does not impact knowledge acquisition, and evidence for other outcomes does not provide unequivocal support for enhanced learning.

Although the superiority of inquiry curricula has been demonstrated, a concurrent literature is growing to discuss the lack of pedagogical change in medical education (Hurst, 2004; Rudland & Rennie, 2003). In 2003, a web-based questionnaire to medical schools education deans documented that 70% of the 123 medical schools in the US used PBL in the preclinical years (Kinkade, 2005). Of schools using PBL, 45% used it for fewer than 10% of their formal teaching, while 60% used it for more than half of their formal teaching. Of the 30% of schools not using PBL, 22% had used it in the past, and 2% had plans to incorporate it in the future.

Due to their lack of pedagogical understandings, teachers in medical schools generally teach as they were taught in undergraduate and graduate schools. Although medical faculty were able to keep up with the rapidly changing science of medicine in the last few decades, the same cannot be said about medical teaching. Medical faculty understand the complexity of scientific changes; for example, if a scientific research uncovers a function or treatment, medical faculty are eager to apply it to their patients. On the other hand, pedagogical changes are not a function of medical education, due to medical faculty's lack of pedagogical preparation and understanding. This could be due to medical teachers' simplistic understanding that to be a good educator, one only needs to have exceptional grasp of the material. Today, teaching in medical classroom remains lecture driven, with little engagement between students and faculty (Graffam, 2007).

**Overview of the Oklahoma University College of Medicine curriculum.** The four-year MD curriculum at the Oklahoma University College of Medicine is divided into two phases: the pre-clinical curriculum, which consists of the first and second years, and the clinical curriculum, which consists of the third and fourth years. The medical school curriculum includes both required courses and elective opportunities. Many courses are team-taught under the leadership of course directors. And the courses are graded both by traditional letter grades and honors/pass/fail grades.

The preclinical curriculum is organs-systems based. The basic sciences curriculum begins with foundation courses, followed by organ systems courses, and culminates with a capstone course. There are many opportunities for self-directed learning throughout the first and second year. The preclinical curriculum courses include: three foundational courses, numerous systems courses, a clinical medicine course, and finally the capstone course. Students have an opportunity to participate in the enrichment program. The enrichment program consists of elective courses offered during the preclinical curriculum. In the enrichment program, students take two courses from the following areas: medical humanities, clinical learning, and research. At the conclusion of the basic sciences curriculum, students take a capstone course. This ten-week course is designed to reinforce, apply, and synthesize basic science concepts taught during the systems courses. This capstone course is also designed to introduce concepts of evidence-based medicine, and to facilitate the transition to the third year.

The first year curriculum includes forty weeks of coursework. It begins with a one-week prologue course, and then transitions into three foundation courses, including molecular and cellular systems, disease diagnosis and therapy, and the human structure. Students take four systems based courses during the spring semester. During the afternoon, students take clinical medicine, “patients, physicians, and society”, and the enrichment track. The second year curriculum consists of 35 weeks. Students take the remaining 3 systems based courses, the clinical medicine II course, the “patients, physicians, and society course”, and enrichment courses if they’re enrolled in it. The second year ends with a ten-week capstone course.

The college of medicine uses a variety of instructional approaches during the preclinical curriculum. These include: lectures, small group sessions, team based learning, clinical preceptor experiences, anatomy dissections, and independent study. During a typical day, students may have some combination of lectures, team based learning, independent study, anatomy dissection, or small group discussion.

In contrast, the clinical years curriculum is experiential, immersive, and participatory. There are few lectures in the clinical curriculum. The clinical years consist of a series of discipline based clerkships, electives, and selectives. Students work in the outpatient environment, and in inpatient settings. Additionally, the college of medicine has a rich online curriculum resource called Hippocrates that is designed to supplement the traditional curriculum.

The third year consists of a variety of clinical clerkships that range from four to eight weeks in length. During the third and fourth year students must take five 2 week selectives from a variety of areas including: dermatology, emergency medicine, neurosurgery, and pathology. During the fourth year students take a four week geriatrics clerkship, a four week ambulatory medicine clerkship and a four week rural preceptorship. There are 22 weeks of electives during the fourth year. The college of medicine uses a hybrid grading system. During the pre-clinical curriculum, an honors pass-fail system is used. During the clinical curriculum, a standard letter grade system is used within a 4.0 GPA system.

Regarding assessment: pre-clinical students are assessed via one or more multiple-choice exams per course. Students may also undergo clinical skills assessments and they may be asked to complete assignments or participate in an audience response system exercise. During the clinical curriculum, students are assessed via written and oral exams and are asked to complete patient write ups. Faculty and residents rate student performance on every clerkship. Across the third and fourth year, students are asked to participate in clinical skills assessments.

**The Learning Cycle**

The learning cycle is a teaching procedure that structures inquiry and transpires in several sequential phases. A learning cycle moves the learners through a scientific investigation by encouraging them first to explore materials, then construct a concept, and finally apply or extend the concept to other situations (Marek, 2008).The best description of the learning cycle is an essay by Ann M. L. Cavallo:

> The learning cycle is best described as a philosophy of science teaching and learning, focusing attention on the students and their learning processes. Importantly, the learning cycle is the means to achieve the primary educational

purpose of promoting a *thinking*, scientifically well-prepared citizenry that is so critically needed in today's world. (Marek, 2009, p.151)

**History of the learning cycle.** Robert Karplus, a physicist at the University of California Berkelry, is credited for seminal work on structure inquiry, which later became known as the learning cycle. This approach to science began in the late 1950s (Marek, 2009). Together with J. Myron Atkins, Karplus created a theory of "Guided Discovery" which is based around students learning based on their own observations (similar to the scientific method). The 1970s mark the first time the term "learning cycle" appeared in the literature. The 1970s also brought different other type of inquiry programs for science to numerous school districts.

During the 1980s, John W. Renner and Michael Abraham identified the relationship between the three phases of the learning cycle (exploration, explanation, and expansion) and the three elements of Piaget's model of mental function (assimilation, accommodation, and organization). They found through a study conducted in high school chemistry classes that the sequence of the cycle phases was important to students learning, but noted that they could be reordered under certain conditions. Towards the end of the decade, modified names for the learning cycle were proposed.

The 1990s made additional changes to the learning cycle in the form of new steps added in a more alliterative fashion: engagement, exploration, explanation, elaboration, and evaluation. This is the so-called *5e* learning cycle. Research focus also shifted from the students' involvement in the learning cycle to the teachers' understanding of it. The greater the understanding of the learning cycle by teachers translated into better implementation of the learning cycle as it was designed.

**The learning cycle teaching procedure.** Learning cycles consist of three phases: exploration, explanation, and expansion. During *exploration,* collaborative learner groups engage in an activity and general data collection using scientific processes (assimilation). The exploration phase is designed to stimulate learners' interest by producing some degree of disequilibration. The outcome of the learning cycle (science concept) is not disclosed to the learners beforehand. During the exploration phase, the teacher acts as a facilitator, providing materials and directions, and guiding the physical process of the experiment. The outcome of the exploration phase is typically a set of data for the learners to analyze and interpret in the next phase.

In *explanation* phase, learner groups present their data for class analysis and discussion. During this process, the teacher guides the learners' analysis of the data by questioning them in both groups and whole class discussion (Marek & Cavallo, 1997). Finally, as a class, the learners, using their own words, agree upon an explanation, or the concept of the learning cycles. After the class has constructed the concept (accommodation), the teacher, if appropriate, may introduce any scientific terms related to the concept. Naming these terms culminates the second phase of the learning cycle.

The *expansion* or application phase allows students opportunities to use the science concept in different contexts (organization). The purpose of this phase is to extend or expand learners' understanding of the concept and help them understand its application to other situations. The application may utilize additional experiments, demonstrations, reading, videos, computer programs, and discussions to help learners expand their understanding of the concept. The use of the concept in the application phase completes the cyclical process, and often leads to new explorations (learning cycles). Learning cycles are often viewed as spirals, as application activities lead to more topics to be explored and explained while building more complex concepts upon the foundation of simpler ones.

**Piaget's & Vygotsky's theoretical underpinning of the learning cycle.** The theory of cognition upon which the learning cycle is based is a model of intellectual development advanced by Piaget. Jean Piaget (1896-1980) was a developmental psychologist, best known for his structuralist theory of cognitive development, in which development is organized into a series of sequential and invariant stages. Piaget became very interested in philosophy, especially logic. He blended this with his interest in science and began searching for biological explanations of cognition. Piaget decided to develop philosophy/biology of life and life forms, the centerpiece of which was the idea that all forms of life (organic, mental, and social) are organized as "totalities" that are greater than the sum of their parts, and that these totalities impose the organizing structure of the parts.

Reacting to a long legacy dominated by behaviorist learning theories, Piaget proposed a dynamic, cognitive model of learning that became known later as constructivism. In constructivism, learning is conceived to be a holistic, "bottom-up" process enacted by an *active learner*. In contrast to behaviorist learning theories, Piaget proposed several new and radical themes: the individual learner is an active constructor of knowledge; developmental process must precede learning through instruction; and language is an epiphenomenon of thought and not constitutive of thought. Piaget called the knowledge and skills possessed by individuals “schemas”, and he explained how they got reorganized with the concepts of assimilation, disequilibrium, equilibrium, accommodation, and organization.

Piaget claimed that individuals learn primarily through their own categories of thought while they attempt to organize the world around them. To eventually arrive at adult-like forms of understanding- or, in Piagetian terms, objective knowledge- individuals activity proceed through a spiral of stages in which they develop different hypotheses based on their experience and incorporate these hypotheses into different naïve theories for understanding and explaining the world around them. Instead, individuals’ epistemologies about the world are continually transformed as they act in and on the world and reflect on the nature and effects of their actions.

It is important to note that although originally based on Piagetian theory, the learning cycle also embodies other constructivist paradigms or learning and development such as social constructivist theory by Vygotsky and meaningful learning theory by Ausubel (Marek, Gerber, & Cavallo, 1999). Vygotsky maintained that “learning is a necessary and universal aspect of the process of developing culturally organized, specifically human, psychological functions.” (Vygotsky, 1978). In other words, learning is what leads to the development of higher order thinking. As a constructivist, Vygotsky repeatedly stressed the importance of past experiences and prior knowledge in making sense of new situations or present experiences. According to Vygotsky’s theory, social learning leads to future development, which represents a huge difference from Piaget who believes that development is a prerequisite to learning (Bybee & Sund, 1982). Vygotsky believes that learning and development are always within two planes: social and psychological. Learning is first situated in an interpsychological plane between the learner and knowing others. However, in later stage learning moves into another intrapsychological plane through a process called "internalization." Internalization is the reconstruction of external operation so they transform from being a social phenomena to being part of the learner's interpersonal mental functioning. Learning is specific to the culture and society as the tools of learning, such as language and signs, differ from culture to culture. Vygotsky maintained that language plays a central role in cognitive development. He argued that language was the tool for determining the ways an individual learns "how" to think. That is because complex concepts are conveyed to the individual through words. Learning, according to Vygotsky, always involves some type of external experience being transformed into internal processes through the use of language. Additionally, speech and language are the primary tools used to communicate with others, promoting learning. This is in a way similar to Piaget who emphasized the role of experiences on assimilation of knowledge.

Vygotsky's concept of the Zone of Proximal Development (ZPD) is perhaps what he is known for most. He proposed that an essential feature of learning is to create the ZPD; that is, learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers (Gredler & Shields, 2008). Once these processes are internalized, they become part of the child's independent developmental achievement. In other way, ZPD is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978). In theory, as long as a person has access to a more capable peer, any problem can be solved. According to Piaget, learning is what results from both mental and physical maturation plus experience (Bybee & Sund, 1982). In contrast to Piaget who believes that development preceded learning; Vygotsky observed that learning processes lead development (Gredler & Shields, 2008). According to Vygotsky the two primary means of learning occur through social interaction and language. Language greatly enhances humans' ability to engage in social interactions and share their experiences. Vygotsky maintained that learning occurs just above the student's current level of competence. Furthermore ZPD is dynamic and fluid space within which individuals move about as the content, learning contexts, and learner characteristics change (Dimitriadis & Kamberelis, 2006).

***Mental functioning.*** According to Piaget, learning occurs primarily through self-regulation. It involves a series of active constructions and adjustments on the part of the individual in response to external perturbances. These constructions and adjustments are both retroactive (loop systems or feedback) and anticipatory. Together they form a permanent system of compensations, always seeking equilibrium. The compensations are accounted for primarily by assimilation and accommodation. *Assimilation* is a matter of making a new object or experience fit into an old schema.

This new object causes a disturbance or disequilibrium that forces the mind to equilibrate. *Equilibrium* is typically motivated by the experience of *disequilibrium*, the uncomfortable sense that one's experience is at odds with one's capacity to understand and explain it. *Accommodation* is a matter of making an old schema fit a new object. For example, teaching medical students about malignant hyperthermia as a disease could be achieved by connecting the pathology of the disease to an earlier concept the learners know, muscle fiber contraction (force). This concept is familiar to all medical students through earlier biology and physiology classes. A review of intracellular action of a fiber contraction and the role of calcium regulation in organized fiber contraction places the subject in the learners' ZPD. Introducing the concept of a genetic malfunction that cuases massive release of calcium under certain circumstances will cause the learners to cognitively disequilibrate and force them to equilibrate by assimilation. Students will then accommodate by connecting the effects of increased intracellular calcium release and the clinical symptoms of malignant hyperthermia: increased muscular contraction causes rigidity and increased heat production, massive lactate release causes acidosis, increased oxygen consumption manifests as blood oxygen desaturation, and increased carbon dioxide production forces the body to remove it manifesting by increased carbon dioxide elimination by the lungs. Learning about malignant hyperthermia causes the learners to go through multiple loops and feedbacks while disequilibrating and equilibrating multiple times; a formal learner should be able to do that.

***Developmental stages.*** Even though Piaget claimed that children are active participants in the creation of knowledge, he also claimed that they progress through distinct development stages, each with its own specific kind of knowledge and ways of organizing that knowledge, as well as specific behavioral characteristics. The first, the *sensorimotor stage*, occurs roughly between birth and two years of age. During this stage, children explore things that can be seen, felt, and touched through their senses. Their knowledge during this stage is largely immediate, sensory, and motor. The next stage, the *preoperational*, occurs roughly between the ages of two and seven years. During this stage, children's thinking is more intuitive and concrete than logical and abstract. One of the best-known examples of preoperational children's centrism is their inability mentally to conserve number, length, and solid or liquid amounts. The third stage, *concrete operations*, emerges roughly between the ages of seven and up. During this stage, children begin to apply logical operations to concrete problems. Children are rather skilled at thinking logically, but only in the context of specific, concrete situations. They have difficulty thinking abstractly and forming generalizations based on particular experiences. They also develop the concept of "Reversibility", "Classification" and "Serration". The fourth stage, *formal operations*, emerges roughly around ages of eleven and up. During this stage, children develop the ability to view problems from multiple perspectives, to think abstractly, to form and test hypotheses intentionally, to generalize from the particular to the abstract, to engage in logical (deductive) reasoning, and to develop ideals. Although Piaget posited that these four stages are sequentially invariant, he also acknowledged that the ages when children pass through different stages are approximate, and that children sometimes move back and forth between stages during transitional developmental periods.

Piaget argued that language does not facilitate cognitive development, and that cognition can develop normally without language acting as a mediational means. Additionally, he thought that although language is instrumental in sharing of knowledge, it is not a source of knowledge. Instead, for Piaget, thought development precedes language development. Language is simply a reflection of the thought. This claim seems rooted in Piaget’s instance that the individual learner is a little scientist, constantly constructing and reconstructing theories about the world and how it works. This perspective is controversial and was strongly opposed by Vygotsky and his followers. From this perspective, socialization and teaching is effective only after children have moved beyond syncretic thought and egocentric speech.

Vygotsky promoted the development of higher level thinking and problem solving in education (Gredler & Shields, 2008). If situations are designed to have learners utilize critical thinking skills, their thought processes are being challenged and new knowledge gained. The knowledge achieved through experience also serves as a foundation for the behaviors of every individual. Vygotsky believes in the "More Knowledgeable Other" (MKO). The MKO is anyone who has a better understanding or a higher ability level than the learner, particularly in regards to a specific task, concept or process. The MKO could be thought of as a teacher or an older adult; however, this is not always the case. Other possibilities for the MKO could be a peer, a sibling, a younger person, or even a computer. This is similar to what Bruner thinks and believes (Bruner, 1996). The key to MKO is that they must have more knowledge about the topic being learned than the learner does. Teachers or more capable peers can raise the student's competence through the ZPD. Vygotsky's findings suggest methodological procedures for the classroom where the ideal role of the teacher is that of providing scaffolding to assist students on tasks within their ZPD. During scaffolding the first step is to build interest and engage the learner. Once the learner is actively participating, the given task should be simplified by breaking it into smaller subtasks. During this task, the teacher needs to keep the learner focused, while concentrating on the most important ideas of the assignment. One of the most integral steps in scaffolding consists of keeping the learner from becoming frustrated. The final task associated with scaffolding involves the teacher modeling possible ways of completing tasks, which the learner can then imitate and eventually internalize. It seems that what Vygotsky is calling *internalization* is close to Piaget's idea of *assimilation*. Students need to work together to construct their learning, teach each other so to speak, in a socio-cultural environment.

**Cognitive and motivational variables.** In addition to research supporting the effectiveness of the learning cycle in facilitating a better understanding of scientific concepts and processes, the role of cognitive variables on science achievement has also been investigated (Cavallo, 1996; Johnson & Lawson, 1998; Lawson & Thompson, 1988). Among cognitive variables, *reasoning ability* has received the most attention. The ability to reason formally is the strongest predictor of meaningful understanding of scientific concepts. Lawson and Thompson (1988) demonstrated that high-formal learners who no longer require concrete objects make rational judgments and are capable of hypothetical and deductive reasoning, performed better than did low-formal learners. High-formal learners are able to understand both concrete and formal concepts. They have developed sound understanding of abstract concepts. Such learners are capable of looking for relations, generating and testing alternative solutions to problems, and drawing conclusions by applying rules and principles. Low-formal learners on the other hand are concrete reasoners who are unable to develop sound understanding of abstract concepts. They are able to understand only concrete concepts. Low-formal learners have not fully developed formal thought yet. Lawson and Renner (1975) reported that interpreting and solving genetics problems requires formal-level operations such as probabilistic, combinational, and proportional reasoning that is in line with Piaget's developmental theory. It is assumed in this research that all medical students are formal thinkers and thus can handle teaching of more than one concept at a time. This is very important to medical educators as most of the teaching that we do depends on formal learners who can move among concepts smoothly.

**Simulation for Assessment of Learning in Medicine**

Simulation in medical education is a growing enterprise that facilitates learning for individuals and multidisciplinary teams in hospital and school environments. Simulators range from task trainers, to medium fidelity life size and human appearing mannequins, to high fidelity mannequins that project physiological signals and respond to pharmacological interventions in a realistic looking healthcare setting. Training has a wide range of applications, from basic to advanced technical skills acquisition, to interpersonal factors such as communication and teamwork, to assessing the learners in a safe environment. This training can be provided through the use of high-fidelity simulation as well as other methods such as standardized patient scenarios and task trainers. Dr. David Gaba (2007) defined simulation as “a technique-not a technology-to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner.” (p. 126).

Learning from error is a new concept that has been applied in medical teaching in the last few decades. This method of teaching was not applicable years ago as medical errors may lead to fatal consequences to patients. However, with the invention of human simulators learning by error is easily and safely applicable. This gives medical teachers better chance at focusing on challenging, open-ended investigations without the fear of harming a patient. The negative emotions generated from bad outcomes as a result of mistakes made during simulation can lead to better decision making in real clinical situations (Okuda et al., 2009). As complex skills are constructed from fundamental component skills, the proficient performance of complex skills is achieved by refining and integrating the component skills during repeated performance in a realistic context that is accompanied by feedback on performance. This is precisely what simulation learning can provide.

Despite advances in simulator development, even high-fidelity simulators are imperfect. Although simulation has come a long way in replicating human likeness, there remains a degree of low face-validity, or realism. Some trainees, for example, know that the simulator is not a “real patient,” and so may behave differently than they might in “real” situations. Future developments in simulator technology will likely help to improve the fidelity of training scenarios, which will in turn, improve the assessment of trainee performance.

**History of mannequin simulation.** Simulators in healthcare date back to the 1960's with the development of Resusci-Anne for the purpose of teaching and demonstrating mouth to mouth resuscitation (Cooper & Taqueti, 2008; Cumin & Merry, 2007; Grenvik & Schaefer, 2004).

***Early mannequin simulators.*** The earliest medical simulator is *Resusci-Anne*. The first version of Resusci-Anne simulated airway obstruction and allowed the user to adjust the airway by hyperextending the neck and forward thrusting the chin to aid mouth to mouth resuscitation. Not long after its development, and following the realism of the benefits of external chest compression during cardiac arrest, Resusci-Anne was updated to include a spring in the chest to allow the simulation of chest compressions.

Another historical mannequin simulator that also has its origins in the 1960s is *Harvey*, a mannequin designed to model 27 different cardiac conditions (Gordon, 1974). Harvey could demonstrate blood pressure, jugular venous pulses, arterial pulses, precordial impulses and auscultatory events (Cooper & Taqueti, 2008). Throughout the decades Harvey has been the center of many studies that explored the efficacy of simulation in medical education. A study by The National Heart, Lung, and Blood Institute showed that fourth year medical students trained with Harvey performed better than their colleagues trained with live patients only (Ewy, Felner, & Juul, 1987). For these high performing students, training with Harvey had improved their confidence and cardiology assessment skills. Harvey has also been utilized as a tool to test the cardiology exam and diagnostic skills of medical professionals.

**Simulators in anesthesia.** Simulators have long been used for purposes of developing anesthesia related skills. For example, *Sim One.* is a computer controlled high-fidelity simulator developed for training and testing experiments. Additionally, Dr. David Gaba (1988) developed the simulator known as *CASE* – Comprehensive Anesthesia Simulator Environment to investigate human performance in anesthesia. CASE relied on the ability of a computer to run simulated blood pressure values and later displayed physiological cardiac signals in a realistic operating room environment. With the ability to simulate a number of critical events, a new curriculum entitled Anesthesia Crisis Resource Management (ACRM) was born (Holzman et al., 1995).

At the same time of CASE's development, *GAS.* - Gainesville Anesthesia Simulator was developed and originally used to simulate and diagnose faults within an anesthesia machine (Cooper & Taqueti, 2008). Combining the apparatus with a simulated lung model, GAS is a complete mannequin simulator that enabled users to diagnose critical anesthesia events. GAS later became a licensed product of Medical Education Technologies Inc. which now makes *HPS* (Human Patient Simulator) and *PediaSIM*. The creation of such high fidelity patient simulators provided an avenue for medical personnel to learn psychomotor and cognitive skill in a realistic patient setting.

**Current uses of simulation.** Medical simulation, in general, has been used to (a) practice complex medical procedures and critical events, (b) promote rehearsal of clinical and nonclinical skills such as communication, (c) introduce new equipment/technology, (d) train teams and individuals, (e) experiment with novel interventions, and (f) assess performance (Bradly, 2006). In anesthesia, simulation can be used to provide training in crisis management, new technologies or equipment, cognitive skills such as decision-making, technical skills such as airway management, behavioral skills such as communication, teamwork, and leadership. Additionally, simulation can be used for competency assessments for physicians credentialing and board examinations.

**Advantages of medical simulation.** There are a number of reasons for using simulation in health care environments. Primarily, use of simulation provides zero risk to patients as errors may be obtained and corrected without consequences. Simulation also allows for the presentation of a wide variety of scenarios, including less frequent but still critical events. Additionally, simulation provides flexible, job-specific training and learning that can be tailored to a participant's skill level and/or learning style. Unlike patients, simulators do not become embarrassed or stressed, are available at any time to fit curriculum needs, and have predictable behavior. Thus, training does not have to be delayed due to "real patient" variables. In addition, simulators: can be programmed to simulate selected conditions, findings, situations and complications; allow standardized experience for all trainees; can be used repeatedly with fidelity and reproducibility (Issenberg et al., 1999).

**Simulation in medical education.** In a systematic review of 670 peer-reviewed journal articles related to high fidelity medical simulation in a range of disciplines, including anesthesia, clear evidence was found that repetitive practice involving medical simulation is associated with improved learner outcomes (McGaghie, Issenberg, Petrusa, & Scalese, 2006). Furthermore, it was identified that a dose-response relationship, such that more practice, yielded better results for all levels of learners, including students, residents, and attending physicians.

***Undergraduate medical education.*** Teaching through the use of simulation could be superior to typical problem based learning for undergraduate learning. In science, mannequins are used to teach physiology, while human actors are very effective in teaching multiple different disciplines including neuroscience. Simulation can also help to ease the transition from study into clinical clerkships; for example, the cardiology patient simulator replicates 30 different cardiac conditions. Additionally, virtual reality simulation can be used to aid students in learning through simulated surgeries (Okuda et al., 2009). Morgan and Cleave-Hogg (2000) demonstrated that simulation is a reliable assessment method for medical students' performance.

***Graduate medical education.*** Simulation can be used to teach adverse reactions to anesthesiology in a way that legal and safety concern prevent in real-life situations. For training in obstetrics, motorized muscles allow a mannequin to "give birth" to a mannequin "baby". Valuable emergency medicine skills are being transmitted through the use of simulation, as well as crew resource management skills. Critical care training, such as central line placement, can be taught through the use of simulated practice (Okuda et al., 2009).

***Board certification and credentialing, and medical-legal applications.*** Computer-based simulation of patients is used in several countries' examination processes. The US and Canada use simulation to add additional levels of evaluation. The American Board of Anesthesiology is preparing to use simulation in the evaluation for board certifications. Simulation has also been effective as a tool in cases of malpractice. Some insurance companies have been offering incentives to anesthesiologists who participate in simulations for crisis resource management. Simulation may also have implications if used as evidence in the courtroom for malpractice cases.

***Competency assessment.*** Simulations can be used to assess the competency of a physician and are capable of distinguishing between a novice resident and a more experienced one. The use of an anesthesia simulator offers a number of advantages over traditional assessment methods. First of all, simulation allows for multidisciplinary learning: nurses, pharmacists, medical students, residents, fellows, and physicians. Secondly, scenarios can be standardized so that multiple teams of learners can be trained in the same way, which is especially helpful for assessment and credentialing. By standardizing the scenarios, having the observers view the same events, and scripting the responses to the problems, differences attributed to the "patient," the candidates, or the conduct of the examination are eliminated (Devitt, Kurrek, & Cohen, 1997).

Malignant hyperthermia scenarios have been used frequently to assess anesthesiologists (Boulet, Murray, Kras, & Woodhouse, 2008; Henrichs et al., 2009; Murray et al., 2007). Standards for management of malignant hyperthermia mannequin-based scenario are established using aggregate expert judgments of physicians' audio-video performances (Boulet et al., 2008). A scenario of malignant hyperthermia, among other conditions, provides a great assessment opportunity in anesthesiology as the management of malignant hyperthermia is emergent with a set of agreed upon steps to recognize and treat.

# Chapter III

## Research Methodology

This study is designed to compare factual knowledge retention and clinical skills outcomes of medical students following their experience in one of two different teaching designs: inquiry via the learning cycle and exposition via power point presentation. Clinical knowledge and skills acquired from either teaching practice will be measured by how learners recognize and manage a malignant hyperthermia crisis in a medical fidelity simulation one month following the experimental teaching procedures. Factual knowledge acquired and retained will be compared using a multiple-choice question test immediately following the teaching procedure and one month later. Additionally, correlation between factual knowledge (performance on multiple-choice question test) and clinical skills (simulation) will be studied. A quantitative analysis will be used to compare the difference between the two groups.

### Description of Participants

Following The Oklahoma University Health Sciences Center Institutional Review Board approval, third and fourth year medical students (MSIII and MSIV, respectively) enrolled in the College of Medicine at the University of Oklahoma will be asked to participate in this study. The current demographics of medical students in the College of Medicine is 48% females and 77% whites, and we expect the participants in the study to follow the same demographics. Additionally, the majority of the participants will be under 30 years of age, although their post high school education years may vary from 6 to 10 years. The only exclusion criteria that will be used is refusal to participate in the study.

**Recruitment.** An email will be sent to all MSIII and MSIV at the beginning of the school calendar year in July. To increase recruitments, a second email will be sent a week later to students who did not answer the first email, and a third email two weeks later to students who did not answer the second email they are to agree or deny participation. A $25 gift card will be offered to each student at the completion of the study to compensate for their time, and all students will enter a lottery to win one of two free opportunities to attend an anesthesiology national meeting. The students will be informed that performance assessment generated from participating in this study will not be used in any of their medical school evaluation.

**Randomization**

One hundred students will be randomized into either an inquiry group or an exposition group using Research Randomizer software (http://www.randomizer.org/). The software will assign each student either the number 1 (inquiry) or the number 2 (exposition).

**Inquiry group (I).** Students who were randomly assigned the number 1 will constitute five groups of 10 students each (five MSIII and five MSIV). These students will be taught about malignant hyperthermia using a learning cycle the investigator developed and used previously.

**Exposition group (E).** Students who were randomly assigned the number 2 will constitute five groups of 10 students each (five MSIII and five MSIV). These students will be taught about malignant hyperthermia using a slide presentation the investigator developed and used previously.

## Teaching Procedures

Students will be taught by the same instructor in 10 different groups, each group consists of 10 participants. All teaching for inquiry and exposition will occur in the lecture room at the Oklahoma University Clinical Skills Education & Testing Center. The instructor and the group will meet for one hour. All content taught will be similar between the two groups but the teaching practices will be different.

**Inquiry teaching.** During one hour, the instructor will follow the lesson plan on malignant hyperthermia. See Appendix A.

**Exposition teaching.** During one hour, the instructor will follow a slide presentation format. Following the slide presentation, a 5 minutes period will allow students to ask questions and participate. See Appendix B.

To ensure that the teaching content is similar in each teaching procedure, all teaching will be videotaped. Two anesthesiologist raters will randomly select one videotape from the inquiry teaching, out of five, and one videotape from the exposition teaching, out of five, and analyze the teaching. A checklist of the items the students will be assessed with (simulation and multiple-choice questions) will be used by the raters as teaching rubric to insure similarity of the content during the teaching procedures. Each item will be scored as covered or not. See Appendix C.

## Assessment Procedures

Human Fidelity Simulation has been used extensively to assess management of a malignant hyperthermia crisis (Boulet et al., 2008; Henrichs, et al., 2009; Murray et al., 2007). However, results from a study by Morgan, Cleave-Hogg, Guest, and Herold (2001) indicated that a complex multitask simulator scenario could be somewhat challenging at the undergraduate level. Thus, performance template of the current study involves a single patient management problem only, giving the students opportunity to focus their problem solving abilities. As per our interest is the long term effects of the teaching procedures, the assessment process will take place approximately one month following the experimental teaching procedures.

**Orientation to simulation.** The students as a group are going to be introduced to the simulator mannequin and the monitors in the simulation room. The mannequin will be in a state of awake spontaneously breathing. This will give the students the chance to observe the monitors with normal vital signs (blood pressure, oxygen saturation, and electrocardiogram). The investigator will allow the students during this time to ask questions regarding simulation, but not regarding malignant hyperthermia. Then the student group will witness the investigator demonstrate management of a scenario of bronchospasm. This will give the students a chance to see the mannequin reacting to a crisis where oxygen saturation decreases slowly and intra-thoracic pressures increases accompanied by wheezing in the chest. These symptoms will improve and return to normal when the investigator administers epinephrine intravenously.

Then the students will be asked to return to the class room as a group. They will be given the following instructions: (a) please remember to communicate with the personnel in the control room if anything does not make sense to you, and (b) please think out loud during the assessment so we can guide you if needed. One student will be randomly picked to be assessed next and so forth.

**Anaphylaxis scenario.** Each student will be assessed separately by being asked to go to the simulation mannequin room. The anaphylaxis scenario will serve to familiarize the student with the environment, and is best done without the student knowledge beforehand. This scenario will not be videotaped or rated. A printed handout sheet of information containing the pertinent history, physical exam, and laboratory findings will be given to the student. Following checking the student's preparedness and all equipments, the mannequin will simulate a patient under general anesthesia for a leg surgery. The monitors will show normal vital signs with a patient under general anesthesia. The student will then be asked by the surgeon actor in the simulation room to administer 2 ml of a muscle relaxant intravenously. Thirty seconds following the administration of muscle relaxant, the mannequin will manifest with anaphylaxis symptoms. These symptoms will include: increase heart rate, decreased blood pressure, increased intra-thoracic pressure and chest wheezing. This scenario will be terminated a minute later regardless of the student's management.

Next, the student will be asked to wait in the hallway while the investigator and one assistant set up the simulator for the actual assessment. This set-up includes 3 main steps: (a) a scenario of malignant hyperthermia will be reloaded on the computer that controls the mannequin, (b) two ceiling video cameras that record the action of the student will be positioned to capture the student during the assessment, and (c) the audio that connects the control room with the mannequin room will be checked for functionality. The controlling computer is located in the control room that connects to the mannequin room through a one-way mirror.

**Malignant hyperthermia scenario.** The student will then be asked to enter the simulation room to care for a different patient. A printed handout sheet of information containing the pertinent history, physical exam, and laboratory findings will be given to the student. Following checking the student's and equipments' preparedness, the mannequin will simulate a patient under general anesthesia for a leg surgery. A minute later, the student will be asked by the acting surgeon to administer a muscle relaxant (succinylcholine). A minute later, the mannequin will present with manifestation of malignant hyperthermia episode. This will include increased end-tidal carbon dioxide, increased blood pressure, and increased heart rate. The student's management will be recorded using the video cameras. The experiment will then end in five minutes and the student will be asked to leave the simulation center.

The cycle will be then repeated with a different student until all students have been assessed. Students who have been exposed to teaching or assessment will be asked to not share their experience with any other students participating in the study.

**Standardized performance evaluation.** Each student will be asked to sign a consent form to be videotaped and the tape to be analyzed. Each malignant hyperthermia performance will be videotaped and recorded on a four-quadrant screen that includes two separate video views of the student and the mannequin. Two microphones will be suspended from the ceiling to capture audio during the scenario. The third screen of the four-quadrant video recording is the simultaneous full display of patient vital signs (electrocardiogram, pulse oximetry, inspired and expired gas monitoring, and blood pressure). In the lower right quadrant of the screen, identifying information such as the date and student will be displayed. This quadrant of the screen could also be used to add information to clarify participant actions during the scenario.

Similar to other studies on simulation (Morgan et al., 2001), the general approach to scoring the scenario will include two analytic methods (checklist and essential action) and a single global rating scale. For the analytic scoring, two trained anesthesiologists will score each student's performance separately using a detailed checklist of diagnostic and therapeutic actions and an abbreviated checklist system that consists of three essential actions for the scenario. In a previous study, a list of technical actions and point values for a malignant hyperthermia scenario were created and used (Gaba et al., 1998). The checklist scoring system included two essential actions and 33 possible actions totaling 95 points, and each action was weighted based on its importance with respect to overall patient care. The checklist action that we will use is a modification of the checklist action that was used by Gaba et al. In our checklist, we have deleted some of the actions used be Gaba et al. as we concluded that these actions are above and beyond the expectations of a medical student. Our checklist scoring system will include three essential actions and 12 possible actions totaling 50 points (Table-I). A subject who misses two essential actions or more by the two raters will be considered "deficient" and the points will be scored as zero. The rater anesthesiologists will also provide a single global rating of the performance on a scale of 0-10, where zero is very bad and 10 is excellent. The anesthesiologists will be blinded to students' assignment groups (inquiry or exposition). The final score of the assessment will be recorded as the mean score from the two assessments.

Additionally, a third rater anesthesiologist will be available to analyze videotapes for any dispute in results.

Table 1

Checklist Scoring System for malignant hyperthermia scenario.

| **Action** | **Point Value** |
|---|---|
| Initiation of MH protocol | |
| -Diagnose MH or notify surgeon | EA |
| -Request MH box | 5 |
| -Calls for help | 5 |
| -Terminate triggering agent within 1 minute | EA |
| Dantrolene administration | |
| -Administer dantrolene within 10 minutes | EA |
| -Administer dantrolene 2.5 mg/kg | 10 |
| Ventilation and oxygenation | |
| -Uses 100% oxygen | 5 |
| -Hyperventilate by ventilator | 5 |
| -Clears triggering agent with high flow | 5 |
| -Disconnects from ventilator and uses Ambu-bag | 5 |
| Requests blood gas or potassium levels | 5 |
| Cooling action of any kind | 5 |

The checklist includes three essential actions (EA) and 12 possible actions totaling 50 points.

**Multiple-choice test.** Students in each group will be asked to take a 15 minutes/15 item multiple-choice test prior to (pre-test) and immediately following the teaching procedures (post-test). The same questions arranged differently will be repeated prior to the simulation assessment one month later (post/post-test). See Appendix D.

**Statistical Procedures**

Data will be analyzed and compared between the two treatment groups, inquiry and exposition. A *p*-value less than 0.05 will indicate that there is a significant difference between the two groups. An interrater reliability analysis using the Kappa statistic will be performed to determine consistency between raters. For each of the scoring systems (simulator checklist, multiple-choice questions test, and global rating), an independent-samples *t* test will be used to test the null hypothesis that there will be no differences in performance between the two groups. Pearson correlation coefficient will be used to test any correlation between performance on simulation and performance on multiple-choice question test one month following teaching procedures.

**Risks and Benefits to Participants**

Minimal risks to subjects include: (a) total time spent in participating in the study, which will be 3-4 hours (Table –II), (b) experiencing simulation and testing that could cause anxiety to some students, (c) potential anxiety for students who are planning to apply into Anesthesiology and are afraid that this experience will influence any of the program's future opinion about them. On the other hand, there are many benefits to the students participating: (a) increasing the amount of knowledge from teaching, (b) experiencing simulation session and learning from it, (c) and monitorial benefit.

Table 2

Estimated time for conduction of investigation.

| **Time (minutes)** | **Process** |
|---|---|
| 15 | Multiple choice pre-test |
| 60 | Learning procedure |
| 15 | Multiple choice post-test |
| 10 | Introduction to simulator |
| 15 | Multiple choice post/post-test |
| 5 | Bronchospasm scenario |
| 5 | Set up for a student |
| 5 | Anaphylaxis scenario |
| 5 | Set up for real assessment |
| 5 | Malignant hyperthermia scenario |

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# Appendix B

## Malignant Hyperthermia Lesson Plan

## Malignant Hyperthermia Lesson Plan

**Concept:** Malignant hyperthermia is a genetic disorder where a mutation in the ryanodine receptors on the sarcoplasmic reticulum causes, when stimulated by anesthetic gas or succinylcholine, a massive release of intracellular calcium that may lead to death if untreated.

**Format:** Learning cycle presented formally with data on power point slides and discussion during each phase of the learning cycle.

**Students:** $3^{rd}$ and $4^{th}$ year medical students.

**School:** University of Oklahoma College of Medicine/Department of Anesthesiology.

**Teacher:** Faculty in Anesthesiology.

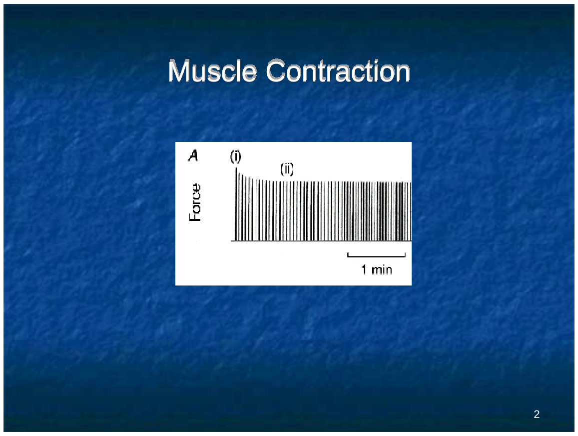
The lesson plan includes: a) teacher's guide, b) student's guide and c) two real patients' cases with multiple-choice tests.

## Teacher's Guide

Malignant Hyperthermia is a genetic disorder where a mutation in the ryanodine receptors on the sarcoplasmic reticulum causes, when stimulated by anesthetic gas or succinylcholine, a massive release of intracellular calcium that may lead to death if untreated. This lesson should introduce third and fourth year medical students to the concept of malignant hyperthermia, understanding the pathophysiology, diagnosis, and treatment. The lesson plan is a learning cycle with three phases: exploration, explanation, and expansion.

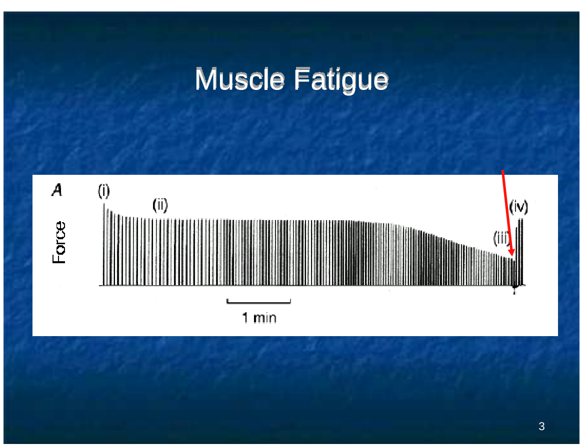
**I. Exploration**

**Slide 2**



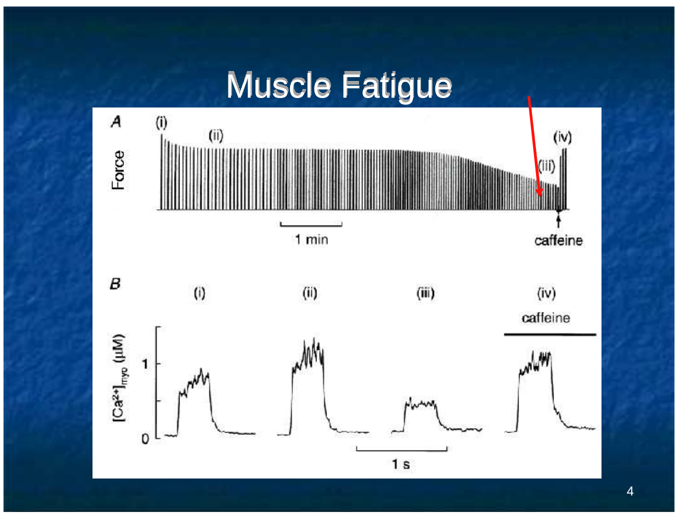

All students should have been to the physiology lab before and know the chart of muscle force related to time where continues stimulation to a muscle fiber causes contraction (force). The teacher should try to stimulate a discussion when showing this slide to make sure all students are on the same page. Question such as “who can explain to us this figure?” could be helpful to start the discussion. Teacher should also be analyzing students’ behaviors to make sure they are engaged and enthusiastic about the discussion. This slide should take 2-3 minutes.

**Slide 3**



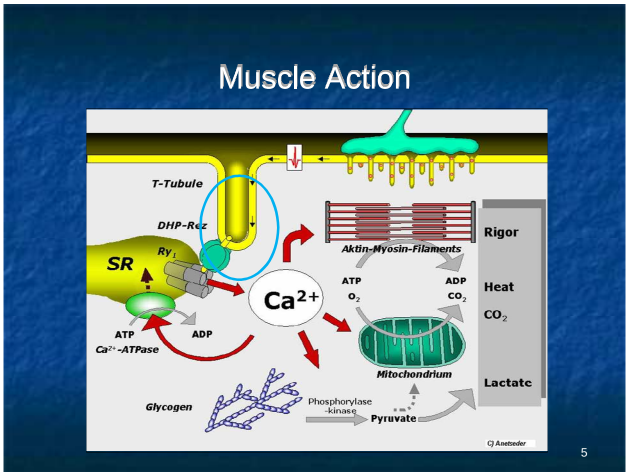
This slide is an extension to the previous one. However a focus on muscle fatigue should present here. Teacher should expect students to explain in their own words how intracellular calcium depletion contributes to the fatigue effects. Teacher should not move on before students get to this conclusion. A calcium effect on normal muscle is an important concept for the students' understanding of the concept. Teachers should then ask what substance was injected that led to the increase in the force despite muscle fatigue. This slide should also take 2-3 minutes.

**Slide 4**




This slide is summary of the last 2 slides and will help the students understand the relation of intracellular calcium, and muscular action and fatigue. The teacher should also emphasize on the effects of caffeine on intracellular calcium.

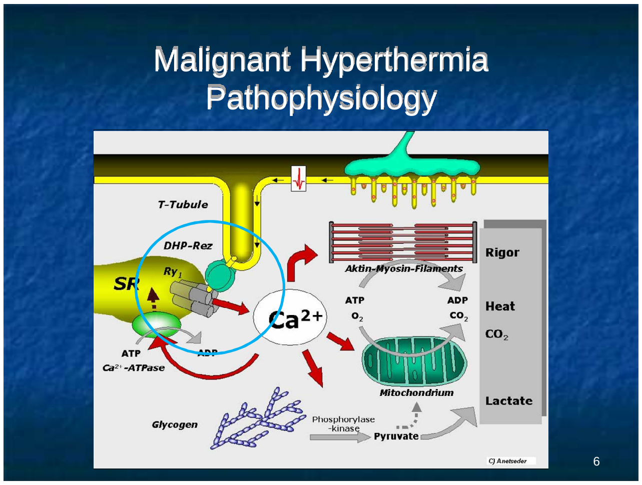
**Slide 5**




This is the last slide in the exploration phase. The teacher should spend extra time on this slide as it is very important to the understanding of the concept. The teacher should help the students explain this complicated intracellular process. Concentration on the ryanodine receptors should take place. Why are those receptors important? What happen if we have a mutation in those receptors? With questions like this the teacher should be able to lead the students to state the concept of anesthetic effects on the mutated receptors in their own words. This slide should take around 5 minutes.

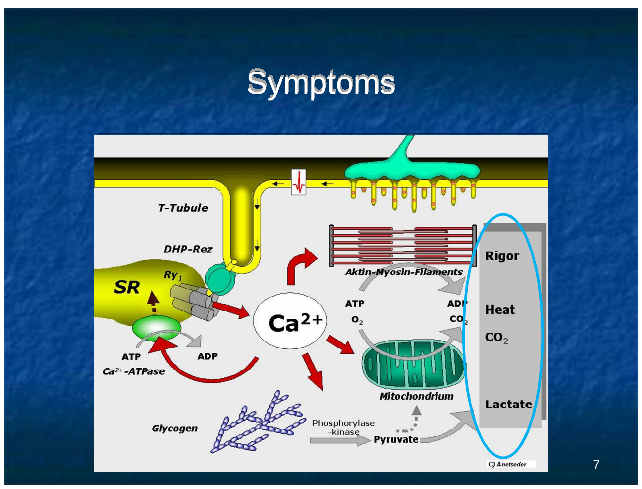
## II. Explanation

### Slide 6



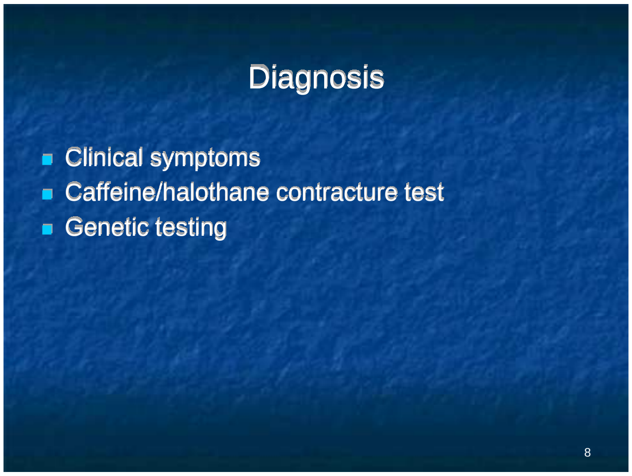

The teacher can mention in more details why ryanodine receptors are important in malignant hyperthermia (pathophysiology of the disease) and how anesthetic gases affect these receptors.

### Slide 7



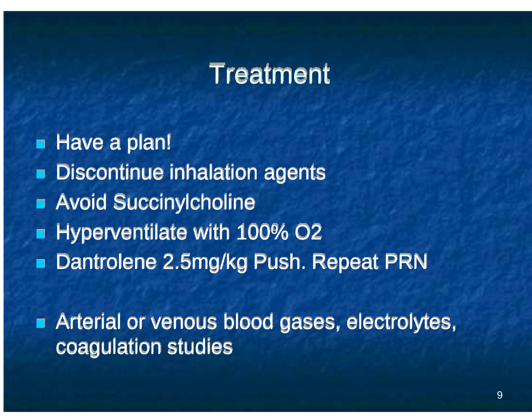

This slide focuses more on the symptoms of MH from the understanding of the disease. The teacher should expect the students to mention some of the symptoms from their understanding of the previous slides (increased $CO_2$, acidosis, muscle rigidity, and heat) and the teacher then mention other symptoms such as hypoxia and hyperventilation.

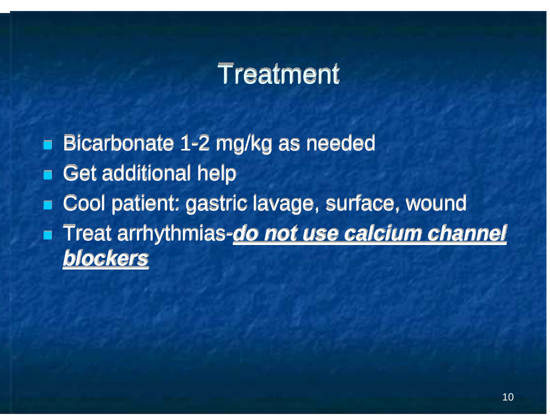
**Slide 8**




Diagnosing MH with the focus on the gold standard test (caffeine contracture test) should relate the disease back to slide 3 with the effects of caffeine on increased intracellular calcium.

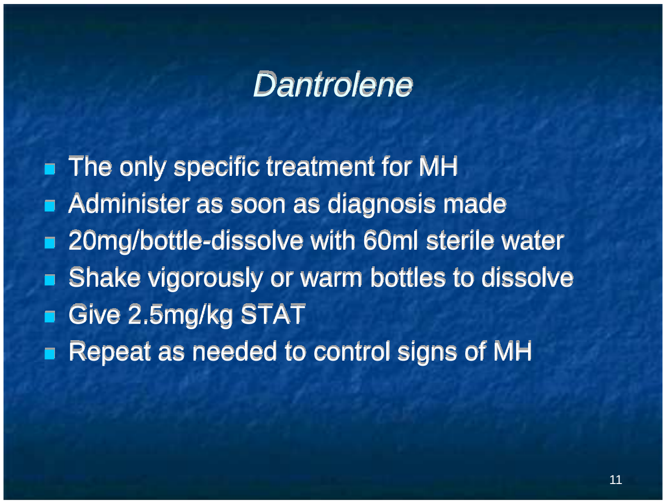
**Slides 9-10**




Treatment of an MH episode gives the students better understanding of what to expect when dealing with the disease. Main focus will be on essential items such as discontinue triggering agent and administer dantrolene.

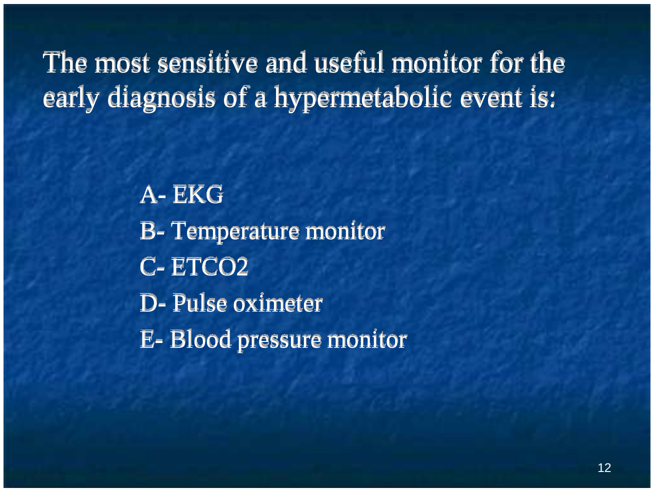
**Slide 11**




Due to the importance of dantrolene, this slide will give in details all information needed to use it during malignant hyperthermia episode.

**III. Expansion**

**Slide 12**




Slide 12 should be a simple way of assessing the students' understanding of the concept. The teacher then distribute the hand out which has 2 different sections. One that has a clinical case related to MH with 5 multiple choices questions that the students should read. This case will alert the students to the importance of the concept and the disease as a life threatening one. The second part of the handout is the most recent information regarding the disease with the diagnosis and treatment. This handout will serve also as a reference the students can use in the future. The teacher can continue the expansion when working with the students individually in the operating room. Before ending the class, the teacher should asses the understanding of the students and investigate and deficiency in their comprehension to the concept.

## Student’s Guide

### I. Exploration

During slides 2,3,4, and 5 the students should engage in discussion regarding the effects of intracellular calcium and the role of ryanodine receptors in regulating the release of calcium. They also should develop an idea on how is this can be related to the anesthetics they use in administering anesthesia. The student should follow the directions of the teacher and pay attention to the hints he/she gives during this time to reach the concept. When reaching the concept they should mention it in their own words.

### II. Explanation

The students should share their observation or previous knowledge regarding the intracellular calcium with the class. The students should pay attention to the teacher’s explanation of the effects of general anesthetic on the mutated ryanodine receptors. They should be able to construct their knowledge based on the teacher’s explanation and previous experiences or readings about the concept.

### III. Expansion

The students have the responsibility to go over the materials the teacher distributed to expand on their understanding of malignant hyperthermia and its relation to anesthetic gases. While reading the case presented, the student should try to answer the multiple-choice questions before reading the narrative to asses their understandings of how devastating the disease can be if not fully understood. They should then read the latest on diagnosing and treating malignant hyperthermia. Next time the student work with the instructor, they should engage in discussion regarding the materials (using all the appropriate terminology) to cover any gaps in understanding the concept.

**Case One**

## Elevated Temperature following Masseter Spasm

28 y/o female, 38 weeks gestation, without any significant previous medical history presented for stat c-section. The patient underwent one general anesthetic previously for tonsillectomy without complications. Additionally, family history is negative for MH or any other metabolic disease.

General anesthesia was performed and the patient was induced with propofol and succinycholine (rapid sequence induction). Following administering succinycholine, patient developed masseter spasm that prevented opening her mouth. However, mask ventilation was adequate for few minutes where mouth opening was possible and tracheal intubation was achieved. Maintenance of anesthesia was achieved with propofol IV infusion and nitrous oxide; inhalation agent was not used. The patient remained stable during the procedure and increased in ETCO2, temperature, HR did not occur. The patient lost 1000 of blood but did not require blood transfusion. At the end of surgery, the trachea was extubated and the patient was transferred to the PACU stable and awake and alert.

One hour later, the patient temperature increased to 38.5 C˚, but the patient was still awake and alert with stable vital signs. Blood gas was normal with PCO2 of 30 mmHg and BE of -4.

1) All of the following trigger an MH episode in susceptible patients **except**:

A. Sevoflurane

B. Halothane

C. Succinycholine

D. Nitrous oxide

2) When faced with a masseter spasm, the anesthesia provider should do all the following **except**?

A. Ventilate with a face mask

B. Tracheal intubation

C. Discontinue all triggering agents

D. Monitor the patient in the recovery room for 4 hours at least

E. Check for myoglobinuria in 6-12 hours

3) What is the best action that should be taken in the recovery room now?

A. Administer dantrolene 2.5 mg/kg IV

B. Actively cool the patient

C. Continue monitoring

D. Administer antibiotics for pneumonia

4) What is currently considered to be the “gold standard” for diagnosing MH susceptibility?

A. Molecular genetic testing

B. Halothane-caffeine contracture testing

C. Masseter muscle rigidity with hypercarbia

D. 3-fold rise in CK following a rapid intraoperative temperature elevation

5) Caffeine halothane contracture testing is indicated in all the following **except**?

A. Clinical history suspicions for malignant hyperthermia

B. A first-degree relative of a patient with documented MH

C. Unexplained muscular rigidity with MH suspicion

D. Sudden cardiac arrest on induction of anesthesia

**Narrative:**

1) Halogenated agents and succinycholine are the only pharmacological triggering agents of MH episode. Nitrous oxide, propofol and narcotics are considered safe.
Answer D

2) Masseter (jaw) muscle rigidity (MMR) may occur after the administration of succinycholine, particularly in children. MMR signifies MH in approximately 15% of cases. **When a patient develops MMR, triggering agents should be discontinued and ventilation should be established with a face mask** as direct tracheal intubation is impossible due to a closed mouth.
Answer B

3) This is a tough question as no clear indication of MH episode is available. Although the patient had a masseter spasm following succinycholine administration (now with 15% chance of developing MH), but the temperature could not be explained by other reasons. I believe that any elevation in temperature following masseter spasm should be treated as MH episode.
Answer A

4) Currently, halothane-caffeine contracture testing is considered the best test with regard to sensitivity and specificity for diagnosing MH susceptibility. However, since only 6 centers in North American currently administer the test (for which a fresh muscle specimen is required), the test is not available to most patients with suspected MH susceptibility.
Answer B

5) Currently, the *in vitro* contracture test (IVCT) is the gold standard for diagnosing MH. However, the IVCT is very expensive, requires a surgical procedure that can only be performed on-site in one of approximately 10 specialized testing centers in the US, and has 97% sensitivity and 78% specificity. Consequently, **IVCT is only indicated in patients who have had clinical episodes and (possibly) their immediate family members.** Sudden cardiac arrest on induction of general anesthesia is most likely an indication for arrhythmias and not MH. This patient was recommended to be referred to a testing
Answer D

**Case Two**

## Scoliosis Surgery without Triggering Agent

14 y/o boy with CP presented for spinal fusion (T6-L2) under general anesthesia and somatosensory and motor evoked potential monitoring. The boy was diagnosed with MH when he was exposed to GA for tonsillectomy, although the diagnosis was never confirmed with muscle biopsy or contracture test.

Following flushing the anesthesia machine for 20 minutes and disconnecting the gas vaporizers, anesthesia was induced with propofol and tracheal intubation was achieved. Anesthesia was maintained with propofol and sufentanil. Four hours later, ETCO2 was suddenly elevated with loss of motor evoked potential and tachycardia. Blood gas obtained was as follows: PH: 7.05, PCO2: 89 mmHg, PO2: 89 mmHg, HCO3: 18 mEq/dl, BE: -10. Temperature was normal.

1) What is your diagnosis?

   A- Definitely MH

   B- Probably MH

   C- Definitely not MH as triggering agent was not used

   D- I'm not sure

2) What action should be taken first?

   A- Administer dantrolene 2.5 mg/kg IV

   B- Actively cool the patient

   C- Continue monitoring

   D- Send CPK and liver enzyme

3) The most sensitive and useful monitor for the early diagnosis of a hypermetabolic event is:

A- EKG

B- Temperature monitor

C- ETCO2

D- Pulse oximeter

E- Blood pressure monitor

4) What diseases are associated with MH?

A- King-Denborough Syndrome

B- Minicore myopathy

C- Central Core Disease

D- All of the above

5) Should dantrolene be administered following the initial dose and for how long?

A- Yes as 1 mg/kg every 6 hours for 24 hours at least

B- Yes, if the symptoms come back

C- No, first dose is usually enough

D- No as dantrolene is a long acting drug (24 hours half life)

**Narrative:**

1) Sudden rise in ETCO2 in a patient with previous history of anesthetic complication is MH until proven otherwise, especially if PCO2 does not improve with increasing ventilation. It is clear that stress and surgery may initiate an MH episode in MH susceptible individuals without pharmacological triggering agents.
Answer A

2) Actively cooling the patient and sending blood for blood work (CPK, BUN, Cr, and Liver enzymes) are part of the treatment for an MH episode. However, the first line of therapy is dantrolene @ 2.5 mg/Kg IV. The dose can be repeated at 1 mg/kg. Continue monitoring is always an option, but the early MH is treated the better the results are.
Answer A

3) Early rise in ETCO2 is the most sensitive indicator of a hypermetabolic state. All other monitors help in detecting MH episode, but they are not as sensitive as ETCO2. Increase in temperature is usually a late sign.
Answer C

4) All three diseases are associated with MH as all of them have defect on the same gene (RYR1) just like MH.
Answer D

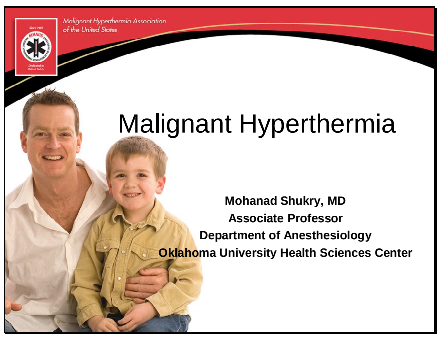
5) Following administering an initial dose of dantrolene with good response, it is always advisable to administer it as 1 mg/kg every 6 hours as MH symptoms may reoccur. The decision is always difficult when the trachea is not intubated as dantrolene cause muscle weakness including respiratory muscles. Clinical judgment is always a key with close observation of the patient in ICU sittings.
Answer A

Appendix C

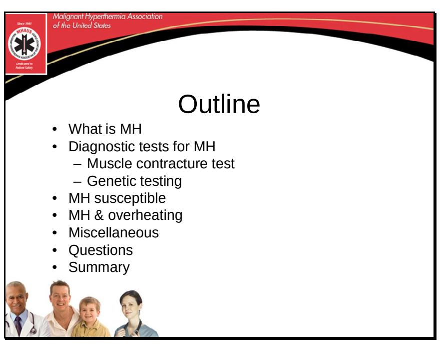
Slide Presentation for Exposition Teaching

## Slide Presentation for Exposition Teaching

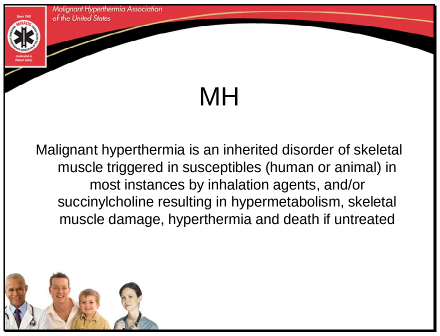
Slide 1



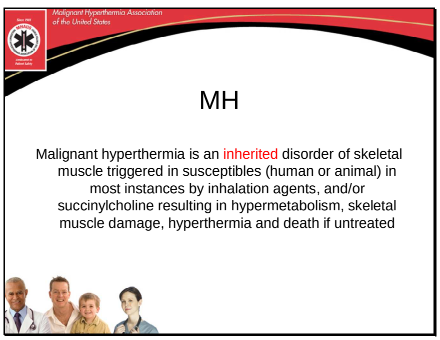

Slide 2



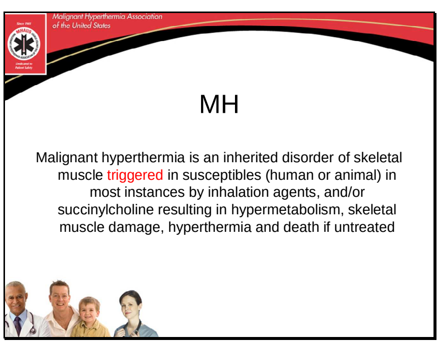
Slide 3



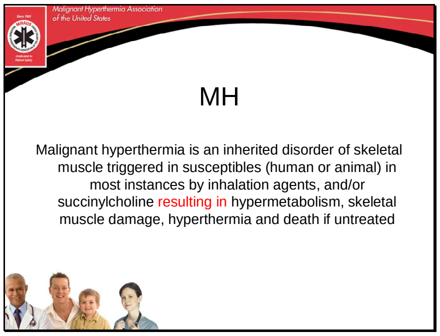

Slide 4



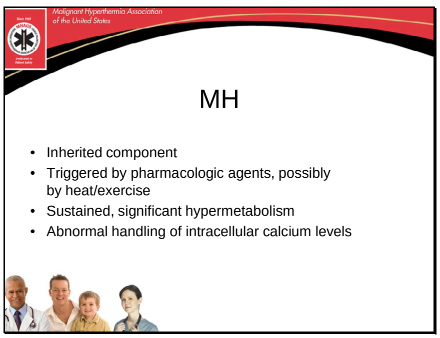

Slide 5



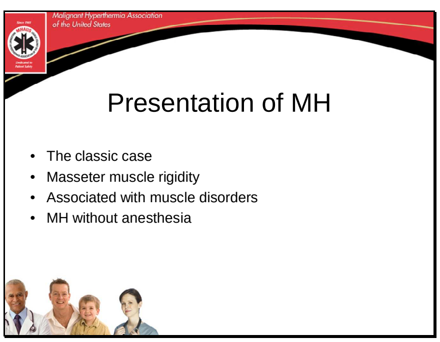
Slide 6



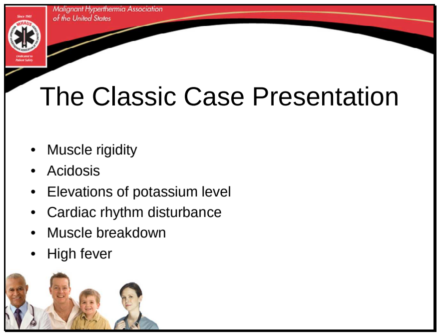

Slide 7




Slide 8



Slide 9




Slide

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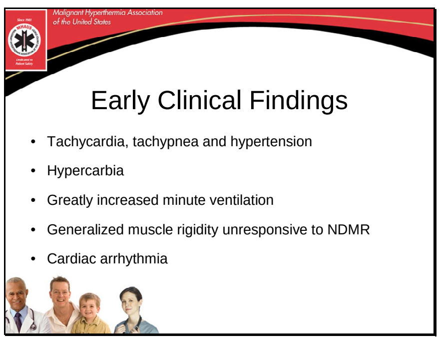


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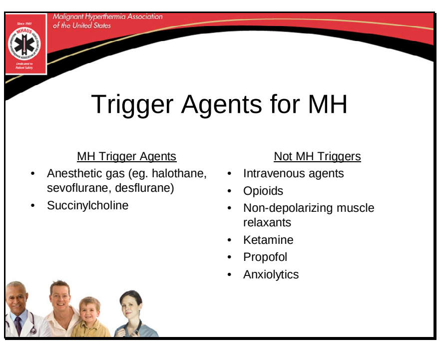
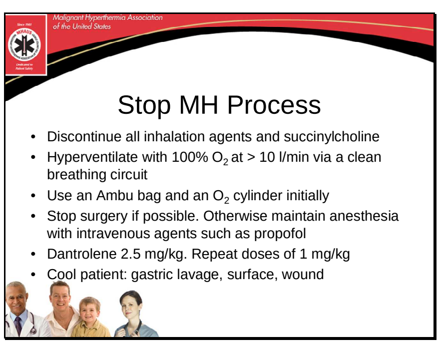


Slide 12


Slide 13


Slide 14



Slide 15

Malignant Hyperthermia Association of the United States

## Monitoring

- ECG, $SpO_2$, $ETCO_2$
- Invasive arterial BP, CVP, core and peripheral temperature, urine output
- PH, arterial blood gases, central mixed venous blood gas, potassium
- Hematocrit, platelets, clotting factors
- Creatine kinase (peaks at 12-24 hours)

Slide 16

Malignant Hyperthermia Association of the United States

## Treat the Effects of MH

- Hypoxemia and acidosis: 100% $O_2$, hyperventilate, sodium bicarbonate
- Hyperkalemia: glucose and insulin, sodium bicarbonate, i.v calcium chloride if significant cardiac effects
- Cardiac arrhythmias: procainamide, Mg, amiodarone, lidocaine. Avoid Ca channel blockers
- DIC: fresh frozen plasma, cryoprecipitate, platelets

Slide 17

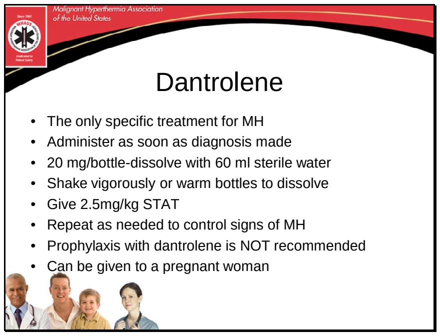
Malignant Hyperthermia Association of the United States

## Initial Laboratory Assessment

- ABG, VBG
- Elctrolytes with glucose
- Creatinine and BUN
- CBC with plateletes
- PT, PTT, CK
- Serum and urine myoglbine

Slide

18




Slide

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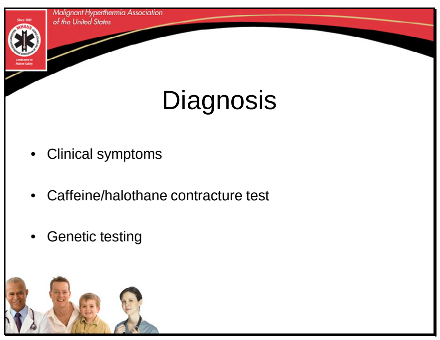


Slide

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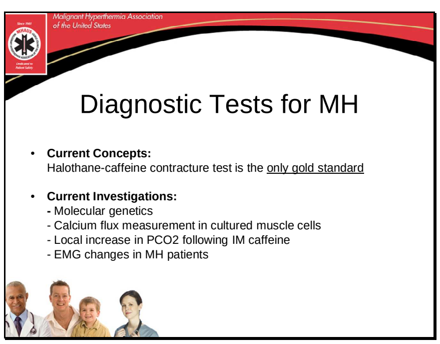
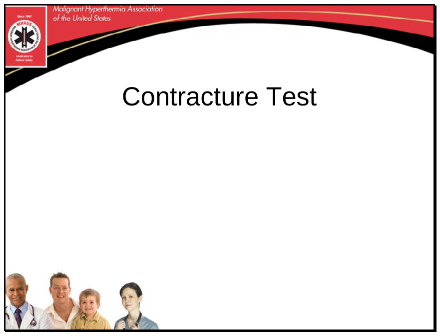
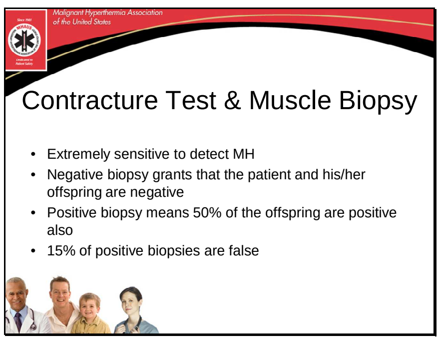


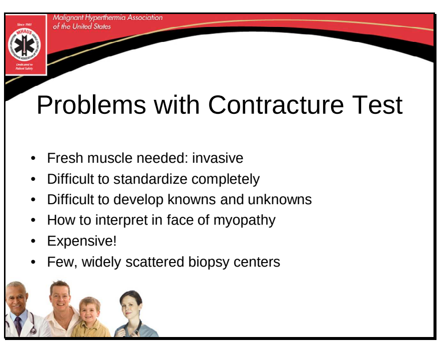
Slide 21




Slide 22




Slide 23



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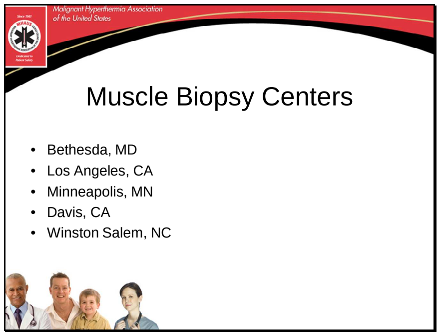


Slide

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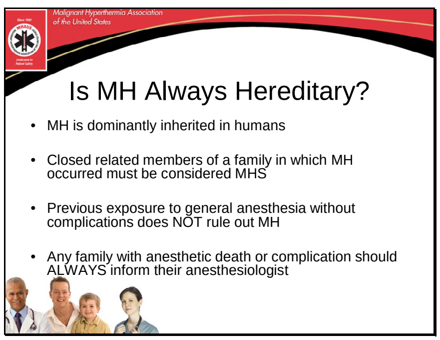


Slide

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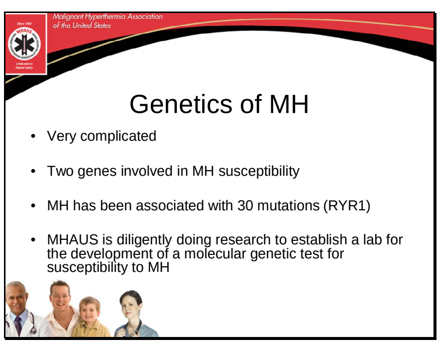

Slide

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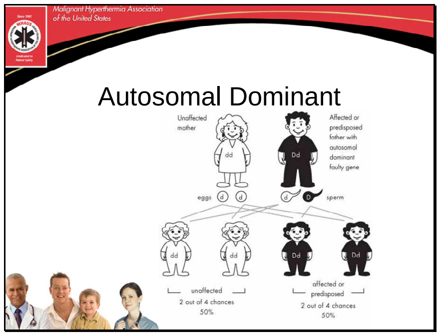


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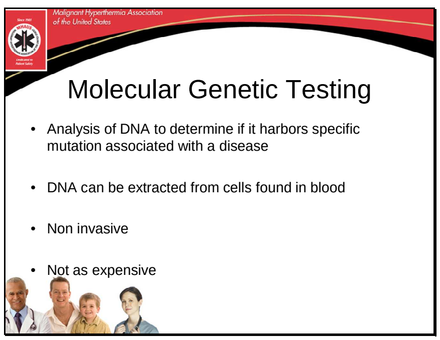


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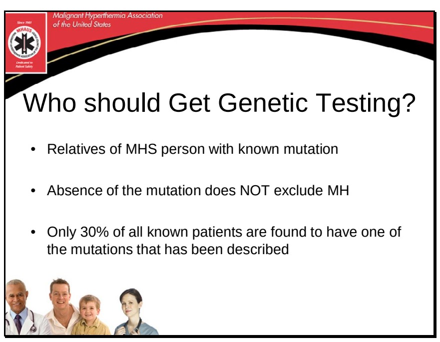

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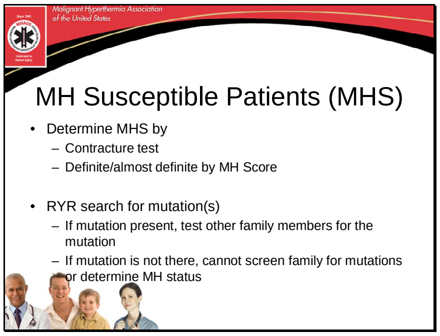


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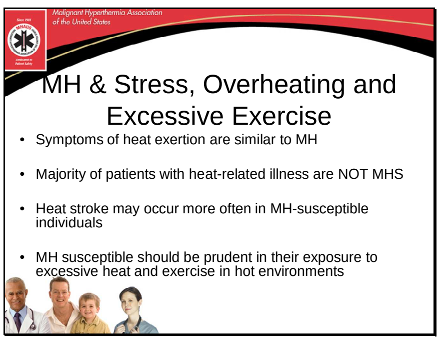


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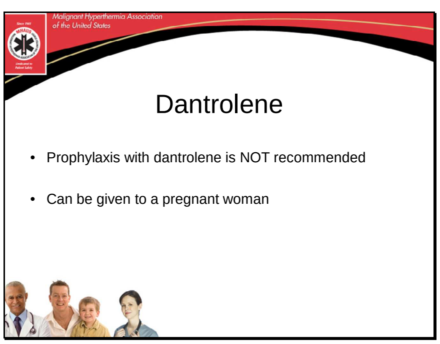

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Malignant Hyperthermia Association of the United States

## Minor Surgery & MH

- Minor surgeries under local anesthesia have been safe for MHS
- Facilities that perform surgeries under general anesthesia should be prepared to deal with MH episode

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Malignant Hyperthermia Association of the United States

## Hospitals & MH

- Academic centers and Children's hospitals are more likely to be prepared to deal with MH
- Anesthesiologists and Nurse Anesthetists are more likely to know more about MH than other health care providers

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Malignant Hyperthermia Association of the United States

## MHS & Operating Room Environment

- Low concentration of anesthetic do NOT trigger MH episode
- OR environment has very low concentration of anesthetics
- Stay 2 feet away from inhalation induction

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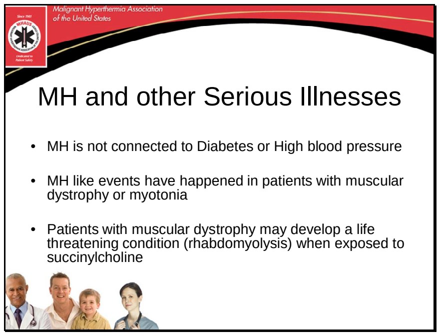


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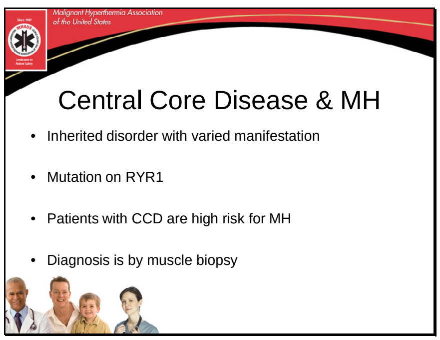


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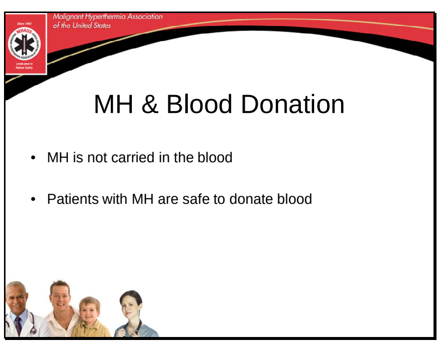

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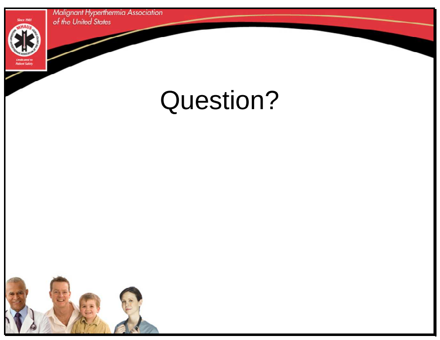


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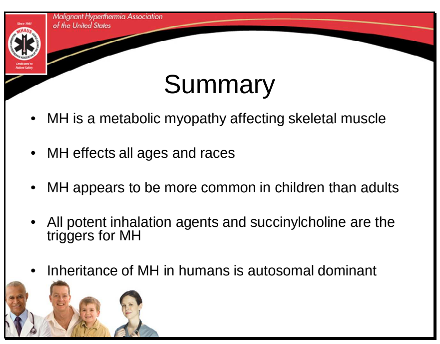

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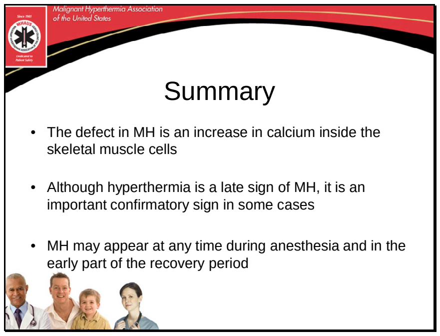


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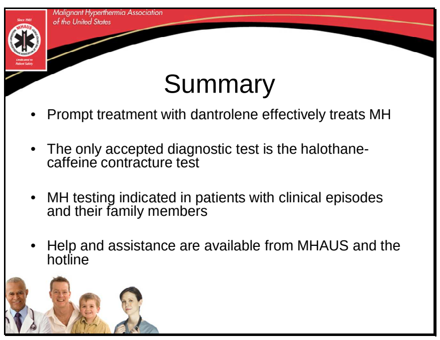

Appendix D

Rubric to Evaluate Teaching Procedures

**Rubric to Evaluate Teaching Procedures**

The teaching procedure covers all the following (Y/N):

- Clinical diagnosing of MH episode
- MH triggers
- Drug treatment of MH
- Management of MH crisis including:
    - Notify surgeon
    - Request MH box
    - Terminate triggering agent within 1 minute
    - Calls for help
    - Administer dantrolene 2.5 mg/kg
    - Administer dantrolene within 10 minutes
    - Uses 100% oxygen
    - Clears triggering agent with high flow
    - Hyperventilate by ventilator
    - Disconnects from ventilator and uses Ambu-bag
    - Requests blood gas or potassium levels
    - Cooling action of any kind
- Sensitive monitor for early MH diagnosis
- Dantrolene's mechanism of action in treating MH
- Indication of caffeine halothane contracture testing
- Limitations of caffeine halothane contracture testing
- Gold standards for diagnosing MH
- Management of masseter spasm
- Diseases associated with MH

Appendix E

Multiple-Choice Test

## Multiple-Choice Test

1. Caffeine halothane contracture testing is indicated in all the following **except**?

    A. Clinical history suspicious for malignant hyperthermia
    B. A first-degree relative of a patient with documented malignant hyperthermia
    C. Unexplained muscular rigidity with malignant hyperthermia suspicion
    D. Sudden cardiac arrest on induction of anesthesia

2. All of the following trigger an malignant hyperthermia episode in susceptible patients **except**?

    A. Sevoflurane
    B. Halothane
    C. Succinylcholine
    D. Nitrous oxide

3. What is currently considered to be the “gold standard” for diagnosing malignant hyperthermia susceptibility?

    A. Molecular genetic testing
    B. Halothane-caffeine contracture testing
    C. Masseter muscle rigidity with hypercarbia
    D. 3-fold rise in CK following a rapid intraoperative temperature elevation

4. The most sensitive and useful monitor for the early diagnosis of a malignant hyperthermia is?

    A. EKG
    B. Temperature monitor
    C. Exhaled $CO_2$
    D. Pulse oximeter
    E. Blood pressure monitor

5. When faced with a master spasm, the anesthesia provider should do all the following **except**?

   A. Ventilate with a face mask
   B. Administer succinylcholine
   C. Discontinue all triggering agents
   D. Monitor the patient in the recovery room for 4 hours at least
   E. Check for myoglobinuria in 6-12 hours

6. The principle treatment of malignant hyperthermia is?

   A. Dantrolene
   B. Iced normal saline
   C. Oxygen
   D. Verapamil

7. Dantrolene is all of the following **except?**

   A. Decreases calcium ion release from sarcoplasmic reticulum
   B. May alleviate chronic muscle spasticity
   C. May lead to hepatic dysfunction during long-term administration
   D. May cause severe hyperkalemia

8. Intraoperative events that correlate with the onset of a suspected malignant hyperthermia episode include all the following **except?**

   A. Progressive mixed acidosis
   B. Unexplained tachycardia
   C. Rising end-tidal $pCO_2$ at fixed minute ventilation
   D. Hypokalemia

9. Limitations affecting performance of contracture testing for malignant hyperthermia include?

   A. Need for fresh skeletal muscle
   B. Existence of multiple chromosome sites of the human genetic defect
   C. Need for testing known MH-susceptible individuals as controls
   D. Availability in only 100 test centers in the US

10. Characteristics of malignant hyperthermia include all the following **except?**

   A. Autosomal dominant genetic transmission
   B. Association with central core myopathy
   C. Improved survival after the introduction of dantrolene
   D. Triggering by local anesthetics

11. At preoperative evaluation, which of the following MOST strongly increases the probability of a subsequent intraoperative hyperthermic event?

A. Increased resting CPK concentrations
B. History of temperature increase during general anesthesia
C. Familial history of an intraoperative hyperthemic event.
D. History of intraoperative muscle rigidity and hypercarbia with postoperative
E. Massively increased CPK concentrations

12. Which of the following is NOT a trigger for malignant hyperthermia?

A. Succinylcholine
B. Halothane
C. desflurane
D. Ketamine

13. Which of the following is most clearly associated with malignant hyperthermia?

A. Central core disease
B. Bilateral strabismus
C. Myotonia congenital
D. Down's syndome

14. Desflurane should be avoided in patients with each of the following **except?**

A. Central core disease
B. Family history of malignant hyperthermia
C. Neuroleptic malignant syndrome
D. Marked masseter muscle rigidity

15. Low or normal $ETCO_2$ would be unusual during an intraoperative episode of malignant hyperthermia?

A. True
B. False

**Answers**

1. Answer D
2. Answer D
3. Answer B
4. Answer C
5. Answer B
6. Answer A
7. Answer D
8. Answer D
9. Answer A
10. Answer D
11. Answer D
12. Answer D
13. Answer A
14. Answer C
15. Answer A