# Designing an Effective Skill Learning Environment

By
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Abstract

This paper explored the dynamic process of psychomotor skill development. The design of effective skill development experiences requires the integration of a complex mosaic of interacting factors having the ultimate goal of constructing long-term memories. The results of this investigation are presented in three manuscripts (Chapters 2-4). Chapter 2 explores how the design of the simulation learning environment can foster learner active engagement. Active engagement creates a personal connection with the learning experience and motivates the learner to take greater responsibility in the learning process. Design features such as simulation fidelity, managing learner anxiety, and debriefing methods help to create an effective learning environment. This chapter presents an Active Engagement Model which describes how the interaction of the different components of the learning environment facilitates engagement.

Chapter 3 describes the neurophysiological basis of skill learning and how the design features of the learning environment can facilitate the construction of long-term memories (schemata). Robust schemata represent the persistent cognitive representations of skills, indicating true skill learning. The efficient management of cognitive processes during skill learning and performance underlies the importance of schema construction and is based on the principles of the Cognitive Load Theory. Robust skill schemata can be processed automatically leaving working memory reserves available for active processing of other informational elements. This chapter presents design features that may help facilitate construction of skill schemata.

Chapter 4 describes an experimental pilot study comparing physical practice with mental imagery practice strategies in developing an ultrasound-guided needling skill. Simulation-based skill development, while valuable, has access limitations that may impair optimal skill

development. The results of the study suggested that mental imagery may be an effective adjunct practice strategy that can be used outside the simulation environment to mitigate the limitations of simulation learning.

Chapter 5 synthesizes many important principles of skill learning, presented in earlier chapters, into a few basic guidelines that may better inform the design of the skill-learning environment. Optimal design principles must incorporate features that foster learner engagement, enhance the skill learning cognitive mechanisms, and provide sufficient opportunities to develop competent skills prior to actual patient care.

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Table of Contents

# Chapter 1

# Introduction

## Problem and Significance

Training health care practitioners to provide safe and competent care requires a multifaceted approach beginning early in the learners' educational experience and extending throughout their careers. One critical facet of this training experience involves the development of competent psychomotor skills. Ethical ideals and public demands for competent health care providers exert external pressures on educators to design curricula that facilitate learner skill development to ensure safe and competent care prior to entering the clinical arena (Kohn, Corrigan, & Donaldson, 2000). Although, most nursing academic leaders believe their curriculum design successfully prepares most of their students to provide competent care, a 2007 survey of hospital-based nursing executives reported only 10% of new graduates were properly prepared to care for patients (Berkow, Virkstis, Stewart, & Conway, 2008). These contradictory views uncover a phenomenological concern: Are current curriculum designs for psychomotor skill learning insufficiently translating skill development to the clinical setting – to provide safe and competent patient care? This concern may be related to a lack of understanding by educators of the process of transferring skills learned in training to the real practice environment (Stefanidis, Scerbo, Sechrist, Mostafavi, & Heniford, 2008).

Recent systematic and meta-analytic reviews in nursing and medical education revealed simulation-based learning to be the most effective learning environment to acquire psychomotor skills (Beal et al., 2017; McGaghie, Issenberg, Cohen, Barsuk, & Wayne, 2011; Shin, Park, & Kim, 2015). Simulation-based skill development is a complex, multifactorial process depending on the dynamic interaction of the learner, the educator, and the learning environment (Fisher, 2016). Simulation educators create this unique learning environment by following evidence-based simulation-learning design principles.

Although common simulation skill performance metrics, such as procedural checklists and global rating scales, may evaluate skill proficiency during simulation training, these tools inaccurately predict competent performance on real patients (Prabhu, Smith, Yurko, Acker, & Stefanidis, 2010; Stefanidis, Scerbo, Korndorffer Jr., & Scott, 2007). The challenge of accurately predicting competency in practice may also stem from the lack of valid skill performance tools used in the clinical setting with which learner skill competency may be evaluated (Buckley, Kavanagh, Traynor, & Neary, 2014). Learners rarely acquire skills from one instructional experience. Repetitive practice of psychomotor skills is one of the foundational principles of simulation-based skill learning (Debarnot, Sperduti, Di Rienzo, & Guillot, 2014; Kantak & Winstein, 2012). A thorough understanding of the skill learning process coupled with appropriate evaluative methods are critical requirements for educators designing the simulation learning environment (SLE).

Psychomotor skill learning engages complex neurophysiological processes of the human cognitive architecture. Effective instruction and practice should lead to the construction of long-term memories that incorporate the procedural information and motor movement plans required to perform the skill (Debarnot et al., 2014; Rao, Tait, & Alijani, 2015; Sweller et al., 2011). Once constructed, these long-term memories (schemata) may be accessed from the inexhaustible long-term memory stores to guide performance of the skill (Sweller et al., 2011). The optimal function of these neurophysiological processes may be impeded by internal and external factors, including poorly designed features of the simulation learning environment, instructional and evaluative methods (Choi, van Merrienboer, & Paas, 2014; van Merriënboer & Sweller, 2010).

Perhaps, one of the greatest limitations to simulation training is sufficient access to effective training facilities. There are significant resource burdens of building expensive simulation facilities and hiring trained simulation faculty to provide effective instruction with feedback and debriefing experiences (Al-Ghareeb & Cooper, 2016). Frequently, simulation facilities cover multiple disciplines within the training institution which may limit the learners' access to the environment. Proper skill development requires frequent practice to initially acquire a skill and then continued practice or performance to strengthen and maintain the skill. Novice learners may lack or have limited access to busy simulation centers. Over time, learners who have not engaged in further practice or performance may experience degraded skill performance. Several researchers have emphasized the importance of continued practice to develop competency in skill performance (Qiao et al., 2014) and the proper assessment of skill learning that may translate into competent patient care (Buckley et al., 2014).

In view of the limitations of access to the SLE, using mental imagery techniques may provide an effective extension to simulation training. Mental imagery (MI) is the imagined rehearsal of physical movement without actual observable movement (Jeannerod, 1994). Researchers have reported successful outcomes in skill learning using MI techniques for basic surgical (Arora et al., 2010; Arora et al., 2011; Sanders et al., 2008; Stefanidis et al., 2017) and anesthesia skills (Lim, Krohner, Metro, & Rosario, 2016). The effectiveness of MI techniques in skill development is based on brain imaging studies showing similar brain regions activated during overt motor movement and mentally imaging the same movement (Allami et al., 2014)

**Purpose of the Research**

Health care professions educational institutions have been educating practitioners for centuries yielding significant improvements in the delivery of patient care and yet, there continues to be a disparity in the perception of skill competency of new graduates between educators and the stakeholders of health care delivery (Berkow et al., 2008). Despite this perceptual disparity, educators continue to create innovative simulation learning environments that introduce skill learning experiences in a safe environment prior to actual patient care. Unfortunately, despite durable empirical evidence of the benefits of simulation skill learning, evidence of the transferability of skills to actual patient care is still in its infancy. The purpose of this research proposal was to explore factors that may inform and improve an evolutionary design paradigm of the SLE to facilitate development of competent procedural skills in health care professions learners and more effectively prepare novice practitioners for actual patient care. This investigation looked at three of the main factors in skill development - the characteristics of the different components of the simulation environment, the neurophysiological processes of skill development, and how to maximize simulation training methods that may facilitate skill development and transfer. This proposal described two distinct phases of this investigational pathway.

In phase one, I initially explored the research on the simulation learning environment to determine the factors that effectively engage the learner in utilizing the simulation experience to best facilitate skill development. Engaging learners in simulation learning involves important interactions with the SLE participants and the environment (Fisher, 2016). In the Fisher (2016) paper, I reported that learner engagement is a critical requirement for effective skill learning and that certain design features of the SLE will foster learner engagement (see paper #1 in Chapter 2). Next, I investigated current research on the neurophysiological foundations of skill development that may inform crucial design features of the SLE that optimize skill development. Researchers have demonstrated specific neurophysiological changes that occur in the learner's brain during skill development (Patel, Spreng, & Turner, 2013). Instructional methods that support these changes should also become the foundation to inform design of the SLE.

Phase two included an experimental pilot study, using pre- and post-test design, to compare the efficacy of mental imagery practice with physical practice to develop ultrasound-guided needle placement skills in nurse anesthesia students. Access limitations and improper design of the SLE may prevent learners from developing robust cognitive schemata representing performance of this skill. Additionally, educators may assume some skills are learned because their initial assessments of learners' skill performance demonstrated competency. Unfortunately, commonly used skill competency assessments lack the ability to accurately predict competent skill performance in real-life settings. Both of these factors may lead to patient safety concerns in which novice practitioners poorly perform critical procedures in novel settings that overload their cognitive resources. In view of these patient safety concerns, I explored an alternative skill learning method (mental imagery) that does not require constant access to a simulation environment and may be performed for extended periods outside the SLE to ensure the formation of robust and automatized skill performance schemata. A unique component of this investigation was the addition of an assessment of cognitive load using a secondary task. This additional assessment should differentiate between performers that are still learning the skill (high cognitive load) and those who are using automatized schemata to perform the skill (low cognitive load). Higher cognitive loads should inform educators that significant cognitive resources are still required to perform the skill and that the skill may not be truly learned. This situation may result in the novice practitioner performing poorly in the unique and oftentimes, mentally challenging clinical setting. Low cognitive loads indicate that the performer is using automatized schemata and cognitive resources are available to process unique components of the situation commonly encountered in clinical settings.

For this experimental pilot investigation, participants were randomly assigned to either a control group that uses physical practice or an intervention group that uses mental imagery to practice the skill. Comparison of pre- and post-testing of needling skills between the two groups revealed if there was any significant difference between the use of physical or mental practice to acquire this skill. The findings should inform educators of the effectiveness of these methods to facilitate skill development.

**Research Aims and Questions**

The following aims and corresponding research questions were explored with this investigative pathway:

Aim 1: Determine through a review of literature what factors inform the design of the simulation learning environment that effectively foster learner engagement? (Manuscript 1)

Aim 2: Determine through a review of the literature, what are the neurophysiological foundations of psychomotor skill development and how these factors can be used to inform and improve the design of the simulation learning environment? (Manuscript 2)

Aim 3: In phase two (Trial 1), using an experimental pilot study, determine the effects of physical or mental imagery practice strategies on complex skill development. The researchers asked the following research questions (Manuscript 3):

1. Was there an improvement in skill performance, as measured by a “time-to-complete” (TTC) assessment of an ultrasound-guided needle directing skill,

when engaging in a three-week practice program using mental imagery or physical practice strategies?

2. Was there a significant difference in psychomotor skill development, as measured by the time-to-complete (TTC) score, using mental imagery versus physical skill practice strategies?

Aim 4: In phase II (Trial 2), explore the cognitive load effects placed on participants as they perform the primary task (US-guided needling skills) and a secondary task. The following are the research questions related to this aim:

1) Was there is a change in cognitive load when performing the primary task and an additional secondary task after completing this training period using physical or mental practice strategies (pre-post within group analysis)?
2) Was there is a significant difference in mental workload (cognitive load) during performance of a primary and a secondary task, as measured by the secondary task score, using mental imagery versus physical skill practice strategies (post-test between group analysis).
3) How much of the variance in the primary task performance, as measured by TTC, was explained by the type of practice strategy (mental imagery versus practice group) and the secondary task (cognitive load) while performing the primary task?
4) For exploratory purposes regarding alternative methods to measure cognitive load, how did scores from the Secondary task measure, Paas scale, and the NASA-TLX questionnaire relate to each other?

**Theoretical Framework**

Sweller (1988) developed the Cognitive Load Theory (CLT) to describe learning processes within the neuroarchitecture of the brain. Actively processing perceptual information or retrieved information from long-term memory creates a cognitive load, representing the sum of the individual elements of information that must be simultaneously processed in the brain during skill learning and performance (Sweller et al., 2011). The learner's working memory (WM), located primarily in the prefrontal cortex, handles the simultaneous processing of these informational elements (Baddeley, 2003). The efficient processing of WM depends on its capacity to handle the cognitive load placed by these informational elements (Sweller et al., 2011). The capacity of WM is limited by the number of elements it can efficiently process simultaneously (four to seven elements) and can only retain that information for about 30 seconds without being actively updated (Cowan, 2010; Sweller, 1988). Actively updating information requires additional WM resources. If the amount of information that must be processed at one time exceeds this limited capacity of WM, learning and performance may be impeded (Kalyuga & Singh, 2016). Novel complex skills contain a high number of interacting informational elements, placing a high cognitive load on WM in the novice learner (van Gog & Paas, 2008). Additional factors may divert attention away from the actual skill learning task, adding irrelevant informational elements to the cognitive load (Choi et al., 2014; Derakshan & Eysenck, 2009; McConnell & Eva, 2012; Qiao et al., 2014; van Gog & Paas, 2008). Acute stress and unusual situational factors play a significant role in impairing performance after skill development by diverting attention away from performing the task (Bajunaid et al., 2017). In summary, overwhelming WM resources with additional informational elements impairs skill learning and subsequent performance.

True skill learning requires the creation of new schemata, elaboration of existing schemata, and their automation (van Gog & Paas, 2008). The ultimate goal for educators in designing learning environments should be to incorporate effective instructional methods that align with the learners' cognitive architecture to effectively create robust schemata (van Gog & Paas, 2008). True learning means an individual is able to access vast stores of knowledge and experience, in the form of schemata, from LTM and utilize that information in WM to effectively interact with the environment (F. Paas & Ayres, 2014; Young, van Merriënboer, Durning, & ten Cate, 2014). With continued practice and experience, schemata are strengthened and become automatized. Once automatized, a schema can be processed with little or no load placed on WM. If skill practice terminates prior to automatization of the skill schemata, WM will have a high cognitive load to actively process the skill sequencing and movement plans. To make critical evaluations of learner skill competency prior to actual patient care, educators must determine if learner performance in training reflects the use of automatized skill schemata. During performance on an actual patient, if the learner has not automatized the skill schemata, additional situational stressors may add to the already heavy cognitive load and negatively affect performance. Assessing performance using a skill performance assessment coupled with a cognitive load assessment may determine if the learner is using automatized schemata to perform the skill. This assessment process should inform the educator of the level of skill development for each learner. This dual assessment process may also inform the educator of the efficacy of the SLE design and identify learners who require additional training experience prior to actual patient care.

**Significance of the Experimental Study**

Anesthesia practitioners perform many complex and critical procedures on patients, one of which is ultrasound-guided regional anesthesia (USGRA). Performing USGRA requires specific visual motor skills and precision as a practitioner guides a nerve block needle through the skin and underlying tissue to a target nerve commonly surrounded by vital structures such as blood vessels, lungs and other organs, and the nerves themselves (Udani, Kim, Howard, & Mariano, 2015). USGRA is rapidly emerging as a commonly used anesthetic procedure. Novice and some experienced practitioners attempting USGRA may not have had sufficient opportunity to develop ultrasound-guided needling skills which may lead to an increased failure rate and even patient harm (Ramlogan et al., 2010). The proper guidance of a nerve block needle using ultrasound imaging is a major determining factor in successful regional anesthesia (Marhofer & Chan, 2007; Smith et al., 2012).

Even if practitioners have been given simulation experiences and can properly perform this skill in the training environment, there is little research that supports effective transfer of competent performance to the clinical setting (Chen et al., 2017; Niazi, Haldipur, Prasad, & Chan, 2012). Simulation research has focused on effective skill evaluation during the training period, yet is lacking robust studies looking at the retention and transferability of skill competency to real-life clinical practice. A possible reason for this concern is the dissimilarity of the environments of simulation and the clinical setting. High-fidelity simulation offers training experiences that are nearly life-like, but still lack the unique factors common in real-life patient care that add additional cognitive load to the novice practitioner and may impair performance (Baker et al., 2017; Kantak & Winstein, 2012). Kirlik (2010) reminded translational researchers to follow ecological validity principles in designing studies to ensure that the methods, materials, and setting closely approximate the clinical setting to produce robust evidence of transferability. Educators using current and sometimes incomplete metrics may not be able to accurately predict clinical skill competency (Stefanidis et al., 2008). Performance metrics commonly used in simulation training evaluate completion of procedural steps and accuracy of performance, but do not provide information on the cognitive load required to perform the skill. By adding a metric of cognitive load during performance assessment, the educator may be able to distinguish between the learner who is using maximal cognitive capacity to perform a skill versus the learner who has spare cognitive reserves to attend to the unique situational elements of the clinical setting, but who both are able to perform the skill competently (Aldekhyl, Cavalcanti, & Naismith, 2018; Haji, Rojas, Childs, de Ribaupierre, & Dubrowski, 2015; Yurko, Scerbo, Prabhu, Acker, & Stefanidis, 2010).

This experimental pilot investigation explored two aspects of skill development in nurse anesthesia training. Firstly, to address the concern of limited access to simulation learning experiences, this investigation sought to determine if mental imagery practice strategies can be used as an effective adjunct for skill development outside the simulation environment. Secondly, this novel investigation sought to disentangle one aspect of transferability of psychomotor skills to clinical practice, guided by the neurophysiological foundations of skill learning and automaticity. Skill automaticity may allow a practitioner to perform complex skills with sufficient cognitive reserve in WM to be able to process additional mental demands placed on the performer common during actual patient care. The evaluation of skill automaticity was determined using a secondary task performance during the performance of the primary task. Exploring skill learning using the principles of the CLT may fill an essential gap in the research literature of psychomotor skill transfer and promote an evolutionary shift in simulation training design. The goal of this unique line of inquiry in anesthesia skill training was to foster greater understanding of skill learning in the novice learner and to more accurately predict competent skill performance in the real-life patient care situations.

**Definition of Terms**

Skill learning – Instructional and practical experiences that lead to the formation of permanent and robust automatized schemata in long-term memory. This relative permanence of these memories defines the capability to perform a skill over time (retention) and in different circumstances (transferability) (Mayer, 2010).

Schema(ta) – Long-term memories incorporating the cognitive processes of stimulus identification, response selection, and the execution (motor movement plans) of a specific movement or an entire skill (Sweller et al., 2011).

Mental imagery – The mental rehearsal of a motor skill or movement in which no physical movement occurs (Jeannerod, 1994).

Ultrasound-guided needle direction (needling) – This is a skill described by the guidance of a nerve block needle, using ultrasound imaging, to touch a target structure(s) embedded in a simulated tissue block. This skill represents a simulated practice of an ultrasound-guided regional anesthetic procedure.

**Assumptions**

Assumptions for the pilot experimental investigation included:

1. Student registered nurse anesthetists (SRNAs) are experienced critical care registered nurses returning to a graduate educational program to build upon a foundational knowledge framework of physiology, pathophysiology, pharmacology, and critical patient care.

2. The training of SRNAs involves extensive didactic work and psychomotor skill development of a myriad of unique anesthesia skills including intubation, fiberoptic bronchoscopy, central intravenous line placement, and a host of regional anesthesia procedures.
3. The growing use of ultrasound-guidance in regional anesthesia and diagnostic procedures adds a unique challenge to nurse anesthesia educators that must incorporate this highly complex skill into already full, existing simulation curricula.
4. Newly matriculated SRNAs are characteristically highly-motivated to learn the skills of their new profession. The competitive nature of admission to the nurse anesthesia programs yields highly competent nurses with successful past educational experiences. These unique characteristics of the potential participants in this pilot investigation should provide a fertile environment to produce strong empirical evidence to support these proposed evolutionary changes to skill development in nurse anesthesia education and encourage additional research in this pathway of inquiry.
5. This study proposed an innovative approach to nurse anesthesia skill training using an alternative practice strategy that may extend skill development outside the SLE. In view of the resource burdens placed by simulation centers and limited access to the SLE for the teaching and practice of critical anesthesia skills, the introduction of mental imagery practice strategies to current simulation-based skill training may have a strong impact in creating more effective skill learning environments and less resource burden on institutions and nurse anesthesia faculty.
6. Finally, this investigation explored a novel skill assessment paradigm, incorporating an additional measurement of cognitive load during skill testing. The addition of a cognitive load assessment to currently used skill assessments, such as procedural checklists and global

rating scales, may more closely align with performance in the clinical setting where many unique factors can add to the mental load experienced by the novice practitioner performing skills for the first time.

**Review of the Literature**

Safe and effective patient care depends on the competent performance of a myriad of skills by the health care practitioner. Historically, skill development in the health care professions has followed the apprenticeship training model, as originally proposed by Halsted in 1889, where learners develop their procedural skills on actual patients (Halsted, 1904). Although this training model continues to be used, the model is no longer acceptable by the stakeholders of health care – especially the patient (Grantcharov & Reznick, 2008; Reznick & MacRae, 2006). Grantcharov and Reznick (2008) proposed the incorporation of a pre-patient training paradigm using a variety of platforms based on simulation learning.

For anesthesia practitioners developing USGRA skills, simulation learning improves the success rate of these procedures (Niazi et al., 2012). Simulation training is being used effectively for USGRA training, but simulation training strategies and assessment of skills have not been firmly established (Udani et al., 2015). This may, in part, be the result of a lack of a standardized skill level classification for the learner and novice practitioner. Researchers commonly classify learners who can properly perform a skill without help or feedback from an instructor as competent, proficient, or even expert. Using the Dreyfus/Benner model of skill level classification characteristics (beginner, advanced beginner, competent, proficient, and expert), it is unlikely that any learner or novice practitioner would be able to achieve the advanced levels of proficient or expert during their training or even shortly after (Dreyfus, 2004; Griswold-Theodorson et al., 2015). Griswold-Theodorson et al. (2015) proposed that simulation-based skill learning should prepare learners to enter the clinical setting at the competent level. The advanced stages of skill development (proficient or expert) reflect years of experience, incorporating vast amounts of additional information to existing schemata (schema elaboration) in long-term memory (van Merriënboer & Sweller, 2010). When the proficient or expert level practitioner performs a skill, the practitioner is able to access an extensive reservoir of experiential knowledge in the form of extensive automatized schemata with which to guide performance in almost any circumstance (Stefanidis et al., 2008; van Merriënboer & Sweller, 2010). In fact, by measuring the cognitive load during performance, researchers have been able to accurately distinguish novice practitioners from experts (Bugdadi et al., 2017; Qiao et al., 2014).

**Skill Learning.** Skill learning is a critical aspect of human life, including health care practice, and should reflect the relative permanence of the capability to perform a skill (Schmidt & Lee, 2014). Skill learning rarely occurs from a single exposure to a skill learning experience, but rather, is the result of repetitive practice and experience. The skill learning process cannot be directly observed and must be inferred by observing and evaluating performance over time. Schmidt and Lee (2014) proposed that practice has two effects on skill performance – one is a transient ability to perform a skill and the other effect induces observable neurophysiological changes in the learner's brain, reflecting a relative permanence in the capability to perform the skill. The educator's goal for skill learning in the learner should be to construct long-term memories (schemata) of the skill which can be accessed to guide skill performance in many different clinical situations (Qiao et al., 2014; Young et al., 2014).

The construction of these long-term memories provides the basis of a permanent change in an individual's ability to perform a skill (Wulf, Shea, & Lewthwaite, 2010). Schemata that have been strengthened by sufficient practice become robust and automatized. Robust schemata that have become automatized can be treated as a single informational element or even unconsciously processed, leaving WM resources available to process unique situational information common to the clinical setting (F. Paas & Ayres, 2014). This informational processing principle is supported by research demonstrating functional brain reorganization and progressive temporal reductions in prefrontal activation that accompany skill learning, reflecting a decreased use of WM resources (Leff et al., 2008). Automatized skill memories are permanently retained in LTM and may result in greater transferability of the skill to the clinical setting (van Merriënboer & Sweller, 2010). The unique characteristics of both the learning and clinical environments may have additive effects on the cognitive load (Choi et al., 2014) and the performance of skills that have not been automatized is more likely to show impairment with this increased cognitive load (Sweller et al., 2011). Practitioners with automatized skills demonstrate economy of movement and improved accuracy when compared to novice practitioners still learning the skills (Marcus, Vakharia, Kirkman, Murphy, & Nandi, 2013).

Many supervisors express that new graduates are not prepared to perform competently in the workplace, yet, educators seem confident that their training curriculum is sufficient to produce well-qualified graduates (Berkow et al., 2008; Young et al., 2014). In view of this disconnect between training effectiveness and clinical performance, a new line of research should focus on the retention and transferability of simulation-acquired skills to the clinical setting (Aldekhyl et al., 2018).

This disconnected vision between educators and workplace supervisors may be the result of the limitations of educational training to effectively transfer skill performance to the clinical setting. This incongruity may also be related to the lack of complete understanding of the skill learning process and the difficulty in transferring skills learned in training to the real practice environment (Young et al., 2014). The primary goal of psychomotor skill training should not only be to facilitate skill performance during training, but, should also foster the retention and transferability of skill performance to the clinical setting (Wulf et al., 2010). Proficiency-based simulation training has been shown to be effective in improving skills during training. Yet, there continues to be weak empirical evidence suggesting that skills acquired in simulation training effectively transfer to the clinical setting (Stefanidis, Korndorffer Jr, et al., 2007). The weakness of evidence of skill transfer from the simulation environment to the clinical setting may be complicated by the use of incomplete metrics during training coupled with the lack of continued assessment in the clinical setting using the same metrics (Stefanidis et al., 2008).

A lack of proper skill assessment in the clinical arena, which may provide crucial feedback to educators on the efficacy and transferability of their skill instruction, creates a gap in understanding the skill transfer mechanisms (Buckley et al., 2014). This lack of follow-through of skill assessment into clinical practice also prevents educators from determining if current training methods transfer to competent skill performance with actual patients. Aldekhyl et al. (2018) added a cognitive load measurement during performance assessments of medical trainees learning simulated point-of-care ultrasound techniques. These researchers reported that concurrent assessment of cognitive load with common performance assessments allowed for greater sensitivity to differentiate skill learning levels and the level of schema formation and automatization in the learners. Determining schema formation and automatization may help to better predict skill transfer to actual patient care (Aldekhyl et al., 2018). By adding cognitive load measures to skill assessments, educators may expand the debriefing process to include levels of skill development. This would provide the learners with more information about their level of skill learning and may provide a degree of encouragement to practice the skill more. The debriefing process may give the learner more effective and accurate feedback of their performance. Naismith, Cavalcanti, and Haji (2018) suggested that researchers use multiple measures of cognitive load to strengthen empirical conclusions and to triangulate measurements of cognitive load to reinforce the validation of these measures.

Cognitive load can be measured using subjective and objective methods. Subjective measures of cognitive load include mental effort scales such as the Paas scale and the NASA-TLX questionnaire (Ayres, 2018). These easily administered questionnaires ask individuals to self-rate the amount of mental effort required to complete a task. Objective measures of cognitive load include physiological measure such as heart rate, heart rate variability, endogenous steroid secretion (salivary cortisol), pupilometry, and eye-gaze tracking methods (Ayres, 2018). Additionally, this author described the use of a secondary task that can be introduced during performance of a primary task that may indicate the level of WM resources available during performance. Using cognitive load assessments during performance of a newly acquired skill may inform the educator and the learner of the degree to which the skill has been learned and may possibly predict the effective transfer of that skill into the clinical setting.

In a rare study of transfer of skills in the health care professions, increased fidelity in eye surgery simulation training improved the transfer of surgical skills to the clinical environment (Starpoli, 2018). Researchers have also proposed innovative training models, such as deliberate practice, to facilitate skill development (Hastings & Rickard, 2015; McGaghie et al., 2011). In their review of deliberate practice training in anesthesiology, both groups of researchers concluded that this type of training is an effective skill learning strategy, but, requires additional faculty instruction, time, and access to simulation facilities. Several simulation design strategies, such as whole-task, part-task (fragmentation), variable versus massed practice, and mastery-based learning have resulted in improved performance during training (McGaghie, Issenberg, Petrusa, & Scalese, 2010). To adapt training strategies using the cognitive architecture model of the CLT, simulation design may include fragmenting skills into part-task training to prevent overwhelming WM resources. Unfortunately, when learners get into the clinical setting, they must collect and process multiple fragmented schemata in WM, possibly exceeding its processing reserves; which may result in poor performance (Young et al., 2014). Part-task training is frequently beneficial in simulation, especially with complex skills (Barrington et al., 2016), although most studies have reported improved performance using whole task training. In the current investigation, the ultrasound-guided needling task is a critical component of the complete skill required to perform USGRA procedures on actual patients. Competent needling skills are crucial for successful regional anesthesia procedures and have been identified as one of the most important components of USGRA training strategies (Niazi et al., 2012). This investigation used a part-task training strategy (US-guided needling) for the skill investigated.

If retention and transferability of skills to the clinical setting require more practice time, health science research should also focus on the efficacy of additional training strategies that can be accomplished outside the simulation environment. Mental imagery training is an effective strategy for many psychomotor skills training programs in sports, music, medicine, psychology, and education (Schuster et al., 2011). In the past several decades, health science educational researchers have found mental imagery techniques are effective skill learning strategies, especially in surgery (Rao et al., 2015). Mental imagery training shows promise for psychomotor skill learning in USGRA.

**Mental Imagery Training.** Mental imagery of a skill (also referred to as motor imagery) is the cognitive rehearsal of a movement within WM without the appropriate perceptual input and in the absence of overt movement (Collet & Guillot, 2010; Munzert, Lorey, & Zentgraf, 2009). In a randomized control trial, Eldred-Evans and colleagues (2013) found that adding mental imagery training to a laparoscopic skills training produced the highest precision, accuracy, and performance scores when compared with either no additional training or virtual-reality training. A recent meta-analysis of randomized control trials (RCTs) that included mental imagery training found a mixed impact of this type of training for surgical skill acquisition (Rao et al., 2015). Several of the studies included in the meta-analysis proposed that there was no difference in performance when using mental practice or physical practice and offers insight into the effectiveness of mental practice strategies (Arora et al., 2011; Eldred-Evans et al., 2013; Immenroth et al., 2007; Sanders et al., 2008). In a study comparing mental imagery techniques with textbook learning, even though performance after mental training was equally as effective as textbook training, the respondents expressed that the mental practice helped them feel more confident to perform the skills than common textbook training (Geoffrion et al., 2012). In several studies, researchers concluded that mental imagery techniques may be cost-effective alternatives to physical practice in simulation training (Arora et al., 2010; Arora et al., 2011; Eldred-Evans et al., 2013; Sanders et al., 2008).

Only two randomized investigations were found in the anesthesia literature. Lim et al. (2016) found no significant difference in acquiring epidural anesthesia skills between learners using mental imagery techniques or low-fidelity simulation training. These researchers concluded that MI training may be as effective as simulation training to learn epidural anesthesia skills. In another randomized controlled trial, Hayter and colleagues (2013) found that participants' performance in a simulated crisis management scenario did not significantly improve after using mental imagery techniques when compared to traditional training. The negative impact of using MI in this study may be related to the design of this study and the metrics used by the researchers (Moppett & Sevdalis, 2013). Crisis management skills are dissimilar to procedural skills and MI training interventions may not be as effective with these types of skills.

The effectiveness of mental imagery training strategies is based on the results of extensive brain imaging research. One study, showing brain region activation in participants learning tasks with mental imagery, showed similar brain activations when compared with participants who physically performed the task (Allami et al., 2014). Additionally, brain imaging research showed that participants using mental imagery to practice a task experienced similar learning-related neuroplastic changes when compared to participants who used physical practice to acquire a skill (Patel et al., 2013). The results of these studies support the principle of functional equivalence when using MI or physical practice. Functional equivalence may indicate that using MI to learn USGRA skills is similarly effective as physical practice. Mental imagery cannot be directly observed as it encompasses internal cognitive processes without overt physical movement. The aforementioned studies by Allami et al. (2014) and Patel et al. (2013) supported the principle that MI practice activates many of the same brain regions and causes similar neuroplastic changes as physical practice, which may indirectly measure the process of MI. Other indirect measures are the self-report of mental imagery use by the individual and improved performance of a skill after using these techniques. Mental imagery practice cannot be used as the sole practice strategy to develop a skill and should be combined with some physical practice to correct erroneous schemata formation. In a randomized controlled study, researchers discovered that mental imagery techniques as the sole practice strategy showed poor results in skill development and suggested that MI techniques should be combined with physical practice (Mulla et al., 2012).

In summary, providing safe and competent health care requires practitioners to develop many simple, as well as, many highly technical psychomotor skills during training and into their careers as novel procedures are introduced into the profession. The area of simulation research is growing to show simulation-based skill development improves skill learning prior to actual patient contact. Unfortunately, the current research evidence does not completely support the retention and transferability of skills from the SLE to clinical practice. In the past few decades, educational researchers have expanded our understanding of skill development based on principles of the cognitive load theory and the neurophysiological foundations of information processing and learning. The ultimate goal of learning should be to construct robust schemata that can be readily accessed and run automatically to competently perform the skill with sufficient working memory processing reserve to manage additional unique information common in the performance of skills in the clinical setting. Optimal skill evaluation during training should assess the learner's use of these automated schemata using additional assessments of cognitive load such as secondary tasks, physiological measures, and/or subjective questionnaires. This current research proposal sought to uncover the foundations of SLE design paradigms that allow the optimal skill training in nurse anesthesia education, including the transferability of skill competency to actual patient care.

In view of the access limitations to the SLE, learners' may not adequately construct robust skill schemata. Additional skill learning techniques should be sought that may extend skill learning outside the simulation environment. Mental imagery practice strategies have been effectively utilized in many different aspects of skill development, including sports, music, and just recently, in health professions education. There is still insufficient empirical evidence to conclude that mental imagery strategies are similarly effective as physical practice to acquire, retain, and transfer highly technical skills such as ultrasound-guided needling skills. This study proposed to expand the current research in skill development using mental imagery techniques.

**Research Design**

An experimental design, using a pre- and posttest, guided the conduct of this pilot study. Students enrolled in a single nurse anesthesia program were asked to participate in the study. Participants were initially trained in basic ultrasound imaging and then evaluated on an ultrasound-guided needling skill (pre-test). Volunteers were randomly allocated to either a control group using physical practice strategies (PP) or an experimental group using mental imagery practice strategies (MI). The experimental group was given instruction of a unique skill development technique (MI) and the control group used conventional physical practice to develop the skill. At the end of the skill development period (SDP), both groups were re-evaluated performing the skill again incorporating a secondary task to assess primary skill learning (post-test). This experimental design explored the relationship between the type of skill practice used and the skill learning process.

A convenience sample of students from a nurse anesthesia program from the southern region of the United States were invited to participate in the study. This nurse anesthesia program is a 27-month program admitting 34 new students yearly. Graduating students receive a master's degree and are qualified to take a national certifying exam to become Certified Registered Nurse Anesthetists (CRNAs). The newly matriculated students were invited to participate in this investigation via e-mail during the first quarter of the program. At this point in the program, they had not yet engaged in any advanced skill training in the simulation learning environment. Using student nurse anesthetists in an educational setting permitted the introduction of a novel skill training experience in a simulation environment that controlled for other variables such as prior experience with highly-technical skill development techniques and procedures and to eliminate potential harm to patients. The admissions criteria for nurse anesthesia programs are mandated by a governing counsel for accrediting nurse anesthesia programs, thus, a sample from one program was likely to be fairly representative of student registered nurse anesthetists (SRNAs) from other programs. Admission criteria for the program constituted the inclusion criteria. All students are required to be bachelor's degree prepared registered nurses with a minimum of one year of critical care experience. Exclusion criteria included students that have used or taught in-plane ultrasound imaging techniques. The skill to be developed is a crucial anesthesia skill that should eventually be mastered as an anesthesia provider. Needle direction using ultrasound (US) imaging is a highly-technical skill and is required to competently perform all ultrasound-guided procedures, including diagnostic and US-guided regional anesthesia (USGRA) procedures. In the current curriculum, this skill is introduced during the third quarter and slowly developed as students practice simulated nerve block procedures during subsequent simulation experiences and in the clinical setting. The skill of directing a needle towards an embedded target in simulated tissue with US imaging is introduced and practiced as a single skill, but not formally evaluated in the program. This may partially mitigate the concern with high-stakes test anxiety in the study.

A power analysis for the main outcome of group differences in TTC was conducted by the researchers for this study using Cohen's two-step power analysis approach using a power of .80, an alpha of .05, and a medium effect size (Green, 1991). Cohen (1988) suggested using a medium effect size for typical behavioral sciences studies. Sanders et al. (2008) observed a medium effect size in their study looking at the differences between MI and PP in skill development. Initially, a lambda (*L)* was calculated using the following equation for an $m < 10$:

$$L = 6.4 + 1.65m - 0.05m^2 \ (m = \text{number of variables})$$

The initial calculation of the 2 variables (time-to-complete and practice strategy, see Table 1) in this study yielded the following calculation: $L = 6.4 + 1.65(2) - 0.05(2^2) = 9.5$

$$f^2 = R^2/1\text{-}R^2 = .13/1\text{-}.13 = .15$$

$$N = L/f^2 = 9.5/.15 = 63.33\ (64)$$

Using a medium effect size (.13), the Cohen's $f^2$ equaled .15. Using the lambda and $f^2$ values in the second equation suggested that a sample size of 64 participants would be needed for this study. Historically, students in this program have all volunteered to participate in previous research studies. However, given the pool of approximately 34 students, this study will be underpowered, and was best considered a pilot investigation. In addition, a post hoc power calculation will be conducted and reported to guide future studies in this area.

**Study Procedures**

**Enrollment.** An invitation and subsequently a consent form was sent to all student registered nurse anesthetists (SRNAs) by e-mail (for invitation and consent forms, see Appendices A and B). Students desiring to participate in the study were directed to contact the program administrative assistant by email. Participants were given an information packet containing study information, a demographics form, and a consent form to be signed and returned to the administrative assistant. A unique identification number was assigned to each volunteer for data entry purposes. The participants were instructed to keep the number private throughout the study and use the number only when filling out forms used during the study. This special number and the participant's name were secured in a locked file cabinet in the administrative assistant's office (see Figure 1, for Participant flow through the quantitative study). This identifying information was not available for any of the researchers to assure blinding of the investigators.

**Overview of Study.** All participants received basic US imaging principles and techniques in a two-hour lecture. Next, all participants were given instruction on the skill (primary task) to be developed and procedural practice during a demonstration and practice session. Simulation lab faculty expert in USGRA techniques provided feedback to participants during the initial skill practice session. Each participant was allowed to practice guiding a nerve block needle in the phantom tissue block to contact two simulated nerves and one blood vessel under US guidance. Once successful needle contact with the three targets was made, two timed skill performance tests (pre-tests) were conducted. The instructor informed the participant to perform the procedure as accurately as possible, to not advance the needle unless the needle tip is visualized on the US machine, and that the procedure would be timed. Next, the participants were asked to perform the skill again with the addition of a secondary task that must be performed at the same time. The secondary task was to remember the number and locations of additional embedded structures in the tissue block while performing the primary needling skill and report the number and locations on a form after finishing the task. Participants were instructed that their primary effort was to perform the US-needle guidance (primary task) as quickly and accurately as possible; remembering the numbers and locations of the additional structures was to be secondary to performing the primary task. The time in seconds for both tests, along with the participant's identification number were placed on a scoring form and given to the program administrative assistant to be entered into an electronic database (EXCEL file) under the variable "PreTTC". A secondary task score (PreSecTask) during the second test was generated from a secondary task report form and entered into the database by the administrative assistant. (see Measures section and Table 1 for study variables information).

Participants were then randomly allocated to an MI or PP group. The randomization and allocation concealment procedure was administered by the administrative assistant using the sequentially numbered, opaque sealed envelopes (SNOSE) method as described by Doig and Simpson (2005). The study administrative assistant received training for the randomization and allocation concealment procedures as well as study data entry. As random allocation of the subjects occurs after the pretest, the instructors and participants were blinded to the group allocation.

Once all the participants finished the instruction and the pretest, participants were sent, via email, a training packet with a practice schedule describing how and when the participant would practice the skill during the following three-week period according to the randomized group allocation. The practice schedule was designed not to conflict with scheduled courses or with scheduled exams. Additional practice times were offered for participants who were unable to make scheduled practice times. All physical practice sessions were pre-arranged and conducted in the simulation center without instructors present. Participants were asked to keep a personal log of the time and date of each practice session along with the time spent and the number of repetitions they accomplished (see Figure 2, Flowchart of skill development period). The MI group was instructed that they could practice on their own in a quiet location without any distractions for a 30-minute period of time. These instructions were explicit in detailing the importance of using only 30-minutes. Both groups were instructed not to practice (physically or mentally) the procedure outside of the scheduled practice times given to them in the instructions. After the last practice session, each participant was scheduled for two timed post-tests performing the primary task alone and a second time that would include the primary and secondary task. The post-test times and the secondary task score were entered into the database as “PostTTC/PostTTC2” and “PostSecTask”, respectively. Again, the evaluators were blinded to the practice type group of the participant for the post-test. A form indicating the time (in seconds and hundredths seconds), the secondary task score, and the participants’ ID number was given to the administrative assistant in charge of data entry. The difference in the pre-test time and the post-test time was calculated to provide the value for the “DIFFTTC/DIFFTTC2” variables.

## Experimental and Control Groups

**Mental imagery group (MI, experimental group).** Once participants had been randomly allocated to this group, the administrative assistant informed them of a skill practice training module available on the student learning network, through which MI techniques were discussed by a clinician expert in MI techniques. The mental imagery training included pre-imagery relaxation, first- versus third-person imaging, evaluating MI abilities, and a practice MI session using the script created by an anesthetist expert in using MI techniques during USGRA learning (see Appendix E for a partial example of the script). Following this training session, the experimental group were instructed to use MI techniques to practice the procedural skill during the skill development period (SDP), which was temporally congruent with the PP group. Participants were instructed to practice the procedure in a quiet location using MI techniques for 30 minutes, two times a week for three weeks. This practice schedule followed the suggested practice timing by Barrington, Wong, Slater, Ivanusic, and Ovens (2012) and Sanders et al. (2008). Audiotaped MI scripts (MP3 or WAV4 files), following the script development procedures described by Arora et al. (2010) and Ignacio et al. (2016), could be played through headphones on the participant’s smart phone or other electronic device during the MI practice sessions. Participants were allowed to listen to the MI scripts as many times as desired during the 30-minute practice sessions. Mental imagery practice without any physical practice has shown poor results (Mulla et al., 2012). For this reason, the MI group was instructed to physically practice the procedure only one time on the simulated tissue during the 2nd and $4^{th}$ training sessions during skill development period to correct any mental representation errors that may have occurred during imagery practice (see Figure 2, for flowchart of the skill training period). After physically practicing the skill once, the remainder of the practice time would be used for mental practice. These physical practice sessions were scheduled to not overlap with the physical practice group practice times. Participants were instructed that they could consult text references during and in-between practice sessions. All participants were informed of the importance of avoiding discussion of their practice strategies with the other participants and explicitly instructed to avoid any discussion.

**Physical practice group (PP, control group).** The PP group utilized common physical practice techniques to practice the needling skill during the SDP. The participants had access to the simulation center on their own and were given access to an US machine, block needle, and the simulated nerve block tissue and allowed to practice the procedure as many times as desired during the scheduled 30-minute training sessions (see Figure 2, for flowchart for skill development period). Each participant was instructed to keep a practice log indicating the time and date of their practice session as well as the length of time (limited to 30 minutes) and the number of repetitions they completed during each session. No instructor or peer feedback was given during the SDP practice sessions. The participants were instructed they could consult text references during and in-between practice sessions. Both groups were instructed not to watch videos of any ultrasound-guided procedures during the SDP, as observational learning could be an additional skill learning technique useful in skill development (Holmes & Calmels, 2008).

## Measures

**Main outcome measure – Time-to-complete (TTC).** Each participant's performance at two pre-tests (PreTTC and PreTTC2) and two post-tests (PostTTC and PostTTC2) were timed in minutes and hundredth seconds using a timing application on a smart phone. The conceptual definition of the TTC score in this study was the time required for a participant to guide a needle to touch three simulated targets in a tissue block using ultrasound guidance. The operational definition of this variable was the time in seconds for a participant to place a block needle into a phantom tissue block, separately touch three embedded simulated targets under continuous ultrasound visualization, and remove the block needle from the tissue. Scoring for this continuous variable was from 1 to 500 seconds. At 500 seconds, the participant was asked to stop the testing. The observer started the timer when the participant placed the block needle on the tissue block and indicated the readiness to begin the task. The observer pressed the stop button when the needle was removed from the phantom. Each testing event was videotaped using a video-recording system (CAE Learning Space) only to serve as a backup recording of each test in case of a failure of the phone application timer. The camera was focused only on the tissue block and the ultrasound machine so the participant's identity was blinded to the video observer. This video system has a built-in timer that was used for timing the procedure. Both first and second trials of pre- (PreTTC and PreTTC2) and post-tests (PostTTC and PostTTC2) scores for each participant were converted into seconds and hundredths seconds and placed in the database from which the outcome measures (DIFFTTC and DIFFTTC2) were calculated.

**Cognitive Load Measures**

***Secondary task.*** Adding a secondary task to the primary task performance is an effective method to objectively measure the cognitive load of the performer to assess skill learning (Park & Brunken, 2018; Rojas, Haji, Shewaga, Kapralos, & Dubrowski, 2014). Learners that have automatized a skill will use less WM resources when performing the skill and should not be affected when simultaneously performing a secondary skill (Stefanidis, Scerbo, et al., 2007). These authors also described the optimal characteristics of the secondary task. The characteristics include sensitivity, selectivity, and unobtrusiveness (Stefanidis, Scerbo, et al., 2007). Participants performed the testing twice at each pre- and post-test event. The first trial testing was to perform the primary task by itself. A second trial testing added a secondary task to the primary task. To introduce a secondary task during both the second pre- and post-tests of this study, several additional echogenic structures were embedded into a second phantom tissue block and used for the second pre- and post-tests. The tissue blocks used for practice did not contain any additionally embedded structures. The secondary task score was an objective measure of a participant’s ability to attend to a secondary task of identifying and remembering the numbers and locations of additional embedded structures while simultaneously performing the primary task of US-guided needling. The operational definition of the secondary task score was the self-report by the participant of the number of additional embedded structures and their location in relation to the target nerves and/or blood vessels. This secondary task required the learner to allocate attentional WM resources to remember the numbers and locations of these additional structures. It was hypothesized that performers who had not automatized the primary skill would have prolonged times-to-complete (TTC) the primary task due to the need to attend not only to the secondary task but also parts of the primary task. Prolonged TTC scores at the post-test would result in smaller DIFFTTC values compared to performers that used automatized skills and had smaller post-test times. During the second pre- and post-tests, the performer reported to the observer the number and locations of the additional targets after timing of the skill had stopped. An initial secondary task test was given to the participant at the end of the initial training period during the second pre-test (Trial 2) to serve as a baseline measure and entered into the database as “PreSecTask”. The results of the secondary task during the second post-test (Trial 2) was entered into the database (PostSecTask). Scoring for the secondary task was the total number of correct responses (number of additional targets counted [total of five] plus number of correct locations of additional targets [total of five] for a combined total score of 10 points). Any responses reporting numbers greater than five were subtracted from total score. It was hypothesized that a low score would indicate the participant had difficulty attending to the secondary task while performing the primary task. A high score would indicate that the participant was easily able to attend to the secondary task while performing the primary task. Each tissue block used during the second pre- and post-testing events had identical numbers and locations of the additional targets to assure equivalence of secondary task difficulty with all participants (see Figure 4 for a schematic of the embedded structures in the phantom tissue blocks).

***NASA-Task Load Index score.*** The NASA-Task Load Index (NASA-TLX) is a subjective, self-report assessment of perceived cognitive load during the performance of a task that was used in this study to determine more accurate evaluation of mental workload during the testing events. The NASA-TLX was developed and psychometrically evaluated by Hart and Staveland (1988). These authors and Nygren (1991) validated this instrument which has been widely used in flight simulation, air traffic control studies (Metzger & Parasuraman, 2005), task automation (Endsley & Kaber, 1999), and recently in laparoscopic surgery (Yurko et al., 2010). This instrument is a self-report questionnaire that uses a 20-point visual analog scale for six subscales of mental workload (see Appendix F). The questionnaire was given to all participants after the pre- and post-tests. The operational definition for the NASA-TLX was the participant self-rating, via a questionnaire, of their perceived mental, physical, and temporal workload of the task just accomplished. In addition, the respondents self-rated their performance to successfully accomplish the task, their effort to accomplish their level of performance, and their level of frustration at accomplishing the task. The sum of all six subscales created an overall workload score (6-120) and was entered into the database as a task load index score (TLX). A low score indicated the participant did not invest much mental effort in completing the task. A high score indicated the participant perceived that the task required a very large investment of mental workload to accomplish the task and had a high level of frustration in completing the task.

***Paas Scale Score.*** The Paas Scale is another subjective, self-report assessment of perceived mental workload experienced during the performance of a task developed by Fred G. Paas (1992). The operational definition was the participant's self-rating of their perceived level of mental effort required to complete the task. It asks a single question with rating levels from 1 (very, very low mental effort) to 9 (very, very high mental effort) (see Appendix G). Paas (1992) reported that previous versions of this scale had high Spearman rank order correlations (.9) when compared to objective measures of task difficulty and that subjective measures of task difficulty have very high face validity. This questionnaire was also administered to each participant at the time of pre- and post-testing as a secondary assessment of mental effort required to perform the skill. The score (1-9) was entered into the database as the Paas score (Paas). A low score indicated the participant did not invest much mental effort in completing the task. A high score indicated the participant perceived that the task required a very large investment of mental workload to accomplish the task.

**Data Analysis**

To describe the sample, the researchers initially used descriptive statistics (mean, standard deviation, frequencies, and percentages) to represent the selected characteristics (age, gender, race/ethnicity, years of nursing practice, and video gaming experiences). To determine homogeneity of the two groups, chi-square or Fisher's exact tests depending on the normality of the data, were calculated on each of the characteristics.

After analyzing the data for normality, several statistical analyses were conducted. For Aim 3, the first question to be answered by this research is if there is was improvement in skill performance, as measured by the TTC of the skill when engaging in a 3-week training program using mental imagery or physical practice strategies. Paired *t*-tests determined if there was a significant with-in group improvement in the "time-to-complete" the skill by comparing the first pre- and post-test scores in each group. The second question of aim 3 will seek to determine if there were significant between-group differences in skill development, as measured by TTC scoring differences. This analysis was done using independent t-tests to analyze if there was a difference in the outcome variable, using the difference of the scores of the first pre- and post-tests (TTC diff), between the physical practice (PP) group versus the mental imagery (MI) group. In this study, a lack of significant difference in time-to-complete scores between the control and experimental groups may have indicated that MI training strategies could be effective alternatives to prolonged physical skill practice in the simulation center. For Aim 4, researchers sought to determine if secondary task scores changed over the course of the training period. Again, paired *t*-tests determined significant pre- to post-test changes within each group. This investigation also sought to determine if there is a significant difference in mental workload during the simultaneous performance of a primary and secondary task when using mental imagery versus physical practice strategies. Using secondary task scores, independent t-tests were used to compare any difference between the two practice groups. Researchers also sought to know how much of the variance in the primary task, as measured by TTC, was explained by the type of practice strategy or by the addition of a secondary task while performing the primary task? The difference in the pre- and post-test secondary task scores will be used to calculate the DIFFSecTask value. Multivariate regression analysis, using the outcome variable (TTC), and the two independent variables of practice type (PP and MI) and secondary task scores, was used to describe the amount of variance of the outcome variable explained by each independent variable.

To determine the degree of relationship between different subjective and objective measures of mental effort required to accomplish the tasks, product-moment correlation analysis (Pearson r) was used to examine the relationships between the secondary task (SecTaskpost), Paas scale (Paas), and NASA-TLX (TLX). These correlation analyses generated additional empirical evidence for convergent validity of the measures of cognitive load. Additionally, researchers used scatter plots and a contingency table to describe the degree of association that exists between the outcome variable and the independent variables. Results of all analyses were considered statistically significant at the level of $p < .05$.

**Human Subjects Considerations**

The recruitment and enrollment of participants in the study did not occur until the Midwestern University (MWU) Institutional Review Board (IRB) had approved the investigation. The University of Kansas Medical Center (KUMC) IRB was also consulted to determine if an external IRB (MWU IRB) approval would suffice for this study. Once approval was given, the participants were sent a letter of invitation to participate in the study (see Appendix A) describing the purpose of the study and some of the procedures. If a student elected to participate, a consent form and a demographic questionnaire was e-mailed to the student (see Appendices B and C, respectively) with instructions to return it to the administrative assistant. From this point forward in the study, all personal information and research data was securely maintained in a locked cabinet and on a password protected computer. Only the administrative assistant had access to the personal identifying information. The data collected during the study was accessible to the investigators and the administrative assistant.

Participants were offered food and drinks after testing times in appreciation for their participation.

**Time Frame**

This investigation began during the summer quarter (June – August), 2018, at Midwestern University. The IRB application was submitted to the Office of Research and Scientific Investigation at Midwestern University during the middle part of May 2018, with expected approval by the end of May or early June 2018. A request to use an external IRB was submitted to the KUMC IRB. Once approval was granted, recruitment letters were e-mailed to the incoming students. The ultrasound instructional component and pre-testing was accomplished within two weeks. Participants had a three-week practice period, immediately followed by post-testing. It was proposed that the collection of data for this study would be finished by the middle to late August 2018. Data analysis began immediately thereafter.

**Scope of Manuscripts**

This research proposal intended to explore three important facets of the design of the simulation learning environment (SLE) that may help to ensure optimal skill development that may translate into competent patient care. These facets were disseminated in three manuscripts focusing on 1) designing the SLE that facilitates learner engagement, 2) exploring the neurophysiological basis of psychomotor skill development to inform effective SLE design, and 3) exploring the use of mental imagery (MI) to extend learning outside the simulation center to facilitate psychomotor skill development and performance.

**Facilitating learner engagement through simulation design.**

The purpose of the first manuscript (Fisher, 2016) was to review design characteristics of the simulation learning environment that foster learner engagement in the learning process. In this manuscript, I described principles of reflection, emotion and stress, reception, and integration and assimilation as important principles of simulation learning. Next, I proposed an Active Engagement Model consisting of the learner, the educator, and the SLE as components of the learning environment that need to be addressed in simulation design. The most critical component in that design is the creation of the Educator/Learner Dyad which maintains and supports all other aspects of the SLE. This paper, written as an exploration into concerns about student difficulties in simulation learning and testing, was a composite of content from education minor courses and an extensive literature review of simulation learning. The manuscript was published in the *Journal of Nursing Education and Practice* in March of 2016.

**Exploring the neurophysiology of skill learning.**

In the second manuscript (currently being revised prior to submission for publication) I explored the skill learning literature to describe the process of skill development in the simulation environment based on skill acquisition models (Dreyfus/Benner model) and the neurophysiology of skill learning. The Dreyfus/Benner model of skill acquisition describes five stages through which a learner may pass as skills are developed. The beginning learner starts at a novice stage and may progress through the advanced beginner, competent, proficient, and expert stages depending on the learning strategies employed by the learner. In pre-clinical training, the beginning learner may achieve the competent stage. The process of skill development is then explored using extensive research in the cognitive load theory. The premise of true skill learning is founded on the creation of robust long-term memories (schemata) through rehearsal of the skill over time. The learning process and performance of a skill depends on the learner's ability to manage the cognitive load placed on working memory. If the cognitive load is overwhelmed by needing to simultaneously process too many informational elements, learning and performance will be impeded. I explored design components of the SLE that may maximize the cognitive load during skill learning and performance. This manuscript was the product of a minor paper requirement for the School of Nursing and is currently being revised with the plan to submit to the *Journal of the Society for Simulation in Healthcare*. I am the sole author of this manuscript.

**Exploring the efficacy of mental imagery strategies to develop skills.**

The final manuscript described the results of a novel pilot study comparing outcomes in two groups using either mental imagery or physical practice strategies to learn and perform a complex anesthetic skill (ultrasound-guided needling) during a three-week training period in newly-matriculated student nurse anesthetists. This study also looked at the impact of using a secondary task to explore the level of skill learning during this same training period. The complete description of this study was presented in this dissertation. I am the primary author and Dr. Karen Wambach is co-author. I plan to submit this paper also to the *Journal of the Society for Simulation in Healthcare.*

## Summary

This pathway of inquiry into skill learning in the simulation learning environment may better inform simulation educators of the important components of the SLE and instructional strategies that engage learners in this unique learning environment with the goal of optimizing true skill learning. By using design principles directed at creating an effective educator/learner association, the educator can foster learner engagement in the learning experience. Additionally, as educators understand the neurophysiological foundations of skill learning and performance, they can create learning experiences in the simulation environment that facilitate construction of robust schemata of procedural skills that are relatively permanent. In view of the gap in the literature supporting transferability of skills from the training environment to the clinical setting, we introduced a secondary task during skill assessment to determine if the practice skill had been automatized. And finally, due to the limitations of access to the SLE, we also explored the efficacy of using mental imagery techniques that may extend the simulation learning experience outside the simulation center for novice learners. Most importantly, by exploring skill learning in the simulation environment, this research pathway may help fill the gap in understanding of how the learner may translate skill acquisition in the SLE to the patient bedside.

**References**

Al-Ghareeb, A., & Cooper, S. J. (2016). Barriers and enablers to the use of high-fidelity patient simulation manikins in nurse education: An integrative review. *Nurse Education Today, 36,* 281-286. doi:10.1016/j.nedt.2015.08.005

Aldekhyl, S., Cavalcanti, R. B., & Naismith, L. M. (2018). Cognitive load predicts point-of-care ultrasound simulator performance. *Perspectives in Medical Education*. doi:10.1007/s40037-017-0392-7

Allami, N., Brovelli, A., Hamzaoui, E. M., Regragui, F., Paulignan, Y., & Boussaoud, D. (2014). Neurophysiological correlates of visuo-motor learning through mental and physical practice. *Neuropsychologia, 55*, 6-14. doi:10.1016/j.neuropsychologia.2013.12.017

Arora, S., Aggarwal, R., Sevdalis, N., Moran, A., Sirimanna, P., Kneebone, R., & Darzi, A. (2010). Development and validation of mental practice as a training strategy for laparoscopic surgery. *Surgical Endoscopy, 24*, 179-187. doi:10.1007/s00464-009-0624-y

Arora, S., Aggarwal, R., Sirimanna, P., Moran, A., Grantcharov, T., Kneebone, R., . . . Darzi, A. (2011). Mental practice enhances surgical technical skills: A randomized controlled study. *Annals of Surgery, 253*, 265-270. doi:10.1097/SLA.0b013e318207a789

Ayres, P. (2018). Subjective measures of cognitive load. In R. Z. Zheng (Ed.), *Cognitive Load Measurement and Application* (pp. 9-28). New York: Routledge.

Baddeley, A. (2003). Working memory: Looking back and looking forward. *National Reviews, 4*, 829-839.

Bajunaid, K., Mullah, M. A. S., Winkler-Schwartz, A., Alotaibi, F. E., J, F., Baggiani, M., . . . Del Maestro, R. F. (2017). Impact of acute stress on psychomotor bimanual performance during a simulated tumor resection task. *Journal of Neurosurgery, 126*, 71-80. doi:10.3171/2015.5.JNS15558

Baker, B. G., Bhalla, A., Doleman, B., Yarnold, E., Simons, S., Lund, J. N., & Williams, J. P. (2017). Simulation fails to replicate stress in trainees performing a technical procedure in the clinical environment. *Medical Teacher, 39*(1), 53-57. doi:10.1080/0142159X.2016.1230188

Barrington, M. J., Viero, L. P., Kluger, R., Clarke, A. L., Ivanusic, J. J., & Wong, D. M. (2016). Determining the learning curve for acquiring core sonographic skills for ultrasound-guided axillary brachial plexus block. *Regional Anesthesia and Pain Medicine, 41*, 667-670. doi:10.1097/AAP.0000000000000487

Barrington, M. J., Wong, D. M., Slater, B., Ivanusic, J. J., & Ovens, M. (2012). Ultrasound-guided regional anesthesia: How much practice do novices require before achieving competency in ultrasound needle visualization using a cadaver model. *Regional Anesthesia and Pain Medicine, 37*, 334-339. doi:10.1097/AAP.0b013e3182475fba

Beal, M. D., Kinnear, J., Anderson, C. R., Martin, T. D., Wambolt, R., & Hooper, L. (2017). The effectiveness of medical simulation in teaching medical students critical care medicine: A systematic review and meta-analysis. *Simulation in Healthcare, 12*, 104-116. doi:10.1097?SIH.0000000000000189

Berkow, S., Virkstis, K., Stewart, J., & Conway, L. (2008). Assessing new graduate nurse performance. *The Journal of Nursing Administration, 38*, 468-474.

Buckley, C. E., Kavanagh, D. O., Traynor, O., & Neary, P. C. (2014). Is the skillset obtained in surgical simulation transferable to the operating theater? *The American Journal of Surgery, 207*, 146-157. doi:10.1016/j.amjsurg/2013.06.017

Bugdadi, A., Sawaya, R., Olwi, D., Al-Ahrani, G., Azarnoush, H., Sabbagh, A. J., . . . Del Maestro, R. (2017). Automaticity of force application during simulated brain tumor resection: Testing the Fitts and Posner Model. *Journal of Surgical Education, Article in Press*. doi:10.1016/j.jsurg.2017.06.018

Chen, X. X., Trivedi, V., AlSaflan, A. A., Todd, S. C., Tricco, A. C., McCartney, C. J. L., & Boet, S. (2017). Ultrasound-guided regional anesthesia simulation training: A systematic review. *Regional Anesthesia and Pain Medicine, 42*(6), 741-750. doi:10.1097/AAP.0000000000000639

Choi, H., van Merrienboer, J. J., & Paas, F. (2014). Effects of the physical environment on cognitive load and learning: Towards a new model of cognitive load. *Educational Psychology Reviews*, *26*, 225-244. doi:10.1007/s10648-014-9262-6

Collet, C., & Guillot, A. (2010). Autonomic nervous system activities during imagined movements. In A. Guillot & C. Collet (Eds.), *The neurophysiological foundations of mental and motor imagery* (pp. 95-108). Oxford: Oxford University Press.

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why? *Current Directions in Psychological Science, 19*(1), 51-57. doi:10.1177/0963721409359277

Debarnot, U., Sperduti, M., Di Rienzo, F., & Guillot, A. (2014). Expert bodies, expert minds: How physical and mental training shape the brain. *Frontiers in Human Neuroscience, 8*, 1-15. doi:10.3389/fnhum.2014.00280

Derakshan, N., & Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance. *European Psychologist*, *14*, 168-176. doi:10.1027/1016-9040-14-2-168

Doig, G. S., & Simpson, F. (2005). Randomization and allocation concealment: A practical guide for researchers. *Journal of Critical Care, 20*, 187-193. doi:10.1016/j..crc.2005.04.005

Dreyfus, S. E. (2004). The five-stage model of adult skill acquisition. *Bulletin of Science, Technology, & Society, 24*, 177-181. doi:10.1177/0270467604264992

Eldred-Evans, D., Grange, P., Cheang, A., Yamamoto, H., Ayis, S., Mulla, M., . . . Reedy, G. (2013). Using the mind as a simulator: a randomized controlled trial of mental training. *Journal of Surgical Education, 70,* 544-551. doi:10.1016/j.j.surg20013.04.003

Endsley, M. R., & Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. *Ergonomics, 42*, 462-492.

Fisher, R. (2016). Designing the simulation learning environment: An active engagement model. *Journal of Nursing Education and Practice, 6*(3), 6-14. doi:10.5430/jnep.v6n3p6

Geoffrion, R., Gebhart, J., Dooley, Y., Bent, A., Dandolu, V., Meeks, R., . . . Robert, M. (2012). The mind's scapel in surgical education: A randomized controlled trial of mental imager. *BJOG: An International Journal of Obstetrics and Gynaecology, 119*, 1040-1048. doi:10.1111/j.1471-0528.2012.03398.x

Grantcharov, T. P., & Reznick, R. K. (2008). Teaching procedural skills. *Bristish Medical Journal, 336*, 1129-1131. doi:10.1136/bmj.39517.686956.47

Griswold-Theodorson, S., Ponnuru, S., Dong, C., Szyld, D., Reed, T., & McGaghie, W. C. (2015). Beyond the simulation laboratory: A realist synthesis review of clinical outcomes of simulation-based mastery learning. *Academic Medicine, 90*, 1553-1560. doi:10.1097/ACM.0000000000000938

Haji, F. A., Rojas, D., Childs, R., de Ribaupierre, S., & Dubrowski, A. (2015). Measuring cognitive load: Performance, mental effort and simulation task complexity. *Medical Education, 49,* 815-827. doi:10.1111/medu.12773

Halsted, W. S. (1904). The training of the surgeon. *Bulletins of Johns Hopkins Hospital, 15,* 267-275.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload* (pp. 139-183). North-Holland: Elsevier Science Publishers B.V.

Hastings, R. H., & Rickard, T. C. (2015). Deliberate practice for achieving and maintaining expertise in anesthesiology. *Anesthesia and Analgesia, 120,* 449-459. doi:10.1213/ANE.0000000000000526

Hayter, M. A., Bould, M. D., Afsari, M., Riem, N., Chiu, M., & Boet, S. (2013). Does warm-up using mental practice improve crisis resource management performance? A simulation study. *British Journal of Anaesthesia, 110*, 299-304. doi:10.1093/bjs/aes351

Holmes, P., & Calmels, C. (2008). A neuroscientific review of imagery and observation use in sports. *Journal of Motor Behavior, 40*(5), 433-445.

Ignacio, J., Domans, D., Scherpbier, A., Rethans, J., Lopez, V., & Liaw, S. Y. (2016). Development, implementation, and evaluation of a mental rehearsal strategy to improve clinical performance and reduce stress: A mixed-methods study. *Nurse Education Today, 37,* 27-32. doi:10.1016/j.nedt.2015.11.002

Immenroth, M., Burger, T., Brenner, J., Nagelschmidt, M., Eberspacher, H., & Troidl, H. (2007). Mental training in surgical education: A randomized controlled trial. *Annals of Surgery, 245*(3), 385-391. doi:10.1097/01.sla.0000251575.95171.b3

Jeannerod, M. (1994). The representing brain: Neural correlates of motor intention and imagery. *Behavioral and Brain Sciences, 17*, 187-245.

Kalyuga, S., & Singh, A. (2016). Rethinking the boundaries of cognitive load theory in complex learning. *Educational Psychology Reviews, 28*, 831-852. doi:10.1007/s10648-015-9352-0

Kantak, S. S., & Winstein, C. J. (2012). Learning-performance distinction and memory processes for motor skills: A focused review and perspective. *Behavioral Brain Research, 228*, 219-231. doi:10.1016/j.bbr.2011.11.028

Kirlik, A. (2010). Brunswikian theory and method as a foundation for simulation-based research in clinical judgment. *Simulation in Healthcare, 5*, 255-259. doi:10.1097/SIH.0b013e3181fi2f03

Kohn, L. T., Corrigan, J., & Donaldson, M. S. (2000). *To err is human: Building a safer health system*. Washington, D.C.: National Academy Press.

Leff, D. R., Orihuela-Espina, F., Atallah, L., Athanasiou, T., Leong, J. J. H., Darzi, A., & Yang, G. (2008). Functional prefrontal reorganization accompanies learning-associated refinements: A manifold embedding approach. *Computer Aided Surgery, 13*, 325-339. doi:10.3109/10929080802531482

Lim, G., Krohner, R. G., Metro, D. G., & Rosario, B. L. (2016). Low-fidelity haptic simulation versus mental imagery training for epidural anesthesia technical achievement in novice anesthesiology residents: A randomized comparative study. *Anesthesia and Analgesia, 122*, 1516-1523. doi:10.1213/ANE.0000000000001260

Marcus, H., Vakharia, V., Kirkman, M. A., Murphy, M., & Nandi, D. (2013). Practice makes perfect? The role of simulation-based deliberate practice and script-based mental rehearsal in the acquisition and maintenance of operative neurosurgical skills. *Neurosurgery, 72*, A124-A130. doi:10.1227/NEU.0b013e318270d010

Marhofer, P., & Chan, V. W. S. (2007). Ultrasound-guided regional anesthesia: Current concepts and future trends. *Anesthesia and Analgesia*, *104*, 1265-1269. doi:10.1213/01.ane.0000260614.32794.7b

Mayer, R. E. (2010). Applying the science of learning to medical education. *Medical Education, 44*, 543-549. doi:10.1111/j.1365-2923.2010.03624.x

McConnell, M. M., & Eva, K. W. (2012). The role of emotion in the learning and transfer of clinical skills and knowledge. *Academic Medicine, 87*, 1316-1322. doi:10.1097/ACM.0b013e3182675af2

McGaghie, W. C., Issenberg, S. B., Cohen, E. R., Barsuk, J. H., & Wayne, D. B. (2011). Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. *Academic Medicine, 86*, 706-711. doi:10.1097/ACM.0b013e318217e119

McGaghie, W. C., Issenberg, S. B., Petrusa, E. R., & Scalese, R. J. (2010). A critical review of simulation-based medical education research: 2003-2009. *Medical Education, 44*, 50-63. doi:101111/j.1365-2923.2009.03547.x

Metzger, U., & Parasuraman, R. (2005). Automation in future air traffic management: effects of dicision aid reliability on controller performance and mental workload. *Human Factors, 47,* 35-49.

Moppett, I., & Sevdalis, N. (2013). From pilots to Olympians: Enhancing performance in anaesthesia through mental practice. *British Journal of Anaesthesia, 110*, 169-172. doi:10.1093/bja/aes472

Mulla, M., Sharma, D., Moghul, M., Kailani, O., Dockery, J., Ayis, S., & Grange, P. (2012). Learning basic laparoscopic skills: A randomized controlled study comparing box trainer, virtual reality simulator, and mental training. *Journal of Surgical Education, 69,* 190-195. doi:10.1016/j.jsurg.2011.07.011

Munzert, J., Lorey, B., & Zentgraf, K. (2009). Cognitive motor processes: The role of motor imagery in the study of motor representations. *Brain Research Reviews, 60*, 306-326. doi:10.1016/j.brainresrev.2008.12.024

Naismith, L. M., Cavalcanti, R. B., & Haji, F. A. (2018). Measuring cognitive load in medical and health professions simulation training. In R. Zheng (Ed.), *Cognitive Load Measurement and Application: A Theoretical Framework for Meaningful Research and Practice* (pp. 167-183). New York: Routledge.

Niazi, A. U., Haldipur, N., Prasad, A. G., & Chan, V. W. (2012). Ultrasound-guided regional anesthesia performance in the early learning period: Effect of simulation training. *Regional Anesthesia and Pain Medicine, 37*(1), 51-54. doi:10.1097/AAP.0b013e31823dc340

Nygren, T. E. (1991). Psychometric properties of subjective workload measurement techniques: implications for their use in the assessment of perceived mental workload. *Human Factors, 33*, 17-33.

Paas, F., & Ayres, P. (2014). Cognitive load theory: A broader view on the role of memory in learning and education. *Educational Psychology Reviews*, *26*, 191-195. doi:10.1007/s10648-014-9263-5

Paas, F. G. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: a cognitive. *Journal of Educational Psychology, 84*(4), 429-434.

Park, B., & Brunken, R. (2018). Secondary task as a measure of cognitive load. In R. Z. Zheng (Ed.), *Cognitive Load Measurement and Application* (pp. 75-92). New York: Routledge.

Patel, R., Spreng, R. N., & Turner, G. R. (2013). Functional brain changes following cognitive and motor skills training: A quantitative meta-analysis. *Neurorehabilitation and Neural Repair, 27*, 187-199. doi:10.1177/1545968312461718

Prabhu, A., Smith, W., Yurko, Y., Acker, C., & Stefanidis, D. (2010). Increased stress levels may explain the incomplete transfer of simulator-acquired skill to the operating room. *Surgery, 147*, 640-645. doi:10.1016/j.surg.01.007

Qiao, Y. Q., Shen, J., Liang, X., Ding, S., Chen, F. Y., Shao, L., . . . Ran, Z. H. (2014). Using cognitive theory to facilitate medical education. *BMC Medical Education, 14,* 7.

Ramlogan, R., Manickam, B., Chan, V. W., Liang, L., Adhikary, S. D., Liguori, G. A., . . . Brull, R. (2010). Challenges and training associated with the practice of ultrasound-guided regional anesthesia: A survey of the American Society of Regional Anesthesia and Pain Medicine. *Regional Anesthesia and Pain Medicine, 35*, 224-226.

Rao, A., Tait, I., & Alijani, A. (2015). Systematic review and meta-analysis of the role of mental training in the acquisition of technical skills in surgery. *The American Journal of Surgery, 210*, 545-553. doi:10.1016/j.amjsurg.2015.01.028

Reznick, R. K., & MacRae, H. (2006). Teaching surgical skills: Changes in the wind. *New England Journal of Medicine, 355*, 2664-2669.

Rojas, D., Haji, F. A., Shewaga, R., Kapralos, B., & Dubrowski, A. (2014). The impact of secondary-task type on the sensitivity of reaction-time based on measurement of cognitive load for novices learning surgical skills using simulation. *Medicine Meets Virtual Reality, 21*, 353-359. doi:10.3233/978-1-61499-375-9-353

Sanders, C. W., Sadoski, W., van Walsum, K., Bramson, R., Wiprud, R., & Fossum, T. W. (2008). Learning basic surgical skills with mental imagery: Using the simulation centre in the mind. *Medical Education, 42*, 607-612. doi:10.1111/j.1365-2923.2007.02964.x

Schmidt, R. A., & Lee, T. D. (2014). *Motor Learning and Performance: From Principles to Application* (5th ed.). Champaign, IL: Human Kinetics.

Schuster, C., Hilfiker, R., Amft, O., Scheidhauer, A., Andrews, B., Butler, J., . . . Ettlin, T. (2011). Best practice for motor imagery: A systematic literature review on motor imagery training elements in five different disciplines. *BMC Medicine*, *9*, 35.

Shin, S., Park, J., & Kim, J. (2015). Effectiveness of patient simulation in nursing education: Meta-analysis. *Nurse Education Today, 35*, 176-182. doi:10.1016/j.nedt.2014.09.009

Smith, H. M., Kopp, S. L., Johnson, R. L., Long, T. R., Cerhan, J. H., & Hebl, J. R. (2012). Looking into learning: visuospatial and psychomotor predictors of ultrasound-guided procedural performance. *Regional Anesthesia and Pain Medicine, 37*, 441-447. doi:10.1097/AAP.0b013e318257a551

Starpoli, P., Gregori, N. Z., Junk, A. K., Galor, A., Goldhardt, R., Goldhagen, B. E., Wei, S., & Feuer, W. (2018). Surgical simulation training reduces intraoperative cataract surgery complications among residents. *Simulation in Healthcare, 13*(1), 11-15. doi:10.1097/SIH.0000000000000255

Stefanidis, D., Anton, N. E., McRary, G., Howley, L. D., Pimentel, M., Davis, C., . . . Brown, C. (2017). Implementation results of a novel comprehensive mental skills curriculum during simulator training. *The American Journal of Surgery, 213*, 353-361. doi:10.1016/j.amjsurg.2016.06.027

Stefanidis, D., Korndorffer Jr, J. R., Markley, S., Sierra, R., Heniford, B. T., & Scott, D. J. (2007). Closing the gap in operative performance between novices and experts: Does harder mean better for laparoscopic simulator training? *Journal of the American College of Surgeons, 205*, 307-313. doi:10.1016/j.jamcollsurg.2007.02.080

Stefanidis, D., Scerbo, M. W., Korndorffer Jr., J. R., & Scott, D. J. (2007). Redefining simulator proficiency using automaticity theory. *American Journal of Surgery, 193*, 502-506. doi:10.1016/j.amjsurg.2006.11.010

Stefanidis, D., Scerbo, M. W., Sechrist, C., Mostafavi, A., & Heniford, B. T. (2008). Do novices display automaticity during simulator training? *The American Journal of Surgery, 195*, 210-213. doi:10.1016/j.amjsurg.2007.08.055

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257-285.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive Load Theory*. New York: Springer.

Udani, A. D., Kim, T. E., Howard, S. K., & Mariano, E. R. (2015). Simulation in teaching regional anesthesia: Current perspectives. *Local and Regional Anesthesia, 8*, 33-43. doi:10.2147/LRA.568223

van Gog, T., & Paas, F. (2008). Instructional efficiency: Revisiting the original construct in educational research. *Educational Psychologist, 42*, 16-26. doi:10.1080/00461520701756248

van Merriënboer, J. J., & Sweller, J. (2010). Cognitive load theory in health professional education: Design principles and strategies. *Medical Education, 44*, 85-93. doi:10.111/j.1365-2923.2009.03498.x

Wulf, G., Shea, C., & Lewthwaite, R. (2010). Motor skill learning and performance: A review of influential factors. *Medical Education*, *44*, 75-84. doi:10.1111/j.1365-2923.2009.03421.x

Young, J. Q., van Merriënboer, J. J., Durning, S., & ten Cate, O. (2014). Cognitive load theory: Implications for medical education: AMEE guide no. 86. *Medical Teacher*, *36*, 371-384. doi:10.3109/0142159X.2014.889290

Yurko, Y. Y., Scerbo, M. W., Prabhu, A. S., Acker, C. E., & Stefanidis, D. (2010). Higher mental workload is associated with poorer laparoscopic performance as measured by the NASA-TLX tool. *Simulation in Healthcare*, *5*(5), 267-271. doi:10.1097/SIH.0b013e3181e3f329

**Appendix A**

*Letter of Invitation to Participate in the Investigation*

June 1, 2018

Dear Students,

I am seeking individuals to participate in a quantitative investigation exploring student registered nurse anesthetists (SRNAs) skill development in simulated ultrasound-guided regional anesthesia skills. Participation in the study is completely voluntary. Your decision not to participate will, if no form, affect your standing in the program. Any personal information about you or any of the study participants will not be revealed in any form. The only person who will be aware that you are participating in the study will be myself as the principle investigator, several of the nurse anesthesia faculty helping with instruction, and an administrative assistant helping with data collection and analysis.

There is always a slight risk that your identity may be discovered as you participate in research studies. The study design and data collection techniques will follow strict confidentiality guidelines of research investigations and should minimize this risk. If you are interested in knowing these guidelines, you may ask me to discuss them with you prior to the study. If, at any time, you feel uncomfortable with any component of the research process, you may stop participating and all data collected from your participation will be destroyed.

If you agree to participate, you will be given instructions and a demonstration on a skill used in performing ultrasound-guided regional anesthesia. You will be asked to perform two sets of tests (a pre- and post-test) of the skill and fill out some simple questionnaires. In between these tests, you will be randomly assigned a specific practice strategy to use over the subsequent 3 weeks. After this practice period, you will complete a set of post-tests and simple questionnaires. Study investigators will then analyze the data collected to look at the relationship of the practice strategies with skill development.

You will be given a special identifying number, which will be the only method of identifying you during the study. Any electronic components of the data will be kept on a password-protected computer under a non-descript file. This study has been approved by the Office of Research and Sponsored Programs (ORSP) Institutional Review Board (IRB) at Midwestern University and the Human Subjects Committee (HSC) at the University of Kansas Medical Center. If you have any questions and want to talk with someone who is not involved in this study, you may contact the ORSP at Midwestern University at (623) 572-3728 or azorsp@midwestern.edu or KUMC HSC at (913) 588-1240 or you may write them at Mail Stop #1032, University of Kansas Medical Center, 3901 Rainbow Blvd., Kansas City, KS 66160.

If you want to participate, please contact Ms. May (nurse anesthesia program administrative assistant) and you will receive a consent form to fill out and return to Ms. May either in person or by sending a copy of the signed form via e-mail (lmay@midwestern.edu). This form explains in greater detail what is involved in participating in this study. Please review it and sign it if you would like to participate.

Thank you for considering participation in this study.

Sincerely,

Rod Fisher, MSN, CRNA

rfishe1@midwestern.edu

Principal Investigator

**Appendix B**

*Informed Consent Form*

**RESEARCH CONSENT**

**Study Title:** Exploring Skill Learning Strategies in Learning Ultrasound-Guided Needling Skills (This study was reviewed and approved by the Midwestern University Institutional Review Board)

**Principle Investigator:**
Rod Fisher, MSN, CRNA, PhD student at the University of Kansas Medical Center, School of Nursing (rfishe1@midwestern.edu or 623-572-3762).

**Co-investigators:**
Karen Wambach, PhD, RN, IBCLC Professor and Dissertation Chair, University of Kansas Medical Center, School of Nursing;
Kristen Mumme, MSN, CRNA, Assistant Professor;
Lee Ranalli, MSN, CRNA, Assistant Professor;
Morgan Morrow, MSN, CRNA, Assistant Professor; Lynda May, Nurse Anesthesia Program administrative assistant

**Sponsor:** None

This consent form provides information that you will need to make an informed decision about participating in this research investigation. Importantly, you will be given information on the known risks and participation responsibilities while participating. You are encouraged to ask any question during the study. If you decide to participate, you will be asked to sign this consent form and return it to the program administrative assistant as part of your permanent record. You will also be given a copy for your own files.

**PURPOSE AND PROCEDURES**

You are being invited to participate in a research study conducted by Rod Fisher, CRNA, MSN, principal investigator. This invitation to participate is because of your experience learning new anesthesia skills as part of your nurse anesthesia training. The main purpose of the investigation is to generate new knowledge of the effectiveness of skill learning methods that facilitate the learning of an important skill used in anesthesia practice. You may or may not benefit in enhancing your own psychomotor skills or feelings of competency by participating in this research study. Any benefit may come as you recognize the information derived from this study may help future practitioners develop skills more effectively.

This consent form explains the components of the study and your responsibilities and rights as a participant. The form also includes any benefits or risks associated with participation. Please read this form thoroughly before agreeing to participate. If you have any questions, please contact the principal investigator, Rod Fisher (rfishe1@midwestern.edu).

Participation in this study is voluntary and you may withdraw from the study at any time without any penalty. Your participation and the results of your testing will not in any way, reflect on your status as a student in the nurse anesthesia program. Your personal information and your participation in the study will be kept confidential. All data collected will be protected in a locked cabinet and on password-protected computers. The only person who will know of your participation will be the principal investigator and an administrative assistant. The research study will take place at Midwestern University in the Phoenix, Arizona.

**BACKGROUND**

The study proposal is available for a thorough review of the background for this study.

**PROCEDURES AND RESPONSIBILITIES**

Your eligibility for participation has already been determined by being a student in the nurse anesthesia program. Once you have given consent, the program administrative assistant will send you an e-mail giving you further instructions. Your participation in the study will involve the following aspects:

- An instructional lecture on ultrasound physics and the ultrasound-guided needling skill.
- A demonstration of the skill by one of the regional anesthesia faculty. This will include developing ultrasound imaging skills for needle direction in a simulated tissue block.
- Two skill performance testing experiences (pre- and post-practice tests).
- Random assignment to one of two practice strategies groups.
- Required 30-minute practice sessions, two (2) times per week for three (3) weeks
- Filling out a demographic data form
- As required by the research review board, data collected in this study may be maintained up to 15 years from the beginning of the study.

**RISKS AND CONFIDENTIALITY**

The practice and examination process is to collect detailed information about your progress as you learn how to perform a skill. The examination experience may be uncomfortable as you perform for the tests, but will be similar to skill practical exams that you have previously experienced. You may stop the exam at any time you feel uncomfortable. You may withdraw at that time or take time to compose yourself to continue with the exam. The decision to withdraw or continue is your decision. The handling of the data will follow strict guidelines of confidentiality in research and all data will be kept secure at all times. Your personal data will also be secured. You are also free to withhold or divulge any information you choose. The results of the study may be disseminated to other individuals or groups. Under no circumstances, will your personal information be revealed to other individuals. The study data will be presented in aggregate form to prevent revealing any information about the participants. Other researchers, guided by strict research participation guidelines, may request access to the data, but there will be no identifying information shared in these cases. Other researchers permitted access to any of the data will be following the same guidelines as the principal investigator to protect your confidentiality.

**STUDY CHANGES**

Although it is not anticipated, you will be notified in advance if any changes are to be made in the design and conduct of the study. You will be able to make a decision at that time whether you wish to continue or withdraw from the study. If any changes are made, you may be asked to give informed consent again.

**COSTS AND REMUNERATION**

There is no cost associated with participation in this study. Occasionally, there will be food or drink offered to study participants at testing times associated with this study. Otherwise, there will be no other form of compensation for participating.

**INSTITUTIONAL DISCLAIMER STATEMENT**

If you feel you have been harmed by participating in this study, you should contact the Director, Office of Research and Special Projects, Midwestern University, Glendale Hall 201, Midwestern University, Glendale, AZ 85308 (azorsp@midwestern.edu) or the Director of the Human Research Protection Program, Mail Stop #1032, University of Kansas Medical Center, 3901 Rainbow Blvd., Kansas City, KS 66160. Under certain circumstances, Kansas state law or the Kansas Tort Claims Act may allow for payment to persons who are injured in research at KUMC.

**CONSENT**

After reading this form, you may ask any other questions regarding this study. Once you feel comfortable with participating in the study, please sign this consent form and return it to the administrative assistant for the Nurse Anesthesia Program in order to protect your personal information.

I have read this consent form and have decided to participate in the investigation noted above. The study purposes and responsibilities of involvement, including potential risks, have been satisfactorily explained to me.

Printed name______________________ Signature__________________________Date______

***You will be given a copy of this consent form for your personal records. It is advisable to keep this record safe to help maintain your confidentiality.***

**Appendix C**

Demographic Information

- ID number____________
- Age? 20-25 years ___  25-30 years ___  30-35 years ___  >35 years ___
- Gender?
    - Female _____
    - Male _____
- Race?
    - American Indian or Alaska Native___
    - Asian___
    - Black or African American ___
    - Native Hawaiian or Other Pacific Islander____
    - White____
- Ethnicity?
    - Hispanic or Latino_____ or Not Hispanic or Latino____
- Total years in nursing practice? ______
- Previous weekly ultrasound instruction, use, or teaching?
    - YES ____
    - NO ____
- What is your video gaming experience? Please check which option best describes you.
    - Never or less than one time per a month ________
    - One to four times per month___________
    - Two or more times per week _________

**Appendix D**

Mental Imagery Script Excerpt

The following is an excerpt of the script that will be used to help the learners begin their mental imagery strategies.

I sit comfortably on a stool in front of a small table with a blue tissue block on the table in front of me. Next to the tissue block is a nerve block needle with an injection tube and stimulation wire attached to the hub. There is a clear plastic bottle of pink ultrasound gel sitting next to the needle. On the opposite side of the table, within arms distance, is the Sonosite ultrasound machine opened and turned on, with three ultrasound probes attached. One probe is the low-frequency, curvilinear probe and the other is the high-frequency, linear probe. The screen on the machine shows a dark screen. I pick up the ultrasound gel bottle. It feels cool to the touch as I turn it up-side-down and give it a quick shake to push the gel up to the spout. I grab the high-frequency probe in my probe hand and invert it to put the gel on. I squeeze out a line of gel along the top edge of the probe. I notice the image on the ultrasound machine turn lighter with the characteristic gel image. I set the gel bottle down and look at the markings on either side of the probe that indicate laterality of the probe. I reach up with my finger and touch one side of the probe through the gel and look at the image on the machine to confirm laterality of the probe and corresponding image. I see the disruption of the gel as I touch one side of the probe. I invert the probe in my probe hand and place it on the middle of the gel tissue block, anchoring my lateral palm on the tissue block. I hold the probe with my thumb and three fingers so I can manipulate the probe easily. I look at the ultrasound image and see a clear image with three circular structures, representing blood vessels and three bright hyperechoic dots that represent the nerves which I plan to touch with the needle.

**Appendix E**

The National Aeronautics and Space Administration-Task Load Index (NASA-TLX) Questionnaire (Hart & Staveland, 1988)

ID number________________

Instructions: Place a mark in the box that reflects how you rate yourself for each concept.

**1. Mental Demand** How mentally demanding was the task?

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Very Low Very High

**2. Physical Demand** How physically demanding was the task?

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Very Low Very High

**3. Temporal Demand** How hurried or rushed was the pace of the task?

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Very Low Very High

**4. Performance** How successful were you in accomplishing what you were asked to do?

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Perfect Failure

**5. Effort** How hard did you have to work to accomplish your level of performance?

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Very Low Very High

**6. Frustration** How insecure, discouraged, irritated, stressed, or annoyed were you?

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Very Low Very High

**Appendix F**

Psychometric self-report of mental effort, adapted from F. G. Paas (1992)

ID Number______________

Instructions: Please circle one category (1, 2, 3, 4, 5, 6, 7, 8, or 9) which most accurately applies to you:

In the test just completed, I invested:

1. very, very low mental effort

2. very low mental effort

3. low mental effort

4. rather low mental effort

5. neither low nor high mental effort

6. rather high mental effort

7. high mental effort

8. very high mental effort

9. very, very high mental effort

**Appendix G Tables and Figures**

**Table 1.**

*Study Variables Related to the Construct of Skill Automaticity*

| Variables | Conceptual definition | Operational definition | Scale |
|---|---|---|---|
| Time-to-complete (TTC) | A timed period to complete a simulated needling task under US visualization | The time in seconds for participant to place a block needle into a phantom tissue block, separately contact three embedded simulated nerves under continuous US visualization, and remove the needle from the tissue block | 1-500 seconds |
| Practice strategy group (PP, MI) | A randomly allocated designation of a group of participants to a specific practice strategy (physical versus mental imagery) for this investigation | PP – The group of participants that were allocated to practice the needling skill using physical practice techniques. MI – The group of participants allocated to practice the needling skill using mental imagery practice techniques | PP=1, MI=2 |
| $2^0$ Task score (SecTask) | The score derived from a secondary task given to all participants during pre- and post-testing used to infer cognitive load during performance of the needling skill | The self-report by the participant of the number of additional embedded structures and their location in relation to the target nerves and/or blood vessels | 0-10 |
| Paas scale score (Paas) | A value given to a perceived mental workload occurring during a task just completed | The participant's self-rating of their perceived level of mental effort required to complete the task | 1-9 |
| NASA-TLX score (TLX) | A value given by the participant of the perceived cognitive load during the performance of a task and a self- | The participant's self-rating, via a questionnaire, of their perceived mental, physical, and temporal workload of the task just accomplished; a self- | 6-120 |

| | | | |
|---|---|---|---|
| | evaluation of their performance, their effort needed to achieve the level of performance, and their level of frustration | rating of: their performance to successfully accomplish the task, their effort to accomplish their level of performance, and their level of frustration at accomplishing the task | |
| Age (age) | The chronological age in years of the participant | Participant self-report of number of years living | 20-45 |
| Gender (Gen) | Designation of human beings based on their reproductive function | Participant's self-report of gender | Male or Female |
| Years of registered nursing experience (YearNurs) | A time period encompassing the years practicing as a nurse | Participant's self-report of the number of years (to the nearest year) that they have practiced registered nursing | 1-15 |

*Note.* Age, gender, and years of registered nursing are descriptive variables.

**Table 2**

*Flowchart of Physical and Mental Practice Sessions (SDP)*

| Pre-test | Week 1 | | Week 2 | | Week 3 | | Post-test |
|---|---|---|---|---|---|---|---|
| TTCpre | Monday | Friday † | Monday | Friday † | Monday | Friday | TTCpost |
| | 30 min | 30 min | 30 min | 30 min | 30 min | 30 min | |

*Note*. Physical (PP) and mental (MI) practice groups will be scheduled at different times in the simulation lab on Mondays and Fridays during the skill development period (SDP). All sessions will last for 30 minutes. There will not be any instructor feedback given during the practice sessions, although, the participants may use required textbooks or personal notes for reference. The pretest (TTCpre) will be administered to all participants at the end of the initial skill training/demonstration session. The posttest (TTCpost) will be administered to all participants after the last practice session for both PP and MI groups. † - indicates that the MI group can physically practice the skill once during this session.

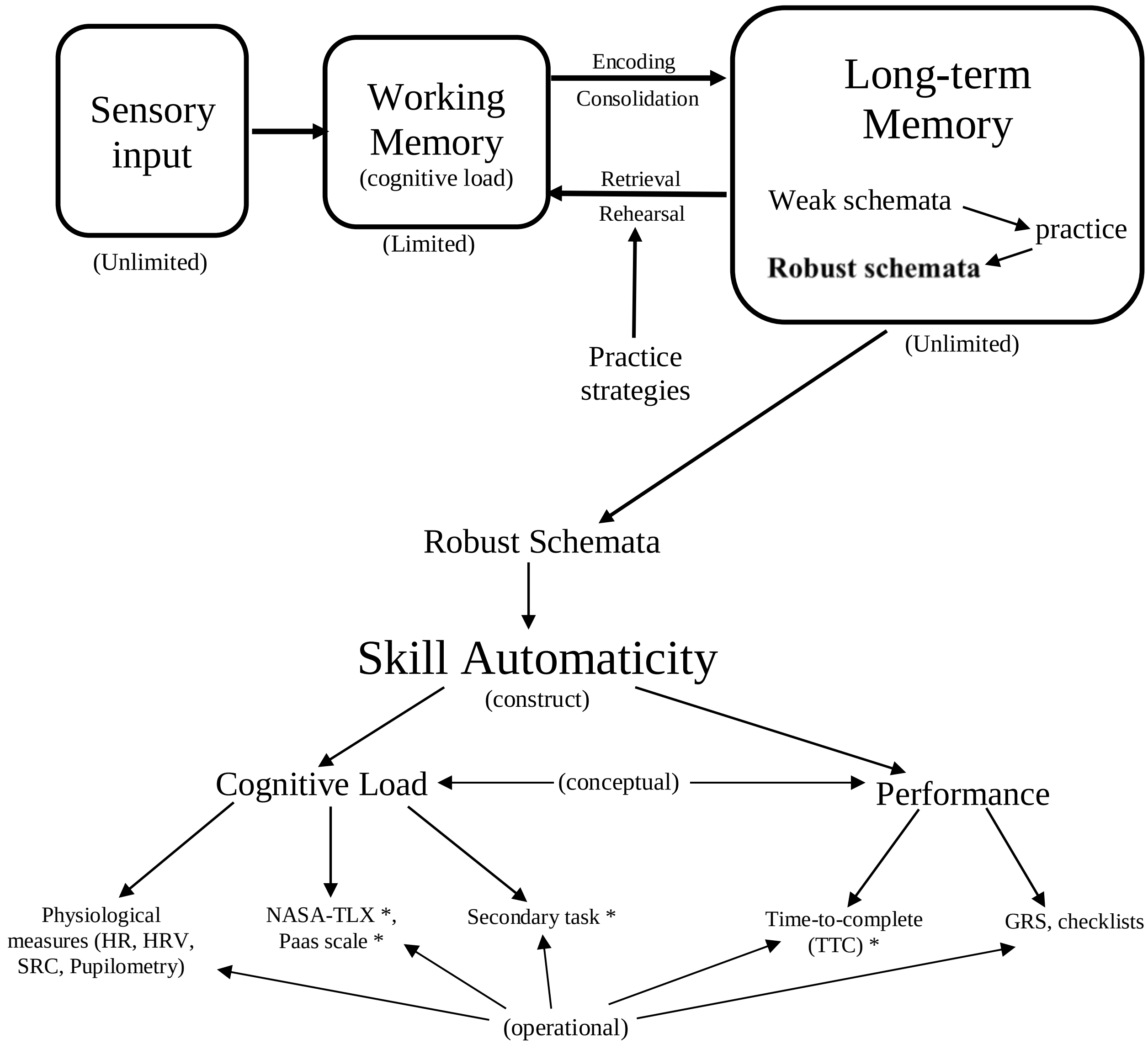



***Figure 1.*** Substruction Diagram of the Skill Learning Process. In the process of learning, the cognitive architecture assimilated perceptual and stored information into working memory. As those informational elements are attended to in working memory, the process of encoding and consolidation begins to chunk these elements together to create schemata. At first, these schemata are weak and may degrade with time unless the individual continues to retrieve and attend to the information in working memory. With continued retrieval and rehearsal (practice), these schemata become robust and automatized long-term memories. Using robust schemata leads to skill automaticity (performing the skill without having to think much about it – indicative of skill learning). We can measure how well we have learned a skill by measuring either the performance of the skill or the cognitive load experienced during performance, or both. This is what will be accomplished by this investigation. Operational measures indicated with an * will be used in this study. Adapted from the Cognitive Load Theory by Sweller, Ayres, and Kalyuga (2011).

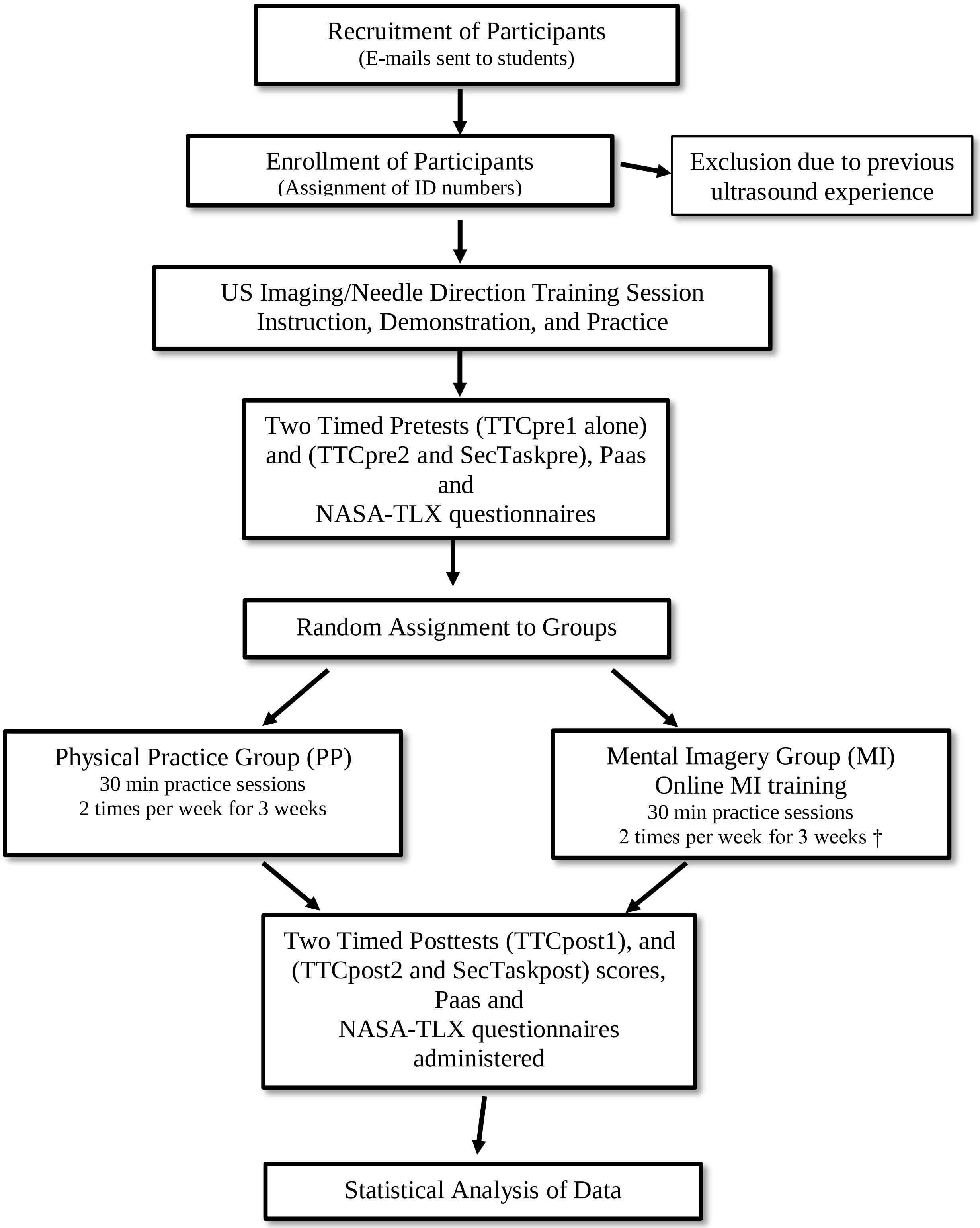



***Figure 2***. Participant/Procedural flow through the Study.
† - one physical practice opportunity during 2nd and 4th practice sessions

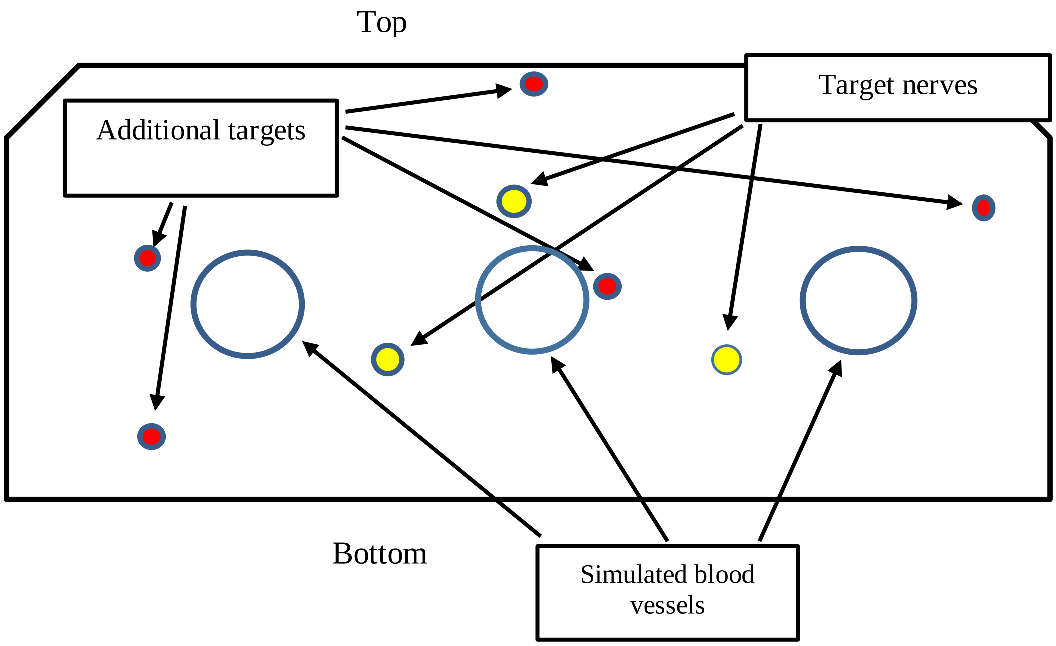



***Figure 3.*** Illustration of the ultrasound-capable phantom tissue block that will be used in this study including the approximate locations of all embedded structures.

# Chapter 2

## Designing the Simulation Learning Environment

This chapter was previously published, without adaptation, as an open access article. [37] Fisher, R. Designing the simulation learning environment: An active engagement model. Journal of Nursing Education and Practice. 2016; 6(3), 6-14. doi:10.5430/jnep.v6n3p6

**Abstract**

Simulation is rapidly becoming a significantly learning methodology in healthcare education. The unique characteristics of simulation learning creates a bridging experience between the classroom and actual patient care and, more importantly, helps learners develop advanced clinical reasoning skills. Learner active engagement is a critical requirement for effective learning during simulation and debriefing, which tasks educators to design simulation learning environments that foster learner active engagement. To foster learner active engagement, the educator and the learner must develop a dyadic relationship of trust, openness, sharing, and safety. The formation of this dyadic relationship implies that the learner has engaged in the learning environment. The simulation literature lacks significant discussion of how the elements of the simulation learning environment can be used to create a learning environment that encourages active engagement in the learning process. From the information gathered through a literature search in CINAHL, PubMed, and Psychology and Behavioral Sciences databases; this article describes the critical elements of effective simulation learning. The purposes of this article are to elucidate how the interaction of important elements of the simulation experience can foster active engagement and to introduce an Active Engagement Model as a framework for designing the simulation learning environment that encourages and supports learner engagement. The components of the model are the educator, the learner, the environment, which must interact

effectively to form the functional entity of the model – the educator/learner dyad. Once the educator/learner dyad is formed, all the elements of the model function in concert to form an effective simulation learning environment.

## Introduction

To respond to societal pressures to prepare more highly qualified graduates possessing advanced clinical reasoning skills, healthcare educators must design innovative learning environments using teaching modalities that foster learner engagement. [1-2] One effective teaching modality is simulation learning. In contrast with the traditional classroom lecture, simulation offers an experiential learning environment in which learners engage on multiple levels: psychomotor, cognitive, social, and emotional. The interactive nature of the simulation and debriefing experience fosters the development of clinical reasoning skills, [3] psychomotor skills, [4] learner self-efficacy [5] and acts to bridge the transition from classroom instruction to actual patient care. This uniquely dynamic learning environment does not occur spontaneously, but must be innovatively designed by educators.

From information gathered through a literature search of the CINAHL, PubMed, and Psychology and Behavioral Sciences databases using the keywords simulation learning, active engagement, learning environments, and debriefing; this article reviews the critical elements and their interactions of the simulation learning environment (SLE). A growing number of simulation researchers reported improved learning following simulation experiences. [6, 7] Other investigators proposed that more advanced cognitive processing and assimilation occurs during effective debriefing after simulation. [8,9] Simulation, coupled with a proper debriefing experience, offers the learner a uniquely effective learning environment in which to develop clinical reasoning skills; provided it is designed and conducted in a manner which fosters learner active engagement.

Along with highlighting the importance of learner active engagement in simulation and debriefing, Dreifuerst identified defining characteristics of the debriefing process: reflection, emotion, reception, and integration and assimilation. [10] It is most certain that these same characteristics are important during the simulation component also and must be considered in the design of the SLE. In 2005, Jeffries introduced a framework for designing simulation experiences describing the elements of the simulation experience. [1] Over the past decade, the simulation education community has focused on identifying important components of effective simulation experiences, yet there has been inadequate discussion on how the design of the SLE fosters active engagement through the interaction of the key elements. Due to the recent growth of simulation education, many educators are unfamiliar with the important interactions of the key elements needed to create effective simulation and debriefing learning environments.

DeMaria et al. proposed that increasing fidelity in the SLE fosters learning through the interaction of realistic psychological, technological, and environmental elements. [11] These authors also suggested that the emotional component of the simulation experience facilitates learning by enhancing memory processing. In a systematic review of current simulation literature, Cook et al, found the following elements are important for simulation-based education: range of difficulty, repetitive practice, distributed practice, cognitive interactivity, multiple learning strategies, individual learning, mastery learning, feedback, longer time, and clinical variation. [12]

It is beyond the scope of this paper to discuss each of the elements described by the aforementioned authors. With this in mind, this paper discusses the main interactive elements of the simulation experience. As educators understand the important characteristics and interactions of the elements of the SLE, they will better understand how to design an environment that fosters learner active engagement and the development of advanced clinical reasoning skills. The purposes of this paper are to explore some of the important characteristics of the key elements of simulation and debriefing learning and expand our understanding of the critical interactions between these elements by introducing an Active Engagement Model to be used as a framework for creating a SLE that fosters learner active engagement.

## Simulation Environment Elements

### Reflection

Reflection is a process of evaluating one's own performance, the decisions made, and the cognitive processes that underlie those decisions. [13] Borrowing concepts used by the military and the aviation industry, healthcare educational practices now incorporate debriefing in simulation experiences to enhance deeper learning and develop clinical reasoning skills. [14] Reflection can occur throughout the simulation experience but is a crucial element of the debriefing component. The adult learning theory emphasizes a unique conceptual framework that supports deeper learning using simulation technology and reflection. [15] When combined with facilitated reflection, learning through effective simulation and debriefing reflects an experiential learning process, which is a key factor in adult learning. [16] Many authors in the simulation literature promoted reflection as a significant component of the debriefing process. [1, 9,14, 17]

Learners may initiate self-reflection during the simulation experience or be guided through the reflective process by the educator. As mentioned above, reflection can occur before, during and after the actual simulation, but is most effective during the debriefing experience when the learner is not cognitively and emotionally occupied with decision-making and personal performance tasks occurring during the simulation component. Through guided reflection, learners revisit the simulation experience and review performance of psychomotor skills and decision-making processes. If the decisions were correct, then the decision-making processes are reinforced. If the decisions were inappropriate, the educator can guide learners in evaluating and modifying, not just their decisions, but also their decision-making processes. Through this reflective process, the learner enhances clinical reasoning skills. Jeffries suggested that a properly designed simulation experience with an adequate reflection component is one of several valuable tools for the educator to help prepare competent healthcare professionals for practice in the workplace. [1] This experiential learning process is the foundation of simulation and debriefing. Learning how to effectively guide the reflection process is challenging for many educators, especially those new to this emerging technology. Cheng et al. proposed that educators should have structured opportunities to develop, maintain and enhance skills in effective simulation and debriefing techniques. [18]

**Emotion and Stress**

Clapper described learning as an emotional event. [15] This is especially true for the simulation experience. Effective educational environments allow learners to enhance the understanding of their surroundings and develop decision-making skills through experience. Beyond providing knowledge and context, life and educational experiences provide social and emotional development. Emotion is created by the learner's perception of an experience and is a significant characteristic of both the simulation and debriefing experiences. Emotional perception is a multi-factorial process resulting from the cognitive processing of many elements: multiple sensory inputs, cultural background, psychosocial development, trait anxiety (TA), and past experiences. As a result, educators may not be completely aware of what the learner is perceiving. A perception of an exciting and safe environment fosters learner engagement. If the learner perceives a threatening environment, he or she may disengage from the experience. Positive and negative emotions associated with the learning environment determine learner engagement and can impact the learning process.

The perception of a threatening environment causes an anxiety or stress reaction in the learner. Derakshan defined this anxiety reaction as an “aversive motivational state” in which the learner engages in avoidance or defensive behaviors. [19] An aversive motivational state may lead the learner to disengage from at least a portion of the learning experience. A challenge for the educator is to identify perceived threats or subsequent avoidance or defensive behaviors before the learner disengages from the experience.

Both the perception of a threat and the body’s physiologic response to anxiety affect cognitive processing in multiple brain areas during memory encoding, consolidation and retrieval. [11, 20, 21] Many people have experienced forgetting a well-known fact during a stressful event, only to remember it later in a more relaxed environment. One possible explanation for this “forgetful episode” is the result of the release of the stress-response chemicals epinephrine and glucocorticoids. In the amygdala, epinephrine and glucocorticoids enhance emotional learning and memory consolidation, [22] but impair retrieval of memories if the stress occurs at the time of the retrieval attempt. [23] This memory retrieval impairment may be one of the causes of test anxiety. Miu, Heilman, & Houser found alterations in decision-making depending on the level of TA (individual’s sensitivity to the perception of threat) of the learner. [24] These researchers found impaired decision-making and more profound anticipatory stress responses in subjects with high TA. Calvo, Avero, & Miguel-Tobal discovered that high TA adversely affects attentional memory and leads to preferential processing of threat stimuli. [25] Additionally, research showed impaired recollection of extrinsic (contextual) details of an emotional experience. [26] This research suggests that the learner may remember a stressful simulation experience but may have performed poorly as the result of impaired attention and impaired retrieval of important facts required to make correct decisions.

Other neurophysiological research shows emotion and stress to be important factors in task management during cognitive processing. [27] Edwards, Edwards, & Lyvers found that stress and anxiety adversely affect task performance, impairing the learner's ability to shift attention during the learning experience. [28] Attention shifting is a common feature unique to the simulation environment. During simulation, the learner's attention constantly shifts between several foci: decision-making, performing psychomotor skills, monitoring effects of the decisions, directing the actions of other participants, and listening to and responding to educator feedback. These actions often occur rapidly and are cognitively intensive. Responding to a perceived threat during the simulation may cause the learner to dedicate important central cognitive functions to deal with the threat (a higher-priority event), leaving other tasks suspended. In this event, task performance and decision-making processes suffer, which may lead to poor performance and learning outcomes. Educators designing learning environments should incorporate methods to identify and modulate emotion and stress in an effort to optimize learning and keep the learner engaged. [29, 30]

Rudolph et al. described the effects of using judgmental and non-judgmental approaches in the debriefing process. [13] These authors suggested that learners may suffer significant emotional harm if improper debriefing techniques are used. Zigmont, Kappus, and Sudikoff indicated that learners are less likely to talk openly if they perceive a judgmental environment. [31] A judgmental environment may hinder all aspects of the simulation experience, especially the reflective process. If learners perceive that they are being blamed for a failed simulation scenario or thwarted the group's effort during simulation, they may experience feelings of humiliation. This may also lead to a reluctance to engage in the debriefing process and future simulation experiences. Educators creating simulation learning experiences should be aware of the adverse effects of a judgmental environment on emotion and monitor the learner and the group dynamics throughout the entire simulation experience.

Zigmont et al proposed that the debriefing process should begin with a "defusing" experience. Defusing allows learners to discuss the emotional impact of the simulation experience. [31] Unless the simulation is evaluative, learners should be instructed that the simulation is a learning experience and that poor scenario outcomes are a part of the learning process. Entering into the reexamination phase of debriefing without resolving the emotional impact of the simulation may prevent learners from focusing on their decision-making processes. Learners may be so frustrated with the outcome of the scenario that they are unable to "learn from their mistakes". Once learners can vent emotions, they will look more objectively at their decision-making processes, which is a critical step in developing clinical reasoning skills. As students vent their emotions, educators can identify elements of the simulation experience that were potentially harmful. This information will improve future simulation design.

**Reception**

Reception refers to a learner's willingness to receive feedback during the simulation experience and most often occurs during the reflection component of debriefing. This "openness", as described by Dreifuerst, is related to learner engagement and may need to be taught to the student. [10] Adult learners re-entering the educational environment may be unfamiliar with constructive feedback and the reflective process. It is unlikely that today's adult learners have been sufficiently exposed to many of the important cognitive activities unique to the simulation experience. Within the last several decades, there has been a growing effort to incorporate the theories and methodologies of adult learning and cognition into higher education which support the use of reflection and feedback in education.

If learners are comfortable with the reflective process, they will be more willing to receive feedback on their actions. In simulation and debriefing, learners engage in cognitive, affective, and psychomotor components. Feedback on each of these components can come from the educator or peers who are participating in the simulation scenario. Kuiper, et al. suggested that by receiving feedback on all components of the simulation experience, reflective learners can visualize and incorporate “affective and behavioral learning” processes required for deeper learning. [32] All participants should be instructed that feedback should be presented in a nonthreatening, positive manner to prevent emotional harm. Learners who are aware that feedback will be positive and constructive should feel comfortable in accepting the critique of their efforts and using it to promote learning.

**Learning Through Integration and Assimilation**

Integration refers to incorporating newly acquired knowledge into existing cognitive frameworks. [10] New learning is best retained if it is incorporated into an existing framework of previously learned knowledge. Learners commonly come to the simulation experience with an existing cognitive framework to which more knowledge and experience can be added. It is the educator’s responsibility to show learners the relationship of the new knowledge to what the learner should already possess. If new knowledge does not fit into the learner’s existing framework, the old framework may have to be “torn down” to construct new framework. Learners who have been out of the educational process for some time may have old, incomplete, or outdated frameworks that no longer agree with or support new knowledge. Through the process of facilitated reflection, learners are guided to recognize the liability of the “old” frameworks and assisted in replacing them with “up-to-date” frameworks upon which the new knowledge may be attached. Other learners may come to the simulation with an incomplete framework that will not support additional new knowledge. In this case, the educator may have to guide the learner to “strengthen” existing frameworks. This may be accomplished either by pre-simulation assignments, sending the learner out from the simulation to “read the text”, or by filling in the knowledge deficits during the simulation and/or debriefing. It is important that during the development of the simulation scenario the educator take into account the knowledge that learners currently possess. Expecting the learner to make decisions based on knowledge not previously acquired will lead to frustration and anxiety.

Assimilation is the ultimate goal of simulation and should be the ultimate goal of all educational enterprise. [10] Assimilation refers to the application of past learning to future experiences. All learners should be able to use the knowledge gained in their education in future experiences. Assimilation may be assessed by asking thought-provoking (Socratic) questions to determine if learners are using the new knowledge. Future simulation scenarios will also measure assimilation.

**The Active Engagement Model**

Designing the SLE involves much more than compiling the important elements of simulation and debriefing experiences. Innovative educators design learning environments that encourage active engagement in the learning process. Engagement refers to more than just physical participation in the simulation and requires significant time to develop properly. Active engagement creates a personal connection with the learning experience and motivates the learner to take greater responsibility in the learning process. Instead of the educator controlling all aspects of the learning, the learner “reaches out” to make personal connections with all parts of the learning environment and helps to ensure proper functioning of the entire “system”. This process of active engagement should begin early in the educational experience and must certainly be well-developed before entering the simulation learning environment.

Experiential learning through simulation has the characteristic of attaching emotion to the experience through realism. This is especially apparent as simulation fidelity and complexity increase. Learners apply previously learned knowledge, skills, and attitudes in making critical decisions while interacting with a simulated patient and other participants. The simulator responds in real-time providing realistic feedback. The learner’s decisions have an immediate impact on themselves, the simulated patient, and other participants joining the simulation. Effective simulation is often challenging, adding to the emotional aspect of the experience. The post-simulation debriefing process enhances learning and development of clinical reasoning skills by reexamining the events, reflecting upon the emotions elicited, analyzing the mechanisms of decision-making, and reviewing the decisions made and the outcomes of the scenario. Reflection should elucidate ineffective decision-making processes and lead participants to discover more appropriate reasoning processes for use in future simulated or real-life experiences.

As mentioned above, the process of learner active engagement does not occur spontaneously in many educational environments. Even before learners enter the simulation environment, innovative educators should design multiple learning environments where active engagement can be learned and fostered. Although classroom and simulation learning environments are dissimilar in many aspects, the design characteristics of both environments that foster active engagement follow similar basic principles. The following is a proposed model, developed by the author, to examine the key interactive elements of the SLE that foster learner active engagement. The model consists of four major interactive components – The educator, the learner, the environment, and the educator/learner dyad (Figure 1). Effective learning does not occur with each of these components acting independently. As will be discussed below, the educator, the learner, and the environment have unique characteristics that determine learner engagement in the experience. If the learner engages, the educator/learner dyad is formed, which becomes the functional component of the model.

**The Educator**

The educator is responsible for designing and managing an effective SLE. During simulation, the educator guides learners through multiple learning experiences: pre-simulation preparation, the actual simulation scenario, and debriefing. Educators bring knowledge, expertise, expert clinical reasoning skills, and maturity to the environment. Other important characteristics required for this model are patience, humility, empathy, creativity, vision, familiarity with the technology, a solid understanding of adult learning theory, and effective debriefing skills. These characteristics and skills are required to design and conduct simulation experiences that encourage learner engagement. Although the educator is critical to the design and management of the environment, it is the learner who must ultimately engage in the experience to develop the facilitator/learner dyad. The development of the educator/learner dyad is critical for effective learning and demonstrates that the learner has actively engaged.

The most important outcome of simulation is to develop clinical reasoning skills. Learners develop these skills by engaging in learning experiences where they are required to make critical decisions. Afterward, they need an opportunity to review the decision-making process to determine its effectiveness. Most learners have difficulty identifying improper decision-making processes using newly acquired knowledge. It is usually easy to point out incorrect actions, but it can be challenging for educators to help learners identify faulty decision-making processes. The reflection process is the most effective method to get learners to visualize their decision-making processes and learn from them. During reflection, an effective educator facilitates the learner's visualization of the decision-making processes used and assists the learner to modify those processes if needed. Facilitating the visualization of both proper and improper decision-making processes is critical for the learner and the educator can only develop this skill through experience.

With the growth of diversity within our educational system, educators may not recognize subtle personal biases. If learners sense a bias in the educator, they may perceive the environment as threatening. This may lead to diminished respect for the educator and prevent engagement; impairing the creation of the critical educator/learner dyad. Educators must be sufficiently humble to be aware of personal biases and be willing to eliminate them. This effort will foster more effective communication with learners, develop trust, and provide a safe learning environment. Simulation learning frequently involves adult learners with unique learning needs and abilities. Educators should also be familiar with how a diverse group of adults learn more effectively and incorporate those principles into the design of the SLE.

The educator must also be aware of the many factors that can cause learner stress and anxiety. During simulation and debriefing, it is very important that the educator monitor the level of anxiety. A distinction should be made between a challenging experience and one that is emotionally harmful. These two types of environments fall next to each other on the continuum of educational environments and there may be a fine line separating the two types. Some situational stress is highly beneficial in simulation education. Stressful experiences can prepare the learner for making critical decisions in the real world. The educator should be able to recognize if the anxiety level crosses the boundary into a threatening environment and quickly defuse the situation, preferably without disrupting the learning experience if at all possible. Sometimes it may be necessary to prematurely stop the simulation and begin a facilitated debriefing experience if the anxiety level is inhibiting the learning process. An awareness of the adverse effects of high-anxiety on learning will encourage the educator to more carefully monitor the environment for signs of stress and anxiety.

High-fidelity mannequins are extremely complex computer-driven systems, which require training and experience to run simulation scenarios effectively. Some systems have pre-programmed scenarios and some systems have to be programmed. Most of the mannequins allow for manipulation of physiologic parameters to create realism (fidelity). The simulation educator can also increase fidelity by designing realistic scenarios and physical environments. The educator must be thoroughly familiar with the simulation technology before engaging in SLE design. An educator struggling to manage an unfamiliar simulator will not be focusing on the learning processes and will find great difficulty getting the student to engage in the learning.

Many of these educator characteristics develop with time and experience. Both the educator and the learner benefit from interactions developed with frequent simulation experiences. The educator develops a greater understanding of the learner's decision-making skills and can assist to enhance those skills. The learner benefits from multiple opportunities to interact with the educator and to practice decision-making skills. It may be advisable to begin initial simulations with simple scenarios where just a few critical decisions have to be made and gradually escalate scenario complexity as the learner becomes more experienced and gains greater decision-making self-efficacy. The educator can use a gradual escalation process to assist students with high TA to develop greater self-efficacy in preparation for more challenging scenarios and testing experiences in the future.

**The Learner**

Unlike the classic classroom environment, the learner in the SLE performs skills and makes critical decisions that impact scenario outcomes in front of others; which may cause psychological harm. Learners come to the SLE with varying levels of psychomotor skill development and decision-making abilities. A learner with less-developed skills may have to perform in front of the educator and peers with perceived higher-level skills. This creates a potentially stressful experience, especially in learners with high TA. Additionally, the principle of active engagement requires that some of the normal educator/learner psychosocial boundaries to be temporarily removed, which may expose the learner to the harmful effects of an unsafe or biased environment. The learner must be taught and clearly understand that the simulation is a learning experience where mistakes occur frequently and are a part of the learning process.

Through past educational and life experiences, learners develop unique cognitive frameworks to assist in understanding their environment and to help in decision-making. If the outcomes of those decisions are positive, those decision-making processes are strengthened and embedded into the learner's vast cognitive frameworks. Learners develop clinical reasoning skills by repetitively accessing these advanced cognitive frameworks during simulation experiences. Active engagement during guided reflection enhances access, proper utilization, modification, and consolidation of these advanced cognitive frameworks.

The ability to engage in self-reflection varies among adult learners. [13] Schön described some professionals as having the ability to self-correct their professional skills by self-scrutiny while others tend to ignore other's perceptions about their ineffective practice habits. [33] The learner who lacks self-scrutiny skills and ignores the perceptions of others will have poor self-corrective skills. An educator may not know if a learner has effective self-reflective skills until a debriefing session. Decker et al. proposed that self-reflective skills must be taught and modeled so that learners are comfortable with the reflective process and are willing to critically look at their decision-making skills. [34] The educator should teach, guide, and encourage this reflective process throughout the entire educational program, but learners must be willing to engage in the learning experience. The engaged learner develops a greater sense of personal responsibility for the learning process, a greater awareness of decision-making errors, and will commit greater effort to correct the errors.

### The Environment

A safe environment for all participants is one of the most important design factors of the SLE. Rudolph et al. proposed that the environment should be challenging, but psychologically safe. [13] The educator and peers participating in the simulation will share critical judgments with the learner. Learners must believe that these judgments are unbiased and that they are offered to improve learning and develop clinical reasoning skills. There should be a sense of trust, ensuring that all that may be revealed about the learner will be kept confidential. The educator must assure that measures are taken to monitor the environment, maintain confidentiality, and decrease the chance of a threat.

Educators should also understand the difference between a challenging environment and one that is perceived as threatening. A challenging environment is one where the learner has multiple opportunities to make critical decisions. A threatening environment is one where the learner is afraid to make critical decisions or feels humiliated and is less likely to foster clinical reasoning skills or any kind of meaningful learning. The design and conduct of the simulation will create either a challenging or a threatening environment. The educator is ultimately responsible for managing the simulation environment and should make sure rules regarding appropriate interaction are well known by all the participants prior to the experience.

If educators primarily use lecture in the classroom, learners may be unfamiliar with the reflective process or engagement in the learning environment. Teacher-centered education (lecturing) is a passive process and does not encourage active engagement. Learner-centered education fosters active engagement. [35] The simulation learning experience proposed in this model is an excellent example of learner-centered education. Another effective methodology that fosters engagement is a team-based approach, where small groups act as a team to accomplish a specific simulation scenario. Sisk found that team-based learning experiences are a promising method for engaging students and fostering productive teamwork. [36] Educators should be familiar with active or learner-centered methodologies and incorporate them into the design of the SLE to motivate students to engage in their own learning.

**The Educator/Learner Dyad**

Effective learning depends on critical interactions between educators and learners. [1] Although the design of an effective SLE rests on the educator, the educator/learner dyad is the main component maintaining the environment and supporting the other elements. Without engagement of the learner, the dyad is difficult to create. As discussed above, there are many factors that affect this educator/learner dyad. Due to the evolution of modern pedagogical principles, educators must become more aware of and protect learners from physical as well as psychological harm in all learning environments. If learners sense value, respect, and safety in the environment, they will freely engage and help to create and maintain the educator/learner dyad. Any perception that this relationship might not be safe to any one of the participants, including the educator, may be devastating to the learning process and may even result in harmful and long-lasting emotional effects.

A feeling of trust must also be cultivated between the learner and the educator and is essential for the development of the educator/learner dyad. Clinical reasoning skills are developed during debriefing when the learner and the educator cooperatively reexamine the simulation experience. Both explore the emotions, the decisions, and the outcomes during the reflection process. During reflection, the learner often has to express sensitive thoughts and feelings which may expose him or her to the harmful effects of an uncaring educator. The educator helps learners identify correct and incorrect decision- making processes through facilitated reflection, and together analyze the impact of those decisions on the outcomes of the simulation. The educator encourages learners to express their feelings along with the rationale for the decisions made. Ultimately, the learner and the educator collaborate to strengthen decision-making processes and incorporate them into the learners' cognitive frameworks for future access and decision-making. There must be open relationship between learners and the educator, including a desire to freely communicate knowledge and feelings. Reciprocal trust is essential for all these activities.

All participants should recognize the value of each other, which requires empathy and humility. Empathy is the ability to acknowledge and understand the thoughts and feelings of another person (learner). Some educators may believe the simulation environment is safe and may dismiss a learner's perception of threat. This lack of empathy will jeopardize the learning experience. Humility is an understanding that we have the same value as each other and that we all can learn from each other. The educational experience is the sharing of knowledge, skills, and attitudes. The haughty educator, who feels that learners will never attain to his or her academic level, will never be able to correct misperceptions of the learner. Learners may feel there is no value in listening to an overbearing and self-important educator. In such cases, it is extremely unlikely that any learning will occur. In another example, an educator may perceive that a learner is disengaged or disinterested and find it difficult to commit the “energy” to engage the learner. Even if the learner makes subsequent attempts to engage, the educator may dismiss it as a feigned attempt to re-engage and leave the learner on the “outside” of the learning experience looking in. A trusting and reciprocal relationship between the educator and learner is crucial for learner engagement and the development of the educator/learner dyad in the SLE.

**Conclusions**

Simulation learning is an effective learning experience that allows learners to develop and refine clinical reasoning skills. Preparation of the learner, the educator, and the environment to effectively utilize the simulation and debriefing process requires active engagement. This article introduces an Active Engagement Model to expand our understanding of the interactive nature of the “main players” of the SLE by describing the characteristics and responsibilities of each model component: the educator, the learner, the environment, and the educator/learner dyad. Each is a critical component to foster active engagement of learners. The educator designs an SLE that encourages student engagement and then facilitates the creation of the educator/learner dyad. Learners bring life-experiences, new knowledge, and uncertainty to the learning environment. They must be motivated and willing to engage completely in the learning process through a “reflective self-discovery” in order to recognize weaknesses in decision-making and clinical reasoning skills and to be humble enough to correct those weaknesses with the guidance of the educator. The environment must be safe and protective of learners who are required to “unveil” themselves in order to access cognitive processes and emotions linked to decisions and actions. This unique environment must be created by educators early in the educational experience. The educator/learner dyad is the functional component of the active engagement model and refers to a safe, trusting and open interaction between the learner and the educator in order to access shared knowledge, understanding, experience, and clinical reasoning processes. This dyadic relationship can either fail to form or become unstable if one of the members fails to engage or if the environment becomes unsafe.

Simulation and debriefing is an effective adjunct to add to the educator’s armamentarium. Designing the SLE is complex and challenging for the simulation educator. Learners must actively engage in the experience for deep learning and clinical reasoning to develop. All educational experiences should teach, support, and encourage active engagement from the first day of classes. Educators who want to develop clinical reasoning skills in their graduates will innovatively design engaging learning environments that utilize the effective learning experience of simulation and debriefing.

**References**

1. Jeffries, P. R. A Framework for Designing, Implementing, and Evaluating Simulations Used as Teaching Strategies in Nursing. Nursing Education Perspectives. 2005; 26(2):96-103.

2. Najjar, R. H., Lyman, B., & Miehl, N. Nursing students' experiences with high-fidelity simulation. International Journal of Nursing Education and Scholarship. 2015; 12(1):1-9.

3. Jensen, R. Clinical reasoning during simulation: Comparison of student and faculty ratings. Nurse Education in Practice. 2013; 13(1): 23-8. doi:10.1016/j.nepr.2012.07.001

4. Aqel, A. A., & Ahmad, M. M. High-fidelity simulation effects on CPR knowledge, skills, acquisition, and retention in nursing students: HFS and CPR knowledge and skills. Worldviews on Evidence-Based Nursing. 2014; 11(6): 394-400. doi:10.1111/wvn.12063

5. Dunn, K. E., Osborne, C., & Link, H. J. High-fidelity simulation and nursing student self-efficacy: Does training help the little engines know they can? Nursing Education Perspectives. 2014; 35(6):403-4. doi:10.5480/12-1041.1

6. Decker, S., Sportsman, S., Puetz, L., et al. The evolution of simulation and its contribution to competency. Journal of Continuing Education in Nursing. 2008; 39(2): 74-80. doi: 10.3928/00220124-20080201-06

7. Hayden, J., Smiley, R., Alexander, M., et al. Supplement: The NCSBN national simulation study: A longitudinal, randomized, controlled study replacing clinical hours with simulation in prelicensure nursing education. Journal of Nursing Regulation. 2014; 5(2): C1-S64.

8. Childs, J. C., Sepples, S, & Chambers, K. Designing simulations for nursing education. In P. R. Jeffries (Ed.), Simulations in Nursing Education From Conceptualization to Evaluation. New York, NY; NLN; 2007. p. 40

9. Shinnick, M. A., Woo, M., Horwich, T. B., et al. Debriefing: The Most Important Component in Simulation? Clinical Simulation in Nursing. 2011; 7(3): e105-e11. doi: 10.1016/j.ecns.2010.11.005

10. Dreifuerst, K. T. The Essentials of Debriefing in Simulation Learning: A Concept Analysis. Nursing Education Perspectives. 2009; 30(2):109-14.

11. DeMaria Jr, S., Bryson, E. O., Mooney, T. J., et al. Adding emotional stressors to training in simulated cardiopulmonary areest enhances participant performance. Medical Education; 2010; 44:1006-15. doi:10.1111/j.1365-2923.2010.03775.x

12. Cook, D. A., Hamstra, S. J., Brydges, R., et al. Comparative effectiveness of instructional design features in simulation-based education: Systematic review and meta-analysis. Medical Teacher. 2013; 35: e844-e75. doi:10.3109/0142159X.2012.714886

13. Rudolph, J., Simon, R., Rivard, P., et al. Debriefing with Good Judgment: Combining Rigorous Feedback with Genuine Inquiry. Anesthesiology Clinics. 2007; 25:361-76. doi: 10.1016/j.anclin.2007.03.007

14. Lusk, J. M., & Fater, K. Postsimulation debriefing to maximize clinical judgment development. Nurse Educ. 2013; 38(1):16-19. doi: 10.1097/NNE.0b013e318276df8b

15. Clapper, T. C. Beyond Knowles: What Those Conducting Simulation Need to Know About Adult Learning Theory. Clinical Simulation in Nursing. 2010; 6(1): e7-e14. doi: 10.1016/j.ecns.2009.07.003

16. Raemer, D., Anderson, M., Cheng, A., et al. Research regarding debriefing as part of the learning process. Simul Healthc. 2011; 6 Suppl:S52-7. doi: 10.1097/SIH.0b013e31822724d0

17. Cheng, A., Eppich, W., Grant, V., Sherbino, J., Zendejas-Mummert, B., & Cook, D. Debriefing for technology-enhanced simulation: a systematic review and meta-analysis. Medical Teacher. 2014; 48: 657-66.

18. Cheng, A., Grant, V., Diechmann, P., Arora, S., Robinson, T., & Eppich, W. Faculty development for simulation programs: Five issues for the future of debriefing training. Simulation in Healthcare. 2015; 10(4): 217-22. doi: 10.1097/SIH.0000000000000090

19. Derakshan, N., & Eysenck, M. W. Anxiety, processing efficiency, and cognitive performance: New developments from attentional control theory. European Psychologist; 2009; 14(2):168-76. doi: 10.1027/1016.9040.14.2.168

20. Talmi, D., & McGarry, L. M. Accounting for immediate emotional memory enhancement. Journal of Memory and Language. 2012; 66(1):93-108. doi:10.1016/j.jml.2011.07.009

21. Yonelinas, A. P., & Ritchey, M. The slow forgetting of emotional episodic memories: an emotional binding account. Trends in Cognitive Sciences. 2015 May; 19(5):259-67. doi:10.1016/j.tics.2015.02.009

22. Rau, V., & Fanselow, M. S. Exposure to a stressor produces a long lasting enhancement of fear learning in rats. Stress. 2009; 12:289-313.

23. Roozendaal, B., & McGaugh, J. L. Memory modulation. Behavioral Neuroscience. 2011; 125:797-824.

24. Mui, A. C., Heilman, R. M., & Houser, D. Anxiety impairs decision-making: Psychological evidence from an Iowa Gambling Task. Biological psychology. 2008; 77:353-58. doi:10.1016/j.biopsycho.2007.11.010

25. Calvo, M. G., Avero, P., & Miguel-Tobal, J. J. Multidimensional anxiety and content-specificity effects in preferential processing of threat. European Psychology. 2003; 8(4): 252-65.

26. Mao, X., You, Y., Li, W., et al. Emotion impairs extrinsic source memory: Am ERP study. Biological Psychology. Forthcoming 2015. http://dx.doi.org/10.1016/j.biopsycho.2015.07.005

27. Sousa, D. A. How the brain learns. 4th Edition. Thousand Oaks, CA: Corwin; 2011. 47 p.

28. Edwards, E. J., Edwards, M. S., & Lyvers, M. Cognitive trait anxiety, situational stress, and mental effort predict shifting efficiency: Implications for attentional control theory. Emotion. 2015; 15(3):350-59. http://dx.doi.org/10.1037/emo0000051

29. Kromann, C. B., Jensen, M. L., & Ringsted, C. Stress and learning. Medical Education. 2010; 44:950-52. doi: 10.1111/j.1365-2923.2010.03817.x

30. Nielsen, B., & Harder, N. Causes of student anxiety during simulation: What the literature says. Clinical Simulation in Nursing. 2013 Nov; 9(11):e507-e12. http://dx.doi.org/10.1016/j.ecns.2013.03.003

31. Zigmont, J. J., Kappus, L. J., & Sudikoff, S. N. The 3D model of debriefing: defusing, discovering, and deepening. Semin Perinatol. 2011; 35(2):52-8. doi: 10.1053/j.semperi.2011.01.003

32. Kuiper, R., Heinrich, C., Matthias, A., et al. Debriefing with the OPT model of clinical reasoning during high fidelity patient simulation. Int J Nurs Educ Scholarsh. 2008; 5: Article17. doi: 10.2202/1548-923x.1466

33. Schön, D. Educating the reflective practitioner: Toward a new design for teaching and learning in the professions. San Fransisco, CA: Jossey-Bass; 1987. 174 p.

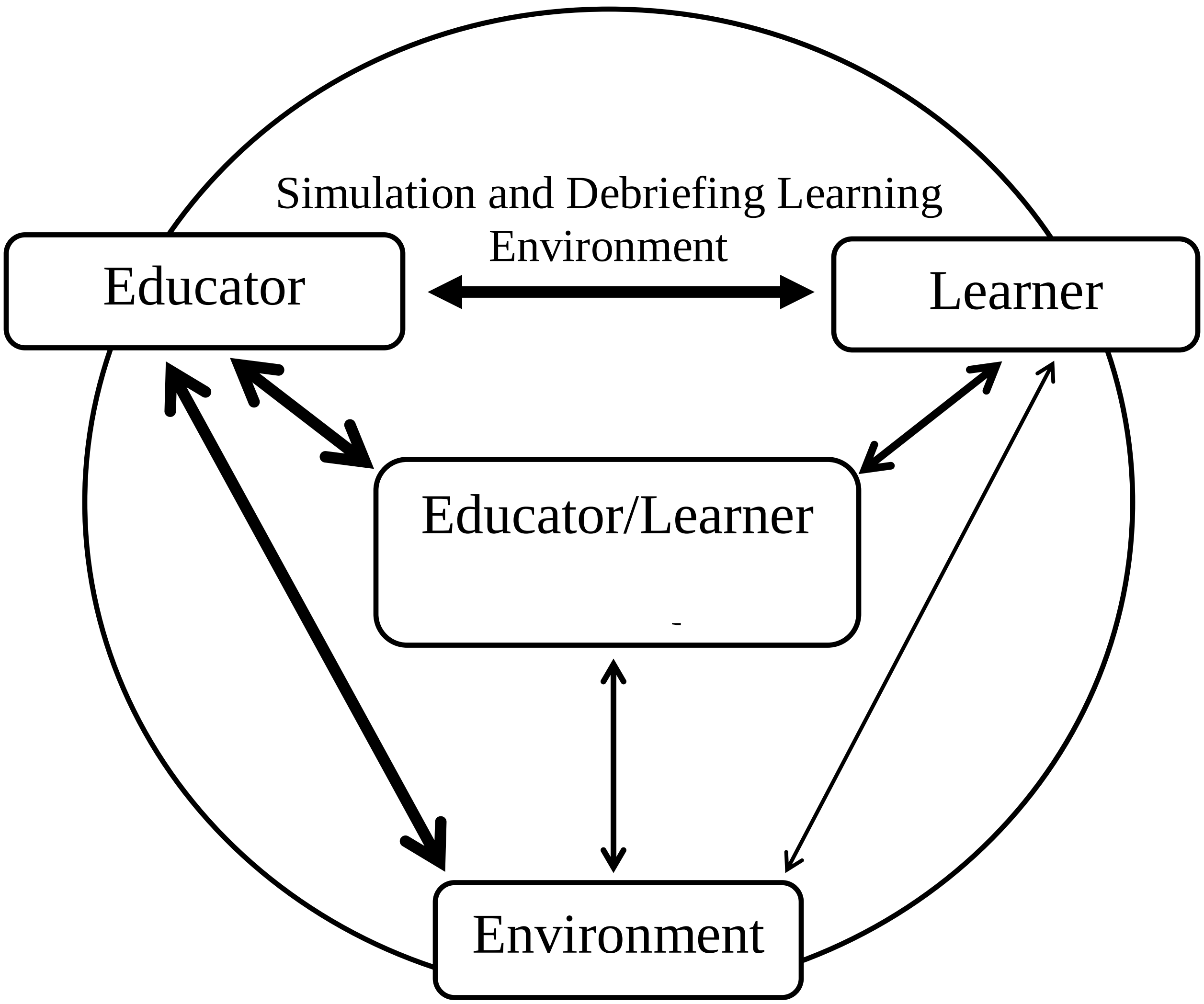
34. Decker, S., Sideras, S., Rockstraw, L., et al. Standards of Best Practice: Simulation, Standard VI: The Debriefing Process. Clinical Simulation in Nursing. 2013; 9: e26-e29. doi: 10.1016/j.ecns.2013.04.008

35. Doyle, T. Learner-Centered Teaching: Putting the Research on Learning into Practice. Sterling, Virginia: Stylus Publishing, LLC; 2011. *xii* p.

36. Sisk, R. J. Team-Based Learning: Systematic Research Review. Journal of Nursing Education. 2011; 50(12): 665-69. http://dx.doi.org/10.3928/01484834-20111017-01

37. Fisher, R. Designing the simulation learning environment: An active engagement model. Journal of Nursing Education and Practice. 2016; 6(3), 6-14. doi:10.5430/jnep.v6n3p6

**Figure 1.** Active Engagement Model for the simulation and debriefing environment. The educator, learner, and the environment are interrelated components that impact the creation of the educator/learner dyad, which is the functional entity of the simulation and debriefing learning environment. Heavier weighted arrows associated with the educator indicate greater influence on the learner and environment components and on the creation of the educator/learner dyad.



# Chapter 3

## A Neurophysiological Approach to Skill Development

The acquisition, retention, and performance competency of the health care professional's psychomotor skills are constant concerns for educators, employers and ultimately, the stakeholders of competent care – the patient. Public demand for competent health care is becoming increasingly influential in the direction of healthcare educational paradigms, exerting external pressure on educational institutions to require demonstration of learner procedural skill competency prior of actual patient contact. This concept is especially evident in anesthesia education where many common procedures, if improperly performed due to the lack of proper training, may result in patient harm. The apprenticeship model of procedural skill development, originally proposed by Halsted,[1] is no longer an acceptable training paradigm to acquire procedural skills.[2] Yet, surgical and allied healthcare professions' training continues to rely on this method of skill development.[3] Recently, there has been strong emphasis for simulation training for the novice learner in a controlled, safe learning environment to develop essential anesthesia skills.[2,4] Balancing the needs of the patient and the learner is a challenge for educators. Moreover, the primary concern in healthcare education must be the safety of the patient over the needs of the learner.[5] In view of these external pressures to produce competent practitioners, health care educators must have a better understanding of the skill development process in the creation of new educational paradigms in knowledge and skill acquisition and retention. The purpose of this paper will be to focus on the novice learner and explore the neurophysiologic foundations of initial psychomotor skill development to inform the design of the simulation learning environment.

**The Evolution of Educational Paradigms**

Anesthesia practitioners belong to a profession based heavily on the performance of procedures, many of which are highly technical. The overall guiding purpose of healthcare professions education is to provide safe and competent care to all patients, beginning with the effective preparation and skill development of the novice learner.[6] Unfortunately, accurately defining and measuring competency seems to be an elusive goal for many educators.[7] Nevertheless, competent performance depends on proper skill development. The unique skills required for many complex procedures impose challenges to skill acquisition for the learner and may lead to a compromise in patient safety. Additionally, a lack of experience with rarely used or novel procedures may also compromise patient safety for the practicing provider.[8] Training the novice learner prior to actual patient contact is a complex and multifactorial process, which includes didactic instruction and a psychomotor skill development experience. Didactic instruction and psychomotor skill development are integral in the proper preparation of the practitioner prior to entering the patient care environment. The simulation setting is the most effective learning environment to develop the many unique and highly technical psychomotor skills required for anesthesia practice.[9]

Dreyfus and Dreyfus originally described psychomotor skill acquisition as existing on a continuum beginning from a novice and progressing to an expert level.[10] This model was later adapted by Benner for a nursing skill acquisition model.[11] The Dreyfus/Benner model explains that a learner progresses through novice, advanced beginner, competent, proficient, and expert stages as they acquire and improve psychomotor skills over time.[12] Educators should refrain from describing progressive skill development as simply the result of repetitive practice. Some types of skill practice are less effective than other types and the efficacy of instructional methods may vary at different stages of skill development.[13,14] Additionally, learners may progress through the stages at varying rates and may even plateau on some levels for extended periods of time making skill development a complex and dynamic process.[15]

There are many educational, affective, and psychomotor factors related to the development and performance of procedural skills that should be addressed in the design of the simulation learning environment (SLE).[15] For example, the acquisition and competent performance of many anesthetic procedures, such as ultrasound-guided regional anesthesia (USGRA), requires the integration and cognitive processing of many elements of information including a) declarative and procedural knowledge, b) complex motor planning using both hands functioning independently, c) environmental and instrumental perceptual feedback cues, d) managing performance anxiety, and e) problem-solving processes.[16,17] This vast array of complex cognitive processes is coordinated primarily in the prefrontal cortex (PFC) in an area commonly referred as the central executive of which working memory (WM) is a central part.[18] From this central executive, coordination of other brain areas produces observable behaviors (intentional or automatic). Sweller developed the Cognitive Load Theory (CLT) to explain how the WM handles this array of information during the learning process and performance of a skill.[19] Through the CLT, Sweller proposed that WM has a limited capacity.[19] This concept is supported by additional research by Cowen.[20] A neurophysiologic approach to skill acquisition using the CLT, may better explain the learner's progression from the novice through the advanced stages of skill development. Helping learners progress through these stages requires adapting instructional methods to match the neurophysiologic state of skill learning of the learners.

**Skill Development**

Psychomotor skill learning is a multifactorial process and includes components such as memory construction, attentional focus to relevant information, and motivational factors.[14] Therefore, informed educators should base the design of skill learning experiences on all components of the skill learning process. Conceptually, motor skill learning may be thought as the construction of robust and enduring memories incorporating all the procedural knowledge and motor movement plans necessary to perform a skill and the ability to use that information to perform the skill progressively more rapidly and with fewer errors.[21] The creation of these skill memories depends on multiple unobservable neurophysiological processes involving the encoding, consolidation, and retrieval of these memories.[14] Skill development should manifest as incremental improvements of skill speed, economy of movement, and accuracy of performance.[21] Skill performance improvements may reflect the brain's ability to efficiently "chunk" multiple informational elements together to improve cognitive processing.[22] In addition, performance improvements may reflect the efficiency of neurophysiologic changes that occur in the brain during the learning process.[14] There has been a recent evolution in health care educational paradigms in the last few decades fueled by the unfolding of new skill learning research and functional brain imaging techniques. This paradigmatic evolution is now beginning to enlighten educators on more effective simulation-based skill learning designs to develop and retain skill performance competency in their learners.

**Neurophysiology of Skill Learning and Performance**

There is a distinction between skill learning and performance. True learning reflects a relative permanence in the ability to perform a skill over time and adapting the skill in different situations.[14,22] Even at the end of the initial introduction and practice of a novel skill, learners can oftentimes perform the skill, but over time, performance may degrade without further practice. A learner's ability to perform a skill over time is the result of progressive structural and functional changes occurring within the brain and these changes offer a novel exploration of the neurophysiological processes that explain skill development.[14] One of the most important neurophysiologic factors in skill acquisition and performance relates to the mental load imposed in the brain as the learner manages multiple cognitive resources during the learning experience.[19,23] The PFC is the most critical brain area involved during initial skill learning and performance.[24] The PFC is an area of the brain where the highest-order cognitive functions occur, including the communication and coordination with other brain areas.[24,25] The functions of the PFC are various and include handling and processing incoming perceptual information, retrieving existing knowledge from long-term memory, generating mental representations to be used in abstract thinking and problem-solving, regulating emotions, and planning motoric events.[23-27] The exploration of PFC function during skill learning and performance is accomplished through research into WM and cognitive load.

**Cognitive Load and Working Memory**

The function of working memory is to gather and organize perceptual information and retrieve information already learned from long-term memory (LTM) into a central space within the brain where it is temporarily held for cognitive processes.[18] During skill learning and performance, WM holds relevant information regarding the sequencing of actions (procedural knowledge), declarative knowledge, motor plans for movement, and errors committed during previous learning.[28] WM simultaneously processes these informational elements (single pieces of information) by comparing them to previously learned information, examining and manipulating these elements if needed.[29] This concept of simultaneous processing of multiple informational elements in WM has been characterized as cognitive load.[19]

WM has significant capacity and temporal limitations. Only three to five pieces of information (elements) can be processed at one time and for only for about 30 seconds without updating that information [20] and these limitations may even vary among individuals.[22,30] These limitations of WM exert a significant influence on the skill learning process and performance.[28] If a basic skill and the environment in which the skill is learned does not produce many information elements, WM may be able to process all elements simultaneously, facilitating learning.[31] If the learning experience contains many elements, WM will attempt to process all of the informational elements, possibly exceeding its capacity to effectively handle all of the elements. If some of those elements are irrelevant to the task, subsequently constructed memories may be incomplete or erroneous. This can be seen with novice learners who may only remember parts of a complex task during performance. In view of the limitations of WM, educators should design learning environments that minimize irrelevant information.[32]

Sweller proposed three types of loads that may be processed simultaneously in WM – intrinsic, extraneous, and germane load,[19,31] During a skill learning experience, all task-relevant informational elements constitute the intrinsic load and informational elements that are not required for effective learning or performing the task (task-irrelevant) constitute extraneous load.[32] The novice learner, lacking knowledge and experience of information that is relevant and irrelevant, may process both types of information at the same time, placing a potential burden or load on WM capacity.[33,34] Learning a novel skill involves managing many informational elements simultaneously and may produce a high cognitive load on WM. Complex skills may also contain many interacting informational elements that have to be processed simultaneously and may result in impaired learning or performance.[31,32] Educators may choose to fractionate highly complex skills into smaller chunks to be later combined into the entire task once components have been learned.[35]

Informational elements repetitively rehearsed in WM are designated as important to remember. Those informational units become memories or neural representations, beginning with the encoding process.[36] The encoding process depends on the frequency and duration of time the information was held in WM, or by the emotive components associated with that information.[14,36] Continued processing of informational elements leads to the formation and consolidation of long-term memories referred to as schemata.[14,32] A schema represents a neuronal network or "cellular assembly" of interrelated informational elements that includes stimulus identification, declarative and procedural information, response selection, and the motor response.[14,32] A schema may be treated as a single informational unit within WM or may completely bypass WM during use.[37,38] Schemata retrieval and processing reduces the number of information elements in WM and, as a result, reduces the cognitive load.[38] Neuroimaging studies showed a decreased activation of the PFC in individuals that have automatized a skill (using constructed schemata), indicating a decreased cognitive load.[24] These principles of schema construction, storage, and retrieval forms the basis of understanding the learner's progression through the stages of skill development and provides a framework upon which to design skill learning experiences.

In contrast to retrieved schemata, all perceptual information processed in WM is treated as individual informational elements. A highly complex task or situation, or an active environment will create an increased perceptual load for WM unless attention can be focused on only the relevant components of the experience.[39] Attentional focus is another important function of the PFC and assists to avoid overwhelming WM with irrelevant perceptual information.[39] Updating information elements in WM requires attentional focus to the relevant task elements.[39] Disrupting attentional focus with irrelevant or extraneous information impairs this updating process and may impair WM function.[28] Irrelevant factors that may disrupt attention are those associated with the simulation environment. Extraneous noise from other groups, extremes in temperature, irrelevant conversations within groups, and potentially social media are all factors that may lead to diverting attentional focus away from the learning experience.[37] Educators should be aware of these disrupting effects to attentional focus during skill learning and design learning environments that minimize these types of disruptions.

**Emotions, Anxiety and the Stress Response**

An important aspect of all learning environments is the additional stress of emotions, especially anxiety, for the learner. Emotion represents a dynamic mental state reflecting an individual's past and present experiences and responses to the environment, circumstances, or relationships with others.[40] The learner may emotionally interact with the learning environment in at least two ways. One interaction involves the inherent emotional state the learner brings to the learning experience. The other emotional state is more situational and is generated in response to the learning experience. Most emotions play a significant role in how the learner approaches and engages in the learning experience. Learner emotions influence the learning process and how effectively the learning experience transfers to different contexts.[40] Both types of emotional state have various overlapping effects on learning and may be, at least partly, managed by the educator through informed and effective design of the simulation learning environment (SLE).[40-42]

The emotions that a learner brings to the learning environment may be positive, negative, or somewhere on a continuum between these polar states. McConnell and Eva proposed that emotions may influence how the learner perceives, processes, and interprets information.[40] These authors explored the effect of emotion on the learner's attentional focus, memory retrieval, and the motivation to act on information received. In their integrative review, these authors found positive emotions allow for more global processing of information, increased flexibility in thinking about that information, and encourages an expanded search for alternative solutions to problems encountered during learning. In contrast, these authors also found that negative emotions cause a more specific focus of attention.[40] The benefits of having a global perspective versus a more specific focus of attention most likely depends on the context of the learning situation and the skill level of the learner. The educator can explore the learner's focus of attention during the learning experience by inquiring on which aspects of the scenario the learner is currently focusing.

Anxiety during simulation is also an emotional state that a learner may bring to the SLE (trait anxiety) or in response to what is being currently experienced (state anxiety).[39,41,42] Anxiety occurs when an individual perceives that he or she does not possess sufficient cognitive or emotional resources needed to deal with the demands of a current or future situation.[43,44] The body's response to anxiety elicits a stress response encompassing a set of psychological and physiological reactions. This stress response is modulated through the PFC which subsequently activates a highly complex set of neural circuitries within the brain to effect behavioral and neuro-endocrine responses.[44] The main effects of stress during learning and performance center around the increased production and release of the catecholamine neurotransmitters and the activation of the hypothalamic-pituitary-adrenal axis with the subsequent release of glucocorticoids from the adrenal medulla.[45,46] These innate responses to stress serve to prepare the organism to successfully adapt to the changes in the environment that are perceived as a threat to this balance between demands and resources; a process called *allostasis*.[45] The two main effects of the stress response on learning and performance are its effects on the neuroendocrine response and the cognitive load of working memory.[44,45]

Severe stress impairs the function of WM and turns the brain from a reflective state to a reflexive state, thus impairing the ability to make decisions.[25] In her integrative review, Arnsten found that this impairment is the result of increased levels of catecholamines (dopamine and norepinephrine) within the PFC, which affect the intracellular signaling pathways and weaken PFC function. Increased glucocorticoid release during the stress response may accentuate the effects of catecholamines throughout the brain further impairing PFC function.[25] In addition, high levels of catecholamines facilitate the affective responses in the emotional centers of the brain, namely the amygdala and striatum, which in turn attach an emotive component to the experience.[25] This physiological response may be one of many plausible reasons why emotional events tend to be remembered more easily than emotionless events. Emotional events are also more frequently retrieved (sometimes covertly) which tends to strengthen these memories.[40]

Anxiety states add additional informational load for processing in WM. During a learning or performance experience, if the amount of information processed in the WM exceeds its limited capacity, there may be preferential processing (attentional bias) of the perceived threat stimuli.[47] Perceived threat stimuli act as task-irrelevant information, taking up critical processing space in WM. This creates an attentional shift away from task-relevant information.[39] If the task is complex, processing task-irrelevant threat stimuli in addition to task-relevant information may overwhelm WM capacity leading to impaired learning and/or task performance.[39] Several investigations found that impaired learning occurs when the learner experiences moderate to severe stress.[22,41,43,47,48]

Repetitive learning experiences with mild to moderate stressors may help the learner to develop positive stress adaptations for future skill learning and performance.[49] Several authors proposed incorporating stress management training, such as mental imagery training, into the simulation learning experience.[43,49] Developing positive stress adaptation in learners during the simulation learning experience is an important part of effective simulation design, but unfortunately, this is aspect of simulation design has received little attention to date. Once the learner enters the clinical environment, maintaining optimal cognitive performance during subsequent skill acquisition and performance should be a crucial goal for all the health care professions. This is especially true when performing highly complex procedures or in situations that produce high anxiety. Educators need to be aware of the effects of anxiety on learning and performance and design the SLE where learners feel safe to make mistakes will be crucial for optimizing the learning experience.[42,50] In addition, highly anxious learners have an increased sensitivity to externally perceived threats, such as a potential to fail or being observed during performance.[39] Although it may be difficult to know beforehand if a learner is more susceptible to the effects of anxiety during learning, educators should identify those learners that exhibit detrimental anxiety during instruction, such as poor performance or diverted attentional focus, and develop plans for additional directed practice opportunities and stress management training for these learners.[42,49]

**Neurophysiology of Skill Memory Construction**

Whether informational elements are perceived or retrieved as schemata from LTM, rehearsal of these elements in WM causes the brain to undergo structural and functional changes to construct more permanent "physical residues" (memories) of the cognitive interactions with an experience.[36] Several researchers have hypothesized that initial memory construction is related to alterations in synaptic connectivity and the growth of dendritic spines within these coalitions of neurons (memory networks).[36,51,52] This initial beginning of a skill memory (engram formation) during early skill learning is the result of repeated sequential firing of neurons in a specific cellular assembly (memory network).[36] The repeated firing within this network causes temporary activity-dependent biochemical changes in synaptic neurotransmitter receptors, enhancing synaptic transmission through these memory pathways.[36] As a result, with repeated rehearsal during this initial learning phase, the learner may quickly acquire the ability to remember and perform the skill. The transient modification of synaptic transmission by repeated activation is referred to as activity-induced long-term potentiation.[51] These transient plastic changes in the synaptic connectivity of this early stage of skill learning rapidly decay if the memory trace is not frequently activated. This decay may be the result of the lack of use or interference with the memory.[53,54] The consolidation of memory networks into schemata for long-term storage is proposed to be the process of more permanent stabilization of memories, becoming resistant to interference or decay.[55] Several authors proposed that consolidation depends on long-term structural changes in cellular matrices, changes in gene-expression, and through a dynamic process of dendritic spine remodeling within the neurons of these memory networks.[36,52,56] These changes are also facilitated by frequent activation of those memory networks during training (on-line), through the retrieval process during skill practice and performance assessments, and even between training experiences (off-line).[57] These long-term changes may also involve the construction and deconstruction of these neuroplastic changes to allow for critical updating of schemata and decision-making processes.[58] Several studies showed the importance of the time period after learning and sleep in the process of schema consolidation.[14,57,59]

Neglect or interference may prevent consolidation.[53] Neglect occurs when the memory is simply not rehearsed/re-activated. Even though a learner quickly acquires a new skill during the initial training experience, that skill memory may deteriorate if the memory network is not strengthened by frequent rehearsal.[54] Interference of memory consolidation can occur if the learner engages in additional didactic or skill learning immediately following the original skill learning experience.[53] Davis and Zhong suggested that subsequent learning may divert attention away from the first skill, causing the transient neuroplastic changes to decay and making consolidation of those memories less likely.[53] Introducing multiple novel skills in one session may interfere with the creation of the initial skill memories.

Schemata may contain parts or all of the cognitive and motor information needed to perform a task. When performing the task, the schema or group of associated schemata are retrieved from LTM and either reprocessed WM as a single informational element, or completely bypass it, eliciting the learned behavior.[60] Once a comprehensive schema is retrieved, the memory program may run automatically. This is the process of automatization.[32,37] Automatized schema do not place a cognitive burden on WM. Only novel information elements (anxiety reactions, interactions with peers, an uncooperative patient, or dealing with an adverse reaction) that are not a part of the retrieved schema, will need to be processed in WM.[32] During a skill training experience, an educator might present the learner with a simulated case with abnormal anatomy or with a procedure needing slight modification to match a revised treatment plan. By adding additional components or complexity to a skill performance scenario, the educator can indirectly measure the learner's cognitive load to determine if the skill had been learned and automatized.[28]

As the result of continued rehearsal and experience, the learner may advance through the higher stages of skill development. The cognitive load of WM improves with the use of automatized schemata compared to multiple novel task elements. More experienced learners at the level of advanced beginner tend to perform simple skills with less errors and without having to think about their performance as much as they did when they were first learning that skill.[21]

**Skill Learning Strategies**

The foundational principle for determining the effectiveness of skill learning strategies is based on the neurophysiologic evidence demonstrating that frequent activation of specific neuronal networks involved in the performance of a skill causes neuroplastic changes in those networks that allow for stabilization and consolidation into long-term memories. These long-term memories can then be easily accessed and more efficiently processed to produce improved skill performance. The competent performance of a skill reflects the efficiency of the encoding, consolidation, and retrieval processes.[14] Common skill learning strategies include physical practice, mental imagery, and observational learning.

Physical practice is the most important and most commonly used skill learning strategy in simulation.[14] There are many types of physical practice strategies that have shown to be quite effective such as deliberate practice,[61] variable practice,[14] and directed self-regulated learning.[62] Unfortunately, there are multiple barriers to skill learning in the simulation environment that create physical practice limitations for the learner.[63] Except in limited learning institutions, access to the simulation environment may be limited. In view of the limitations associated with learner access to simulation environments, other learning strategies that have been shown to be similarly effective as physical practice, but do not require access to simulation environments, are the use of mental imagery (MI) and observational learning (OL).[35,64,65]

Researchers, using electroencephalographic activity, found that mental imagery (MI) techniques and physical practice share many of the same neurophysiologic correlates, supporting the concept of functional and anatomical equivalence.[66,67] MI techniques also produce similar brain reorganizational (neuroplasticity) effects as physical practice.[66] Surprisingly, this group of researchers also found that mental imagery can effectively replace up to 75% of physical practice for learning a motor task and was even more effective than physical practice if the mental rehearsal was performed at high rates.[67] Researchers have proposed that MI may be an effective adjunct and/or alternative learning strategy to repetitive physical practice in the acquisition of complex procedural skills.[68,69]

Observational learning involves either observing an expert skill performance via a live demonstration or video (modeling examples) or studying a written account of an expert working through a problem (worked examples).[65] Hurley proposed that OL and MI activate similar neural pathways as actual physical performance.[70] Repeated activation of the same neural pathways may act to strengthen schema underlying the cognitive processes of skill performance in the same manner as repeated physical practice and mental imagery. OL also occurs as peers watch a member of their group perform a skill.[65] Not only are similar neural pathways activated when observing their peer, but Kirschner, Paas, and Kirschner found that learners also engage in collaborative learning by sharing their “collective” WM with each other.[71] These authors proposed that by sharing cognitive load with group members, they could construct higher quality schemata than if working individually.[71]

**Designing the Simulation Learning Environment**

Several important aspects of the SLE design should be emphasized that encourage learner engagement and effectively activate the neuroplastic processes that facilitate skill learning. Principles of cognitive load will help to inform the educator in this design.[32,72-74] The educator should provide easy and succinct instructions to optimize intrinsic load necessary for skill learning.[31,75] Poorly understood, ambiguous, or redundant instruction contributes to extraneous load and may impair skill development.[31] During the initial stages of skill development, the learner must have accurate information on proper skill performance to create a correct schema. The instructor should give immediate feedback on the learner's performance before consolidation and automatization of schemata occurs. Once automatized, an erroneous schema may be cognitively burdensome to revise compared to creating a correct schema in the first place.[22,24] Instructor observation and feedback are crucial components in the early phases of skill development to ensure correct schema formation. Additionally, educators should continually assess learner cognitive load during skill learning by observing how the learner handles additional informational elements during performance. If the performance of the task declines with additional information, the learner may be experiencing a high cognitive load which may indicate that the skill has not yet been completely learned (automatized).[28] Educators should avoid extraneous distractions during the early skill learning stage to allow the learner to focus attention on the relevant information.[31] As the learner progresses into advanced stages, skills become automatized and the educator can add additional information in the form of questions or additional events to the scenario to help the learner manage additional loads.

The SLE can be a complex and dynamic environment, with many potential barriers to optimal learning. Multiple instructional stations with small groups of learners may generate extraneous noise through the normal conduct of simulation experiences or with irrelevant conversation. All other activity or conversations within the simulation environment have the potential to divert learner attention away from the learning experience, not only for the learner performing a skill, but also for other learners that are observing.[65] Scheduling smaller groups in the simulation center, using physical barriers, or spacing skill stations at appropriate distances may attenuate disturbances from other groups. Ambiguous instructions can be avoided by appropriate and thorough faculty development and preparation and by using explicit grading rubrics and skill guidelines. These barriers should be minimized by thoughtful, informed design of the SLE.[72]

The SLE can also be a stressful learning experience due to the nature of the simulation scenarios and learner performance in front of peers and instructors. Emotion, especially anxiety, plays a significant role in the learning process and may be effectively managed through informed design of the learning environment.[42] Learners must feel safe in the learning environment to avoid the perception of threats which may overwhelm cognitive load during learning and performance experiences.[76] Adequate learner and educator preparation is critical in designing a “safe” and effective learning environment and fostering collegial learner/peer and learner/educator interactions.[76,77]

**Skill Learning Evaluation**

Effective skill learning refers to the encoding and consolidation of motor skill memories into LTM, efficiently retrieving those memories, and processing them with novel information to produce an appropriate behavioral response (skill performance). Evaluating competency is a critical component in the preparation of the learner to enter the clinical environment. Skill learning follows two stages, an initial fast acquisition stage, characterized by transient performance, followed by a latent slow learning stage retaining more permanent memory effects.[14] Evaluating performance immediately after skill acquisition may assess the "correctness" of skill acquisition in the initial stage, but have little power to predict retention of the skill. Retention or transfer evaluations are commonly conducted after a period of time and reflect a more permanent learning effect of the learner.[14] The educator should address these principles of skill learning during SLE design and incorporate both immediate and delayed skill learning evaluations into the simulation design.

In simulation skills training, the skill performance evaluation should be a learning experience for the learner. These examinations may be thought as an additional learning experience as they also act to strengthen and add to existing schemata.[78] Skill performance in front of an evaluator also serves to add a degree of anxiety, like an actual performance on a patient, and produces a more accurate evaluation of the learning and transferability of the skill to the clinical environment.[15,78] Educating learners on the benefits of evaluations may help them understand the value of the information they gain from the experience and how to use that information to modify their future efforts to learn. A thorough feedback of the results of the evaluation by the educator will be critical for the learner to utilize this information. If educator feedback from the evaluation experience is cursory (only the grade or score), the information will be meaningless to the learner on how to improve.[77,79] Skill assessments should also determine if task movements have been automatized. When skills are automatized, other cognitive processes such as decision-making can occur by reducing the attentional focus of skill performance.[22,24]

## Feedback and Debriefing

Feedback and debriefing have been proposed as integral components of simulation learning.[77,80] The effectiveness of these two evaluation methods stems from the basic principle that retrieval and rehearsal of memories of a recent performance helps to reinforce those memory networks.[43] Ideally, time should be taken to allow the learner to reflect on the experience (bring the memory back into WM where it can be reviewed mentally).[81] Many individuals will mentally rehearse (imagine) parts of the scenario in their minds, remember their performance with the help of video recordings.[42,77] Using information from a validated metric (rubric) during feedback improves skill development when compared to feedback offered without the use of a rubric.[16] Summative evaluations with feedback are invaluable to skill development if the learner utilizes the feedback information to guide subsequent practice.[16] Curricular time constraints may prevent the learner to engage in further practice after summative evaluations unless required by the design of the SLE or by a learner's internal motivation to improve performance. More effective SLE designs should include re-engaging the learner after the assessment in a focused practice experience using the feedback from the educator.[16] Focused post-evaluation practice allows the learner to re-activate schemata used to perform the skill, correct errors, and reinforce the appropriate skill components that may have been forgotten (deterioration of memory components).[16]

## Faculty Development

Faculty development incorporating these neurophysiologic principles in simulation learning is crucial to ensure successful and effective skill learning experiences. With this neurophysiological foundation, educators may more clearly understand the importance of evaluating the level of skill development in each learner and adjusting instructional methods that are most effective for each individual learner.[33,82] Learners at different stages of skill acquisition may have varying instructional requirements.[83] Some instructional strategies that are effective for the novice learner can impair skill development in the advanced learner, as demonstrated in the "expertise-reversal effect".[83] Even within a heterogeneous group of learners during a simulation scenario, the informed educator can manipulate the learning experience depending on the level of skill development of each learner in the group. The educator may incorporate higher-level scenario components or ask more complex questions to the advanced learner while keeping the scenario more basic for lower level learners. Important guiding principles for educators in these situations is to continuously evaluate the level of skill development for each learner; monitor the learners for signs of overwhelming stress; manage the scenario to diffuse that stress; and ensure a positive, non-threatening environment where learners feel safe and are willing to freely engage in the learning experience.[76,84] Most importantly, each learner's skill level differences must be maintained confidential by the educator to avoid embarrassment and learner disengagement in the learning experience.[42,76,84]

Among the many components of an effective SLE, debriefing is a critically important element and one that should be more fully developed in the simulation faculty to ensure an optimal learning experience.[85] Other aspects of simulation learning that educators should better understand include a) the guiding principles of experiential learning, b) using feedback effectively, c) developing appropriate relationships between learners, and d) creating the critical learner/educator dyadic relationship.[76]

**Conclusions**

The central focus of this review was to explore the neurophysiological foundation of skill learning during the early stages of skill development to inform the design of the SLE. Brain imaging studies and motor skill acquisition research are rapidly expanding our understanding of how skills are developed, maintained, and transformed. These neurophysiological foundations supply the evidence that skill development occurs in stages with specific training requirements.[82] Basing SLE design on these foundations may represent a crucial component of a revolutionary transformation that simulation training is playing on health care professions education and patient safety.[86]

One of the limitations of this review is the lack of literature supporting the effective transfer of skills developed in simulation training to the clinical environment and on actual patients. There is anecdotal evidence that strong simulation training facilitates learners' transfer of skills into the clinical arena, yet there is limited empirical evidence. This may require the evaluation of clinical skills using a standardized objective assessment tool that can be returned to the educational institution for comparison with previous simulation assessments. More advanced skill development was not addressed here, but many of these same neurophysiological principles may still apply. Several other factors not addressed in this review that may affect learning in the simulation environment are motivation and goal-orientation, age differences with learning skills, and the optimal practice strategies. Clearly, continuing research is needed in these areas.

**References**


1. Halsted WS: The training of the surgeon. Bull Johns Hopkins Hosp 1904; 15:267-75.

2. Grantcharov TP, Reznick RK: Teaching procedural skills. Br Med J 2008; 336:1129-31.

3. Reznick RK, MacRae H: Teaching surgical skills – Changes in the wind. N Engl J Med 2006; 2664-9.

4. Chen XX, Trivedi V, AlSaflan AA, Todd SC, Tricco AC, McCartney CJL et al. Ultrasound-guided regional anesthesia simulation training: a systematic review. Reg Anesth Pain Med 2017; 42:741-50.

5. Cundiff GW, Geoffrion R: Balancing the needs of patients and learners in surgery. J Obstet Gynaecol Can 2016; 38:1124-6.

6. McGaghie WC, Issenberg SB, Cohen ER, Barsuk JH, Wayne DB: Does simulation-based education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. Acad Med 2011; 86:706-11.

7. Sklar DP: Competencies, milestones, and entrustable professional activities: what they are, what they could be. Acad Med 2015; 90:585-7.

8. Kilbane BJ, Adler MD, Trainor JL: Paediatric residents' ability to perform a lumbar puncture: evaluation of an educational intervention. Pediatr Emerg Care 2010; 26:558-67.

9. Chang C: Medical simulation is needed in anesthesia training to achieve patient safety. Korean J Anesthesiol 2013; 64:204-11.

10. Dreyfus SE: The five-stage model of adult skill acquisition. Bull Sci Technol Soc 2004; 24: 177-81.

11. Benner P: From novice to expert. Am J Nurs 1982; 82:402-7.

12. Griswold-Theodorson S, Ponnuru S, Dong C, Szyld D, Reed T, McGaghie WC: Beyond the simulation laboratory: a realist synthesis review of clinical outcomes of simulation-based mastery learning. Acad Med 2015; 90:1553-60.

13. Kantak SS, Sullivan KJ, Fisher BE, Knowlton BJ, Winstein CJ: Neural substrates of motor memory consolidation depend on practice structure. Nat Neurosci 2010; 13:923-5.

14. Kantac SS, Winstein CJ: Learning-performance distinction and memory processes for motor skills: a focused review and perspective. Behav Brain Res 2012; 228:219-31.

15. Khan K, Ramachandran S: Conceptual framework for performance assessment: Competency, competence and performance in the context of assessments in healthcare – deciphering the terminology. Med Teach 2012; 34:920-8.

16. Ahmed OMA, Niessen T, O'Donnell BD, Gallagher AG, Breslin DS, DunnGalvin A et al. The effect of metrics-based feedback on acquisition of sonographic skills relevant to performance of ultrasound-guided axillary brachial plexus block. Anaesthesia 2017; 72:1117-24.

17. Smith HM, Kopp SL, Johnson RL, Long TR, Cerhan JH, Hebl JR: Looking into learning: visuospatial and psychomotor predictors of ultrasound-guided procedural performance. Reg Anesth Pain Med 2012; 37:441-7.

18. Baddeley A: Working memory: looking back and looking forward. Nat Rev 2003; 4:829-39.

19. Sweller J: Cognitive load during problem solving: effects on learning. Cognit Sci 1988; 12:257-85.

20. Cowan N: The magical mystery four: how is working memory capacity limited, and why? Curr Dir Psychol Sci 2010; 19:51-7.

21. Debarnot U, Sperduti M, Di Rienzo F, Guillot A: Expert bodies, expert minds: how physical and mental training shape the brain. Front Hum Neurosci 2014; 8:280-96.

22. Seidler RD, Bo J, Anguera JA: Neuroconitive contributions to motor skill learning: the role of working memory. J Mot Behav 2012; 44:445-53.

23. Bjerrum AS, Hilberg O, van Gog T, Charles P, Eika B: Effects of modelling examples in complex procedural skills training: a randomized study. Med Educ 2013; 47:888-98.

24. Patel R, Spreng RN, Turner GR: Functional brain changes following cognitive and motor skills training: a quantitative meta-analysis. Neurorehab Neur Rep 2013; 27:187-99.

25. Anrsten AFT: Stress weakens prefrontal networks: molecular insults to higher cognition. Nat Neurosci 2015; 18:1376-85.

26. Grahn JA, Parkinson JA, Owen AM: The role of the basal ganglia in learning and memory: neuropsychological studies. Behav Brain Res 2009; 199:53-60.

27. Hardwick RM, Rottschy C, Miall RC, Eickhoff SB: A quantitative meta-analysis and review of motor learning in the human brain. Neuroimage 2013; 67:283-97.

28. Buszard T, Farrow D, Verswijveren SJJM, Reid M, Williams J, Poman R et al. Working memory capacity limits motor learning when implementing multiple instructions. Front Psychol 2017; 8:1-12.

29. Rottschy C, Langer R, Dogan I, Reetz K, Laird AR, Schulz JB et al. Modelling neural correlates of working memory: a coordinate-based meta-analysis. Neuroimage 2012; 60:830-46.

30. DeCaro MS, Thomas RD, Beilock SL: Individual differences in category learning: sometimes less working memory capacity is better than more. Cognition 2008; 107:284-94.

31. Sweller J: Element interactivity and intrinsic, extraneous, and germane cognitive load. Educ Psychol Rev 2010; 22:123-38.

32. Van Merriënboer JJG, Sweller J: Cognitive load theory in health professional education: design principles and strategies. Med Educ 2010; 44:8593.

33. Schilling J: In respect to the cognitive load theory: adjusting instructional guidance with student expertise. J Allied Health 2017; 46:e25-e30.

34. Milton J, Solodkin A, Hlustík P, Small SL: The mind of expert motor performance is cool and focused. NeuroImage 2007; 35:804-13.

35. Spruit EN, Band GPH, Hamming JF, Ridderinkhof KR: Optimal training design for procedural motor skills: a review and application to laparoscopic surgery. Psychol Rev 2014; 78:878-91.

36. Queenan BN, Ryan TJ, Gazziniga, MS, Gallistel CR: On the research of time past: the hunt for the substrate of memory. Ann NY Acad Sci 2017; 1396:108-25.

37. Choi H, van Merriënboer JJG, Paas F: Effects of the physical environment on cognitive load and learning: Towards a new model of cognitive load. Educ Psychol Rev 2014; 26:225-44.

38. Paas F, Ayres P: Cognitive load theory: A broader view on the role of memory in learning and education. Educ Psychol Rev 2014; 26:191-5.

39. Derakshan N, Eysenck MW: Anxiety, processing efficiency, and cognitive performance. Euro Psychologist 2009; 14:168-76.

40. McConnell MM, Eva KW: The role of emotion in the learning and transfer of clinical skills and knowledge. Acad Med 2012; 87:1316-22.

41. LeBlanc VR: The effects of acute stress on performance: implications for health professions education. Acad Med 2009; 84:S25-S33.

42. Nielsen B, Harder N: Causes of student anxiety during simulation: what the literature says. Clin Simul Nurs 2013; 9:e507-12.

43. Arora S, Sevdalis N, Nestel D, Woloshynowych M, Darzi A, Kneebone R: The impact of stress on surgical performance: a systematic review of the literature. Surgery 2010; 147:318-30.

44. Cerquiera JJ, Almeida, OFX, Sousa N: The stressed prefrontal cortex. Left? Right! Brain Behav Immun 2008; 22:630-8.

45. Shansky RM, Lipps J: Stress-induced cognitive dysfunction: hormone-neurotransmitter interactions in the prefrontal cortex. Front Neurosci 2013; 7:123

46. McEwen BS, Bowles NP, Gray JD, Hill MN, Hunter RG, Karatsoreos IN: Mechanisms of stress in the brain. Nat Neurosci 2015; 18:1353-63.

47. Miu AC, Heilman RM, Houser D: Anxiety impairs decision-making: psycholophysiological evidence from an Iowa Gambling Task. Biol Psychol 2008; 77:353-8

48. Lang PJ, Bradley MM: Emotion and the motivational brain. Biol Psychol 2010; 84:437-50.

49. Crewther BT, Shetty K, Jarchi D, Selvadurai S, Cook CJ, Leff DR et al. Skill acquisition and stress adaptations following laparoscopic surgery training and detraining in novice surgeons. Surg Endosc 2016; 30:2961-8.

50. Ganley BJ, Linnard-Palmer L: Academic safety during nursing simulation: perceptions of nursing students and faculty. Clin Sim Nurs 2012; 8:e49-e57.

51. Poo M, Pignatelli M, Ryan TJ, Tonegawa S, Bonhoeffer T, Martin KC et al. What is memory? The present state of the engram. BMC Biol 2017; 1-18.

52. Viggiano D, Speranza L, Crispino M, Bellenchi GC, di Porzio U, Iemolo A et al. Information content of dendritic spines after motor learning. Behav Brain Res 2018; 336:256-60.

53. Davis RL, Zhong Y: The biology of forgetting – a perspective. Neuron 2017; 95:490-502.

54. Pertzov Y, Manohar S, Husain M: Rapid forgetting results from competition over time between items in visual working memory. J Exp Psychol Learn Mem Cogn 2017; 43:528-36.

55. Censor N: Generalization of perceptual and motor learning: a causal link with memory encoding and consolidation? Neuroscience 2013; October 10:201-7.

56. Marshall P, Bredy TW: Cognitive neuroepigenetics: the next evolution in our understanding of the molecular mechanisms underlying learning and memory? NPJ Sci Learn 2016; 1:1-19.

57. Hallgató E, Győri-Dani D, Pekár J, Janacsek K, Nemeth D: The differential consolidation of perceptual and motor learning in skill acquisition. Cortex 2013; 49: 1073-81.

58. Richards BA, Frankland PW: The persistence and transience of memory. Neuron 2017; 94:1071-84.

59. Korman M, Doyon J, Dojansky J, Carrier J, Dagan Y, Karni A: Daytime sleep condenses the time course for memory consolidation. Nat Neurosci 2007; 10:1206-13.

60. Paas F, Ayres P: Cognitive load theory: a broader view on the role of memory in learning and education. Educ Psychol Rev 2014; 26:191-5.

61. Hastings RH, Rickard TC: Deliberate practice for achieving and maintaining expertise in anesthesiology. Anes Analg 2015; 120:449-59.

62. Brydges R, Nair P, Ma I, Shanks D, Hatala R: Directed self-regulated learning versus instructor-regulated learning in simulation training. Med Educ 2012; 46:648-56.

63. Al-Ghareeb AZ, Cooper SJ: Barriers and enablers to the use of high-fidelity patient simulation manikins in nurse education: an integrative review. Nurs Ed Today 2016; 36:281-6.

64. Kim T, Frank C, Schack T: A systematic investigation of the effect of action observation training and motor imagery training on the development of mental representation structure and skill performance. Front Neurosci 2017; 11:499.

65. van Gog T, Paas F, Marcus N, Ayres P, Sweller J: The mirror neuron system and observational learning: implications for the effectiveness of dynamic visualizations. Educ Psychol Rev 2009; 21:21-30.

66. Allami N, Brovelli A, Hamzaoui EM, Regragui F, Paulignan Y, Boussaoud D: Neurophysiological correlates of visuo-motor learning through mental and physical practice. Neuropsychologia 2014; 55:6-14.

67. Allami N, Paulignan F, Brovelli A, Boussaoud D: Visuo-motor learning with combination of different rates of motor imagery and physical practice. Exp Brain Res 2008; 184:105-13.

68. Rao A, Tait I, Alijani A: Systematic review and meta-analysis of the role of mental training in the acquisition of technical skills in surgery. Am J Surg 2015; 210:545-33.

69. Stefanidis D, Anton NE, Howley LD, Bean E, Yurco A, Pimentel ME et al. Effectiveness of a comprehensive mental skills curriculum in enhancing surgical performance: results of a randomized controlled trial. Am J Surg 2017; 213:318-24.

70. Hurley S: The shared circuits model (SCM): how control, mirroring, and simulation can enable imitation, deliberation, and mindreading. Behav Brain Sci 2008; 31:1-58.

71. Kirschner F, Paas F, Kirschner PA: A cognitive load approach to collaborative learning: united brains for complex tasks. Educ Psychol Rev 2009; 21:31-42.

72. Qiao YQ, Shen J, Liang X, Ding S, Chen FY, Shao L et al. Using cognitive theory to facilitate medical education. BMC Med Educ 2014; 14:79.

73. Leppink J, van den Heuvel A: The evolution of cognitive load theory and its application to medical education. Perspect Med Educ 2015; 4:119-27.

74. Naismith LM, Haji FA, Sibbald M, Cheung JJH, Tavares W, Cavalcanti RB: Practising we preach: using cognitive load theory for workshop design and evaluation. Perspect Med Educ 2015; 4:344-8.

75. Ayres P, Paas F: Interdisciplinary perspectives inspiring a new generation of cognitive load research. Educ Psychol Rev 2009; 21:1-9.

76. Fisher R: Designing the simulation learning environment: an active engagement model. J Nurs Educ Prac 2016; 6:6-14.

77. Sawyer T, Eppich W, Brett-Fleegler M, Grant V, Cheng A: More than one way to debrief: a critical review of healthcare simulation debriefing methods. Sim Healthcare 2016; 11:209-17.

78. Sawyer T, White M, Zaveri P, Cheng T, Ades A, French H, et al.: Learn, see, practice, do, maintain: an evidence-based pedagogical framework for procedural skill training in medicine. Acad Med 2015; 90:1025-33.

79. Weinstein DF: Feedback in clinical education: untying the Gordian knot. Acad Med 2015; 90:609-14.

80. Decker S, Fey M, Sideras S, Caballero S, Rockstraw L, Boese T et al. Standards of best practice: simulation standard VI: the debriefing process. Clin Simul Nurs 2013; 9:e26-9

81. Husebo SE, Dieckmann P, Rystedt H, Soreide E, Friberg F: The relationship between facilitators' questions and the level of reflection in postsimulation debriefing. Sim Healthcare 2013; 8:135-42.

82. Carraccio CL, Benson BJ, Nixon J, Derstine PL: From the educational bench to the clinical bedside: translating the Dreyfus developmental model to the learning of clinical skills. Acad Med 2008; 83:761-7.

83. Kalyuga S, Singh A: Rethinking the boundaries of cognitive load theory in complex learning. Educ Psychol Rev 2016; 28:831-52.

84. Arafeh J, Hansen S, Nichols A: Debriefing in simulation-based learning: facilitating a reflective discussion. J Perinat Neonat Nurs 2010; 24:302-9.

85. Cheng A, Grant V, Dieckmann P, Arora S, Robinson T, Eppich W: Faculty development for simulation programs: five issues for the future of debriefing training. Simul Healthc 2015; 10:217-22.

86. Gaba DM, Raemer D: The tide is turning: organizational structures to embed simulation in the fabric of healthcare. Simul Healthc 2007; 2:1-2.

# Chapter 4

## Expanding the Simulation Learning Environment Using Mental Imagery

### Abstract

**Introduction:** Simulation-based skill development, while valuable, has time and cost limitations. Mental imagery (MI) offers an alternative practice strategy to expand the simulation learning effectiveness. We compared learning outcomes when using MI practice or physical practice (PP) in ultrasound-guided (US) needling skills (primary skill) in student registered nurse anesthetists (SRNAs).

**Methods:** Twenty-six SRNAs completed an US-guided needling skill training. Students were timed performing the skill, with and without a secondary task, before and after a three-week practice period using either physical or MI practice strategies. A secondary task was added to the skill performance to evaluate skill automatization and two subjective cognitive load questionnaires to evaluate the mental effort during skill performance.

**Results:** Wilcoxon tests showed that both PP and MI groups had significant improvement in the median difference scores between the pre- to post-test for the primary skill ($p$ = .001 and .05, respectively) and with a secondary task added ($p$ = .001 and .006, respectively). In evaluating the primary skill performance, Mann Whitney U tests showed that the PP group had greater improvement than the MI group ($p$ = .041). When adding a secondary task, there was no significant difference in the median skill improvement score between either practice group ($p$ = .193). Regression analyses showed practice type significantly predicted primary skill performance ($\beta$ = -.43, $p$ = .026), but showed no significant predictive ability when adding the secondary task.

**Conclusions:** MI practice may be a useful adjunct practice strategy when combined with physical practice of an US-guided needling skill. In view of the limitations associated with access to simulation environments, MI may improve the simulation learning environment.

**Introduction**

The expanding use of ultrasound-guided anesthesia procedures requires specialized training and depends on the creation of effective skill learning environments (SLEs) that facilitate the development and retention of these complex psychomotor skills. The ongoing challenge for anesthesia educators is optimizing the design of the SLE, using innovative learning strategies, to facilitate greater skill development prior to actual patient care.[1] Integrating mental imagery (MI) practice strategies is one such innovation that may increase the effectiveness of current SLEs. MI is the imagined rehearsal of a physical movement without actual observable movement.[2]

Recent systematic and meta-analytic reviews revealed simulation-based learning (SBL) to be the most effective learning environment to acquire psychomotor skills.[3-5] Simulation-based skill development is a complex, multifactorial process depending on a dynamic interaction of the learner, the educator, and the learning environment.[6] The primary outcome for SBL must be to develop competent skill performance prior to actual patient care. Competent skill performance is facilitated through the construction of robust psychomotor skill memories (schemata) that direct performance.[7] The fundamental skill development learning strategy is repetitive practice.[8-10] Unfortunately, faculty time, accessibility, and the financial burdens of running costly SLEs produce worrisome limitations to optimal skill development in SBL.[8, 11] Recently, researchers explored the use of MI in health care professions education to mitigate these limitations.[8, 12-14] In a systematic review, Shuster and colleagues found that MI is an effective alternative practice strategy to develop psychomotor skills.[15] The effectiveness of developing skills using MI practice strategies is based on the principle of expanding practice opportunities beyond the simulation lab.[13, 16]

Simulation design limitations may also include the inadequate assessment of skill competency and retention during and after initial training.[17, 18] These additional limitations may result from the lack of a thorough understanding of the skill learning process.[9] Psychomotor skill learning engages complex neurophysiological processes of the human cognitive architecture.[19] Effective SBL should lead to the construction of robust long-term memories (schemata) which incorporate the procedural information and motor movement plans required to competently perform the skill and indicates that true learning has occurred.[7, 9, 19-20] Once constructed, these schemata are accessed from inexhaustible long-term memory stores and cognitively processed automatically to guide skill performance.[7, 9, 21] The optimal function of these neurophysiological processes may be impeded by internal and external factors, including poorly designed features of the SLE (poor instructional or evaluative methods) and limited practice opportunities.[21-22] Incomplete skill development caused by poorly designed SLEs may impede the brain's ability to effectively process information by cognitively overloading the brain's working memory (WM) during learning and performance.[7, 21] Cognitive overloading during the skill learning process may weaken the efficacy of simulation-based skill learning and is frequently the factor leading to increased stress and poor performance.[23] The innovative use of MI, coupled with more accurate learning assessments, may enhance the efficacy of skill development in light of the potential limitations of the SLE.

Common skill assessments may have limited value in predicting competent skill performance in the clinical setting.[24] In view of the cognitive load produced in many learning environments and during actual skill performance, Stefanidis and associates proposed a more robust skill assessment strategy by adding a secondary task to the primary skill performance.[18] These researchers proposed that a secondary task will demonstrate how well a skill has been learned and how much mental load is being simultaneously managed during performance. Performance may be degraded by a high cognitive load if a skill has not been adequately learned.[25] Adding a secondary task may also more closely simulate actual patient care situations by creating additional cognitive loading factors commonly associated with these situations.

The purposes of this pilot investigation were three-fold. We sought to compare the outcomes of MI with physical practice (PP) strategies in developing an ultrasound-guided needling skill in student registered nurse anesthetists (SRNAs) after a 3-week skill development practice period. We looked for skill performance improvement using either practice strategy and differences in skill performance between PP and MI practice strategies. Secondly, we evaluated the strength of this skill development with each practice strategy using a secondary task assessment by exploring a) if there was a significant change in cognitive loading during performance of a primary skill and a secondary task and b) how each practice strategy explained the difference in performance scores. Thirdly, we examined the relationships between the different cognitive load measures to evaluate convergence.

## Methods

This pilot study used an experimental, randomized, pre- and post-test design to examine within and between group outcomes. Midwestern University's institutional review board approved the protocol and the University of Kansas Medical Center extended a reliance agreement.

### Participants

Of the 34 newly matriculated students from a single nurse anesthesia program invited, 27 consented to participate in this study. The admissions criteria for entrance into the nurse anesthesia program constituted the inclusion criteria. Students who had formally taught or frequently used in-plane ultrasound imaging to place intravenous catheters were excluded from statistical analysis; no participants fit these exclusion criteria. One participant withdrew from the study after initial instruction and pre-testing.

**Measures**

***Main outcome measure – Time-to-complete skill (TTC).*** Each participant's performance of a primary skill was timed at each of two pre-tests (preTTC and preTTC2) and two post-tests (postTTC and postTTC2) by instructors expert in ultrasound-guided needling skills. The TTC score was generated by timing (in seconds) each participant's performance of the primary skill. The primary skill involved in-plane guidance of a nerve block needle (Stimuplex 360, BBraun) under continuous ultrasound visualization to touch two embedded simulated nerves and one blood vessel in a tissue block (Peripheral nerve block, CAE Blue Phantom). For the TTC2 scores, a secondary task was added to the primary skill (see below description and diagram in Figure 1).

**Cognitive Load Measures**

***Secondary task.*** To introduce a secondary task during both the second pre- and post-tests (TTC2), five additional echogenic structures were embedded into a second tissue block. During the second tests, each participant was instructed to perform the primary skill while remembering the number and locations of the additional structures. After completion, the participant was asked to draw the locations of the additional structures on a diagram representing a cross-sectional view of the tissue block. Scoring for the secondary task (Pre and Postsectask) equaled the total number of correct responses (number of additional targets found plus the number of correct locations of each target for a total score of 10 points). We proposed that the secondary task would require the learner to allocate attentional WM resources to remember the numbers and locations of these additional structures. Participants who had not automatized the primary skill would have prolonged times-to-complete (TTC2) the primary task due to directing attentional resources not only to parts of the primary task but also the secondary task.[26]

***Subjective Cognitive Load Questionnaires (NASA-TLX, Paas Scale).*** The NASA-Task Load Index (NASA-TLX) is a subjective, self-report assessment of perceived mental, physical, and temporal workload of task completion. Respondents self-rate their performance in successfully accomplishing the task, the effort needed, and their level of frustration. The NASA-TLX, developed by Hart and Steveland and subsequently evaluated by several investigators,[27-28] has been widely used in previous investigations. [29-31] The NASA-TLX consists of six 20-point visual analog scales of mental workload. The sum of all six scales generated an overall workload score from 6 to 120 points (Pre- and Post-TLX).

The Paas Scale asks a single question of perceived mental effort in a completed task with rating levels from 1 (very, very low mental effort) to 9 (very, very high mental effort), generating the pre- and post-tests scores (Pre- or PostPaas).[32] Paas reported that versions of this scale had high Spearman rank order correlations (.9) with objective measures of task difficulty and that subjective measures of task difficulty also have very high face validity. For both measures, a lower score indicated the participant perceived little mental effort in completing the task and a higher score indicated a large mental effort was required.

**Procedures**

After collecting consent forms and demographic data, all participants attended a 2-hour classroom presentation on the fundamentals of ultrasound physics, imaging, and needle guidance. Next, each participant received one-on-one instruction and hands-on practice with feedback on the primary skill by nurse anesthesia faculty. When participants successfully demonstrated the ability to direct the needle under continuous ultrasound guidance to each of the three designated structures, they completed the two pre-tests and questionnaires. Participants were then randomly allocated to either a PP or a MI practice group using a sequentially-numbered, opaque sealed envelope (SNOSE) process.[33] All participants received a special identification number and a skill training packet, informing them of their practice group allocation, practice schedules, and instructions on how to practice the skill over six sessions (30-minute duration) during the subsequent three weeks. No additional instruction or feedback was provided by faculty. Participants were instructed to avoid watching videos of the skill or discussing their practice strategy with other participants or investigators. After the practice period, each participant completed two post-tests (PostTTC and PostTTC2) and the questionnaires. To calculate improvement scores (DIFF* variables), post-test scores were subtracted from pre-test scores. Each participant placed their special identification numbers on all study forms and practice logs to maintain blindedness of investigators. After collection and database entry of all interventional procedural data, a data entry assistant added the group allocation and de-identified demographic data to the database to ensure investigator blindedness. See Figure 2 for study flow diagram.

**Experimental and Control Groups**

After randomization, an administrative assistant informed the MI group of a training module available on the student learning platform. This training module included a PowerPoint presentation of MI principles and a video presentation by a clinician expert in MI training and techniques. This mental imagery training included pre-imagery relaxation, first- versus third-person imaging, evaluating MI abilities, and a practice session using a script (also available in audio format). The script followed the script development procedures described by other investigators.[8, 34] Following this training, the participants were instructed to use MI techniques to practice the primary skill during the skill practice period suggested by other researchers.[13, 35] Audio-taped MI scripts could be listened to as many times as desired during the MI practice sessions. Researchers have found that mental imagery practice without any physical practice yielded poor results.[36] Therefore, the MI group was instructed to physically practice the primary skill once during the 2nd and 4th training sessions with the remainder of the practice time dedicated to MI practice. The PP group (control) had scheduled access to the simulation center and equipment, utilizing common physical practice techniques to practice the primary skill over the same three-week practice period.

**Statistical Analysis**

IBM SPSS Statistics, v. 25 (SPSS Inc., Chicago, IL) was used for all analyses. Descriptive statistics were used to characterize the sample demographics. Mann-Whitney U tests determined homogeneity across the two practice groups. Wilcoxon signed rank tests determined any significant skill performance improvement, as measured by the difference of pre- and postTTC (DIFF, DIFF2) and improvement in the secondary task (DIFFsectask) scores. Mann Whitney U tests determined any significant difference in the improvement scores between the PP and MI groups. Wilcoxon Signed Rank tests examined any significant pre- to post-test changes in secondary task (DIFFsectask), NASA-TLX (DIFFtlx), or the Paas scale (DIFFpaas) scores within each group. Two linear regression analyses, using the outcome variables (DIFF, DIFF2), and the independent variables of practice group (PP and MI), described the amount of variance in the outcome variables. Finally, a Spearman's rho examined the strength of the relationships between measures of secondary task (sectask), Paas scale (Paas), and NASA-TLX (TLX). A value of $P < .05$ was considered statistically significant.

**Results**

Twenty-six subjects (PP: $N = 14$, MI: $N = 12$) completed all study protocol comparing the effects of MI practice (experimental group) with PP (control group) skill learning strategies. The sample was composed of more males than females and the median age was in the early 30's. Table 1 demonstrates the homogeneity of the two groups with no significant differences in demographics or baseline pre-test scores.

Within Group Skill Performance: A Wilcoxon Signed-Ranks Test indicated the median post-test TTC and TTC2 scores for the PP group were significantly lower than the pre-test scores ($Z = 0.00$, $p < .001$ and $Z = 1.00$, $p = .001$, respectively). Participants using MI strategies also improved primary skill performance ($Z = 14.00$, $p = .05$) and primary skill performance plus the secondary task ($Z = 4.00$, $p < .006$). See Tables 1 and 2 for pre- and post-test scores.

Between Group Skill Performance: When comparing practice groups, Mann Whitney U tests indicated the PP group had significantly greater median improvement scores than the MI group (median: PP = 47.70 seconds, MI = 20.42 seconds; $U = 44.00$, $p = .041$). When adding a secondary task to the primary skill, there was no significant difference in the median skill improvement score between the practice groups ($U = 58.00$, $p = .193$).

After completing the practice period, Mann Whitney U tests demonstrated that there was no statistically significant improvement in measures of cognitive load using the secondary task ($U = 82.50$, p = .940) or Paas scores ($U = 68.50$, $p = .432$) between groups. There was a significant difference in NASA-TLX scores between groups ($U = 38.50$, $p = .017$).

Predictive Modeling: Simple linear regression analyses were calculated to predict skill performance improvement based on group allocation and showed mixed results. When performing the primary skill alone, a significant regression equation was found ($F(1,24) = 5.61$, $p$

= .026), with an $R^2$ = .189. Participants' predicted improvement score is equal to 107.75 – 42.29 (seconds). Participants' median TTC score decreased 42.29 seconds due to group allocation. When adding a secondary task simultaneously to the primary skill performance, a second linear regression equation was not significant ($R^2$ = .106, $F(1,24)$ = 2.86, $p$ = .104) indicating group allocation did not significantly predict primary skill performance.

A Spearman *rho* correlation showed that NASA-TLX and Paas scale scores were positively, moderately, and significantly related (pre-scores: *rho* = .58, $p$ = .002; post-scores: *rho* = .44, $p$ = .025). Secondary task scores did not significantly relate to the other cognitive load measures.

**Discussion**

Even though physical practice was shown to be more effective in improving primary skill performance time, we discovered that mental imagery practice might be an effective adjunct practice strategy in developing a novel ultrasound-guided needling skill in nurse anesthesia students. Although primary skill performance improvement showed significant differences between practice groups, when adding a secondary task to the primary skill, those differences disappeared. Adding a secondary task to the primary skill performance may more closely simulate actual patient care situations and reflect a more accurate assessment of the learners' skill performance abilities.[18, 37] An additional question resulting from this investigation was whether learning with novel MI strategies also increased cognitive load. We suggest additional research to disentangle how MI leads to variability in skill learning.

Because the secondary task scores and cognitive load measures did not significantly change from pre- to post-testing, we propose that this length of practice period was insufficient to automatize the primary skill as suggested by other investigators.[7, 21] Brief training periods are common in simulation learning. Learners may show an improvement in skill performance during practical assessments, yet, still not have automatized the skill.[18] This lack of skill automatization during training supports the use of alternative practice strategies, such as MI, that can be effectively used outside the simulation environment to expand skill development.

The main limitation of this pilot study was the small sample size. A power analysis based on moderate effect sizes from previous MI studies suggested a sample size of 32 participants per group; under-powering the study. Another limitation may have been the use of a novel secondary task. The secondary task in this study followed the principles of a memory task as there were no previous investigations using a secondary memory task with developing the ultrasound-guided needling skill available.[16, 24] Using a memory task design avoided interference with the fine bimanual motor requirements of the primary skill. Stefanidis and his associates discovered that secondary tasks have limited sensitivity for novice learners during the early learning phase when they allocate more attentional resources to developing the primary skill.[38] These researchers added that secondary task scores did not significantly improve until learners achieved proficiency levels on the primary task, implying the effectiveness of using secondary tasks to assess automaticity. Additional research on secondary tasks during skill learning suggests that there may be interference when both primary and secondary tasks are presented in the same modality (visual).[37] It is unclear if this interference also impedes skill performance post-learning. Clearly, follow-up research should pursue the use of similar secondary tasks, including different modalities and increasing primary task fidelity, with skill development.

Innovative simulation design should optimize the learning and retention of psychomotor skills through the construction of automatized schemata, which may free cognitive resources to process unique situational factors accompanying clinical experiences. Completely abandoning the apprenticeship model is un-realistic, as skill development must continue past the competent stages, reached in simulation training, into the proficient and expert stages. Mental imagery practice strategies could be effectively employed in the design of the SLE to facilitate skill development. Future research should focus on illuminating effective mental imagery training principles, determining optimal practice period duration that results in skill retention and decreased cognitive loading, and developing effective secondary tasks and practical assessments that simulate actual patient care situations and assess true skill learning.

**References**


1. Diederich E, Thomas L, Mahnken J, Lindeberry M: Pretest scores uniquely predict 1-year-delayed performance in a simulation-based mastery course for central line insertion. Simul Healthc 2018; 13:163-7.
2. Jeannerod M: The representing brain: Neural correlates of motor intention and imagery. Behav Brain Sci 1994; 17:187-245.
3. Beal MD, Kinnear J, Anderson CR, Martin TD, Wambolt R, Hooper L: The effectiveness of medical simulation in teaching medical students critical care medicine: A systematic review and meta-analysis. Simul Healthc 2017; 12:104-16.
4. McGaghie WC, Issenberg SB, Cohen ER, Barsuk JH, Wayne DB: Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. Acad Med 2011; 86: 706-11.
5. Shin S, Park J, Kim J: Effectiveness of patient simulation in nursing education: Metanalysis. Nurs Educ Today 2015; 35:176-82.
6. Fisher R: Designing the simulation learning environment: An active engagement model. J Nurs Educ Pract 2016; 6:6-14.
7. Fraser K, Ayres P, Sweller J: Cognitive load theory for the design of medical simulations. Simul Healthc 2015; 10:295-307.
8. Arora S, Aggarwal R, Sevdalis N, Moran A, Sirimanna P, Kneebone R, Darzi A: Development and validation of mental practice as a training strategy for laparoscopic surgery. Surg Endosc 2010; 24:179-87.

9. Debarnot U, Sperduti M, Di Rienzo F, Guillot A: Expert bodies, expert minds: How physical and mental training shape the brain. Frontiers in Human Neuroscience 2014; 8:1-15.
10. Kantac SS, Winstein CJ: Learning-performance distinction and memory processes for motor skills: A focused review and perspective. Behav Brain Res 2012; 228:219-31.
11. Al-Ghareeb A, Cooper SJ: Barriers and enablers to the use of high-fidelity patient simulation manikins in nurse education: An integrative review. Nurs Educ Today 2016; 36:281-6.
12. Arora S, Aggarwal R, Sirimanna P, Moran A, Grantcharov T, Kneebone R, Sevdalis N, Darzi A: Mental practice enhances surgical technical skills: A randomized controlled study. Ann Surg 2011; 253:265-70.
13. Sanders CW, Sadoski W, van Walsum K, Bramson R, Wiprud R, Fossum TW: Learning basic surgical skills with mental imagery: Using the simulation centre in the mind. Med Educ 2008; 42:607-12.
14. Stefanidis D, Anton NE, McRary G, Howley LD, Pimentel M, Davis C, Yurco AM, Sevdalis N, Brown C: Implementation results of a novel comprehensive mental skills curriculum during simulator training. Am J Surg 2017; 213:353-61.
15. Schuster C, Hilfiker R, Amft O, Scheidhauer, A, Andrews B, Butler J, Kischka U, Ettlin T: Best practice for motor imagery: A systematic literature review on motor imagery training elements in five different disciplines. BMC Med 2011; 9:75.
16. Eldred-Evans D, Grange P, Cheang A, Yamamoto H, Ayis S, Mulla M, Immenroth M, Sharma D, Reedy G: Using the mind as a simulator: A randomized controlled trial of mental training. J Surg Educ 2013; 70:544-51.

17. Prabhu A, Smith W, Yurko Y, Acker C, Stefanidis D: Increased stress levels may explain the incomplete transfer of simulator-acquired skill to the operating room. Surgery 2010; 147:640-5.

18. Stefanidis D, Scerbo MW, Korndorffer Jr JR, Scott DJ: Redefining simulator proficiency using automaticity theory. Am J Surg 2007; 193:502-6.

19. Paas F, Sweller J: An evolutionary upgrade of cognitive load theory: Using the human motor system and collaboration to support the learning of complex cognitive tasks. Educ Psychol Rev 2012; 24:27-45.

20. Rao A, Tait I, Alijani A: Systematic review and meta-analysis of the role of mental training in the acquisition of technical skills in surgery. Am J Surgery 2012; 210:545-53.

21. van Merriënboer JJ, Sweller J: Cognitive load theory in health professional education: Design principles and strategies. Med Educ 2010; 44:85-93.

22. Choi H, van Merriënboer JJ, Paas F: Effects of the physical environment on cognitive load and learning: Towards a new model of cognitive load. Educ Psychol Rev 2014; 26:225-44.

23. Arora S, Sevdalis N, Aggarwal R, Sirimanna P, Darzi A, Kneebone R: Stress impairs psychomotor performance in novice laparoscopic surgeons. Surg Endosc 2010; 24:2588-93.

24. Buckley CE, Kavanagh DO, Traynor O, Neary PC: Is the skillset obtained in surgical simulation transferable to the operating theater? Am J Surg 2014; 207:146-57.

25. Buszard T, Farrow D, Verswijveren SJJM, Reid M, Williams J, Polman R, Chun Man Ling F, Masters RSW: Working memory capacity limits motor learning when implementing multiple instructions. Front Psychol 2017; 8:1-12.

26. Park B, Brunken R: Secondary task as a measure of cognitive load, Cognitive Load Measurement and Application. Edited by Zheng RZ. New York, Routledge, 2018, pp 74-92.

27. Hart SG, Staveland LE: Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research, Human Mental Workload. Edited by Hancock PA, Meshkati N. North Holland, Elsevier Science Publishers B.V., 1988, pp 139-83.

28. Nygren TE: Psychometric properties of subjective workload measurement techniques: Implications for their use in the assessment of perceived mental workload. Hum Fact 1991; 33:17-33.

29. Metzger U, Parasuraman R: Automation in future air traffic management: Effects of decision aid reliability on controller performance and mental workload. Hum Fact 2005; 47:35-49.

30. Endsley MR, Kaber DB: Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics 1999; 42:462-92.

31. Yurko YY, Scerbo MW, Prabhu AS, Acker CE, Stefanidis D: Higher mental workload is associated with poorer laparoscopic performance as measured by the NASA-TLX tool. Simul Healthc 2010; 5:267-71.

32. Paas FG: Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive load application. J Educ Psychol 1992; 84:429-34.

33. Doig GS, Simpson F: Randomization and allocation concealment: A practical guide for researchers. J Crit Care 2005; 20:187-93.

34. Ignacio J, Domans D, Scherpbier A, Rethans J, Lopez V, Liaw SY: Development, implementation, and evaluation of a mental rehearsal strategy to improve clinical performance and reduce stress: A mixed-methods study. Nurs Educ Today 2016; 37:27-32.

35. Barrington MJ, Wong DM, Slater B, Ivanusic JJ, Ovens M: Ultrasound-guided regional anesthesia: How much practice do novices require before achieving competency in ultrasound needle visualization using a cadaver model. Reg Anes Pain Med 2012; 37:334-9.

36. Mulla M, Sharma D, Moghul M, Kailani O, Dockery J, Ayis S, Grange P: Learning basic laparoscopic skills: A randomized controlled study comparing box trainer, virtual reality simulator, and mental training. J Surg Educ 2012; 69:190-5.

37. Park B, Brünken R: The rhythm method: A new method for measuring cognitive load – An experimental dual-task study. App Cogn Psychol 2015; 29:232-43.

38. Stefanidis D, Scerbo MW, Sechrist C, Mostafavi A, Heniford T: Do novices display automaticity during simulator training? Am J Surg 2008; 195:210-3.

**Tables and Figures**

**Table 1.** Demographic and pre-practice baseline skill comparison across groups

| Group | Gender Male:Female | Age median (range) | PreTTC median (range) | PreTTC2 median (range) | Presectask median (range) | PreTLX median (range) | PrePaas median (range) |
|---|---|---|---|---|---|---|---|
| PP | 9:5 | 31 (27-40) | 100.14 (54-216) | 138.85 (77-423) | 8.0 (6-10) | 52.0 (20-85) | 6.0 (2-9) |
| MI | 9:3 | 32.5 (27-40) | 75.60 (42-188) | 158.36 (64-187) | 9.5 (7-10) | 50.52 (9-67) | 6.0 (3-9) |
| PP vs MI (*p* values) * | | .860 | .212 | .595 | .560 | .980 | .560 |

*Mann-Whitney U tests (non-significance indicates no significant differences across practice groups)
PreTTC = time to complete primary skill (seconds) during pre-test. PreTTC2 = time to complete primary skill with an additional secondary task (seconds) during pre-test. Presectask = total score of secondary task during pre-test. PreTLX = NASA-TLX questionnaire score just after completing pre-testing. PrePaas = Paas questionnaire score just after completing pre-testing

**Table 2.** Post-test skill performance, Improvement (DIFF*), and cognitive load scores between practice groups

| Group | PostTTC median (range) | PostTTC2 median (range) | Postsectask median (range) | PostTLX median (range) | PostPaas median (range) |
|---|---|---|---|---|---|
| PP | 43.50 (23-76) | 57.81 (42-120) | 10.00 (6-10) | 37.00 (14-98) | 5.00 (2-7) |
| MI | 53.34 (36-138) | 81.61 (41-150) | 10.00 (6-10) | 53.50 (26-80) | 5.00 (3-8) |
| PP vs MI (*p* values) § | .060 | .118 | .527 | .027 | .781 |
| Improvement Scores (PP/MI) | 47.70/20.42 (144.14/ 154.09) | 77.69/65.79 (358.94/ 142.56) | 0.00/0.00 (8.00/ 7.00) | 8.00/10.00 (93.00/ 65.00) | 0.50/0.00 (7.00/ 5.00) |
| PP vs MI (*p* values) § | .041 | .193 | .940 | .017 | .432 |

§ Mann-Whitney U tests
Non-significance indicates no significant differences across practice groups
Post* values represent TTC, TTC2, sectask, TLX, and Paas scoring during the post-testing period

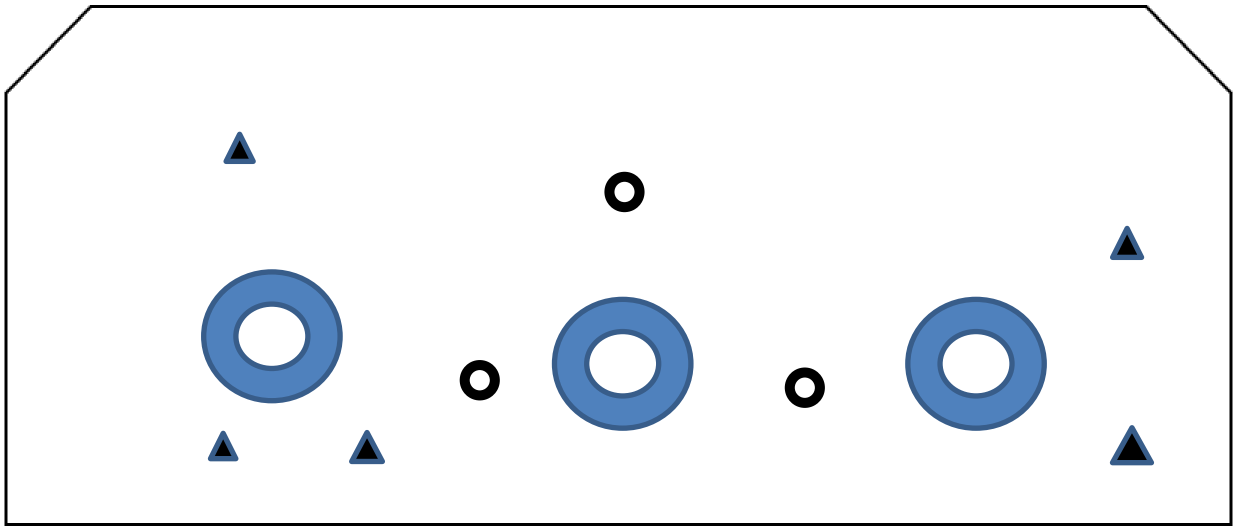


**Figure 1**. Diagram of tissue block with embedded structures
Large circles represent simulated blood vessels. Smaller circles represent simulated nerves. Triangles represent additional echogenic structures embedded for secondary task (pre- and post-TTC2)

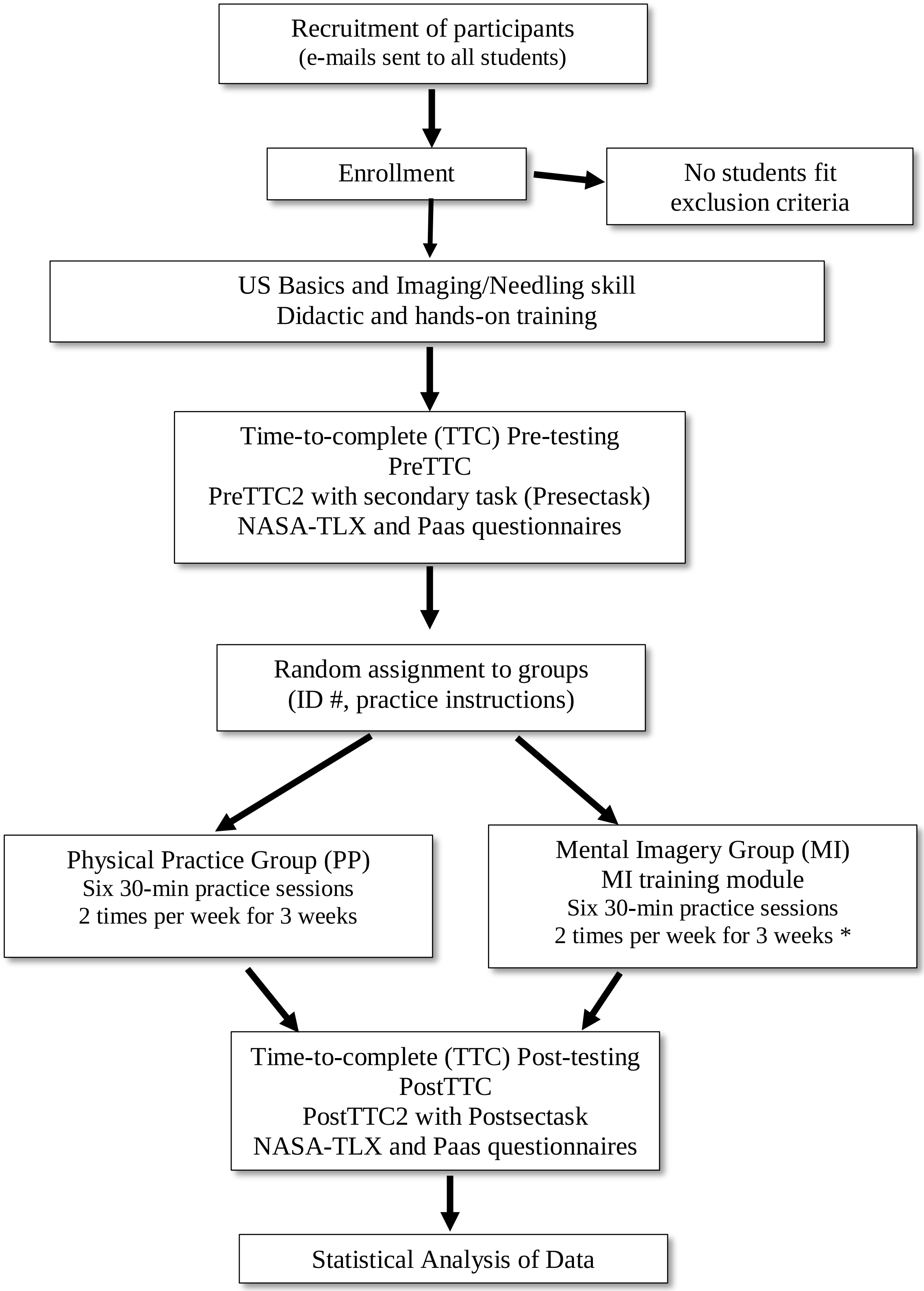



**Figure 2.** Participant/procedural flowchart through study.
* One physical practice of primary skill during 2nd and 4th practice sessions

# Chapter 5

## Summary

This investigative journey explored the dynamic process of psychomotor skill development in the skill-learning environment (SLE). The design of effective skill development experiences in health care professions education requires the integration of a complex mosaic of interacting factors having the ultimate goal of constructing robust long-term memories (schemata) in the learner. Robust schemata construction is necessary to guide future skill performance during actual patient care situations and to facilitate the development of clinical reasoning skills (Kantak & Winstein, 2012). Simulation-based skill development is the most effective SLE available to educators; helping to bridge the skill learning experience from the classroom to the patient care environment (Beal et al., 2017; Shin, Park, & Kim, 2015). The previous chapters reviewed some of the important design features and limitations of simulation-based learning that must be factored into the design of these unique skill-learning environments to accomplish the goal of constructing robust schemata. In view of the complexity and multiplicity of SLE design components, educators must have a thorough understanding of the skill learning process and the factors that enhance or impair this process. The limitations of simulation-based skill development center around providing the learner with informed instruction and providing sufficient access to the learning environment to develop skills effectively. These limitations include the high costs of simulation equipment, facilities, personnel, and expert instruction and guidance.

Educators must be careful in drawing conclusions about skill learning when looking at just one aspect of the SLE or one assessment method due of the complexity and variability of the psychomotor skill development process. Cahill and his colleagues explored the multidimensionality of skill development and suggested an integrative approach, looking at and incorporating multiple factors of skill learning, when designing studies and SLEs (Cahill, McGaugh, & Weinberger, 2001). Poorly designed SLEs may attenuate true learning by inhibiting learner engagement in the learning environment, impairing the neurophysiologic processes involved in robust schema construction, and/or limiting effective skill practice opportunities required to construct and strengthen schemata. I explored several important aspects of the SLE in these three papers: the interactive nature of the principle components of the learning environment in fostering learner engagement, the neurophysiological basis of psychomotor skill development, and the use of mental imagery (MI) techniques to increase the effectiveness of the simulation-based SLE.

To optimize skill development, the learner must actively engage in the learning environment (Dreifuerst, 2009). In Chapter 2, Designing the Simulation Learning Environment: An Active Engagement Model, I explored the interactive nature of the principle components of the SLE: namely, the learner, the educator, and the learning environment. If any one of these components poorly integrates into the SLE, the learner may not actively engage in the learning experience. As a consequence of the failure of these components to functionally integrate, the crucial interaction among these components weakens and may result in impaired learning (Fisher, 2016).

Simulation educators play an important role in facilitating learner engagement in the learning environment through the design features of the SLE. This unique learning environment has many components, including the educator, learner (and participating peers), instructional and practice strategies, and the equipment used to develop the skill. I proposed an Active Engagement Model (Fisher, 2016) that described the important interaction of the principle components in forming the crucial Learner/Educator Dyad. The Learner/Educator Dyad describes a mutually trusting association that can "access shared knowledge, understanding, experience, and clinical reasoning processes" (Fisher, 2016, p. 13). The formation of this dyad facilitates learner active engagement in the learning process. I also proposed that active engagement allows the learner to make a personal connection with the learning experience and helps to focus attentional and motivational resources toward improved learning. The simulation-based SLE is a valuable tool for the educator to help the learner develop simple and complex anesthesia skills. Even though an educational institution acquires a costly simulation facility and equipment, an effective learning environment does not unfold spontaneously for the educator. The educator must design and manage this unique environment based on a thorough understanding of adult learning principles and the neurophysiological underpinnings of psychomotor skill development (Clapper, 2010; Kantak & Winstein, 2012).

One important design principle of the SLE that affects engagement is managing learner anxiety. Some anxiety promotes deeper learning, but excessive anxiety redirects attentional focus away from task-relevant processes and may impair learning and performance (Derakshan & Eysenck, 2009). Excessive anxiety may also be a factor leading to learner disengagement from the learning experience (Fisher, 2016). Educators may effectively manage anxiety by educating all participants on the overall purpose and characteristics of simulation-based learning. Learners should be instructed that mistakes are inevitable during simulation and are significant part of the learning process. They should also be instructed that all interactions within the learning environment should be based on mutual respect and kindness. Educators must exemplify these characteristics and expect the same from the other participants in the simulation experience. The educator should also continuously monitor the environment for signs of excessive learner anxiety or stress and quickly diffuse the situation through adjustments or pauses in the simulation before the learner disengages. There may be a thin boundary between a challenging learning environment and one that is perceived to be threatening by the learner. This fine-line may also vary from learner to learner. Monitoring anxiety may be accomplished by assessing the attentional focus of the learner throughout the simulation experience. Other important design features that facilitate skill learning include progressively increasing simulation fidelity, creating challenging scenarios, effective debriefing, teaching and modeling reflection and integration of concepts into existing cognitive frameworks (Fisher, 2016).

To foster learner engagement, educators must also understand and integrate the neurophysiological principles of true learning into the design of the SLE. True skill learning results in the creation of robust schemata. By utilizing schemata, the learner is able to efficiently recall detailed cognitive processes; such as stimulus identification, response selection, and the psychomotor movement plans that will guide competent future performance (Kantak & Winstein., 2012). Kantak and Winstein also proposed that learner engagement allows for a greater investment and focus in the cognitive processes during the encoding phase of the learning process which leads to correct and robust schema formation. Educators who base the design of the SLE on the neurophysiological foundations of skill learning have additional empirical evidence from which to create effective learning experiences.

The SLE designer must have a clear understanding of the important distinction between initial skill acquisition and true learning outcomes (Kantac & Winstein, 2012). If commonly used performance metrics demonstrate initial skill competence, simulation designers may believe their learning environments facilitate true skill learning. Two research groups proposed that commonly used performance metrics may effectively evaluate the initial, transient phases of skill development, but lack the power to predict more permanent retention of skill performance – a measure of true learning (Kantac & Winstein, 2012; Stefanidis, Scerbo, Korndorffer, & Scott, 2007). Introducing additional performance metrics, such as secondary tasks, to current skill evaluations during training may give educators a more accurate evaluation of true skill learning.

In Chapter 3, A Neurophysiological Approach to Skill Development, I explored the neurophysiology of skill learning. Utilizing the evolving technological advances in neuroimaging techniques, researchers have been able to follow the skill learning processes occurring within the brain and identify regions that are being used during the different phases of psychomotor skill learning, i.e., encoding, consolidation, and retrieval. Identifying the locations of the brain that are either activated or "quiet" during performance provides researchers and educators with valuable information on true learning. Paas and Ayers (2014) observed that when a learner performs a skill that has not been adequately learned, the prefrontal cortex shows increased activity indicating that the learner is using working memory (WM) to perform the skill and automatized schemata have not yet been developed. These researchers proposed that once a skill has been truly learned and robust automatized schemata are directing performance, less working memory resources are required, and the prefrontal brain regions are less activated. As a result, we are able to visually determine true skill learning during performance. Although brain imaging is costly, researchers using these results can offer empirical evidence of the efficacy of other simpler methods to determine true learning.

One simple assessment strategy to evaluate true learning involves using a secondary task during the evaluation of a primary skill to determine the amount of WM resources that are available during performance. If a learner uses automatized schemata to perform the primary skill, the introduction of a secondary task should not affect performance of the primary skill

(Stefanidis et al., 2007). Sweller (1988) proposed the Cognitive Load Theory to explain how the brain's WM processes information during learning and performance. An important principle of this theory proposes that WM, primarily located in the prefrontal cortex, is significantly limited in the amount of information it can process simultaneously (Cowen, 2010; Sweller, 1988). If learning or performance of a skill requires the simultaneous processing of multiple informational elements, WM resources will be overwhelmed and may result in impaired learning and performance. If a learner has created an automatized schema representing learned skill, sufficient WM resources will be available to process additional situational elements that are common in real patient care situations without degradation of skill performance. Processing these additional situational elements during subsequent skill performance helps the learner recognize and adapt to unique situational factors during each performance. These unique situational experiences assist the learner to develop clinical reasoning skills. With an understanding of the neurophysiological processes of skill learning and performance, educators can design learning experiences that facilitate the creation of robust automatized schemata and clinical reasoning skills. One important design principle is to slowly incorporate more complex situational factors into simulation scenarios as the learner shows improved skill development. By utilizing this design principle, the educator avoids overwhelming the learner's working memory with multiple informational elements, reducing the cognitive load. As the learner starts utilizing automated schemata to perform the primary skill, more working memory resources will be available to process the additional situational factors. As the learner successfully processes the additional situational factors during performance, these factors become incorporated into the existing schemata. The learner begins to develop clinical reasoning skills as the result of incorporating more and more situational factors into the basic skill performance schemata. Additionally, the educator can introduce effective evaluative strategies, such as secondary tasks and retention tests, to determine if their SLE design is facilitating optimal skill development and true learning.

Having explored the crucial interaction among the principle components of the SLE and the neurophysiological foundations of true learning, I designed and reported the results of an experimental pilot study exploring the use of mental imagery (MI) practice strategies that may increase the effectiveness of the SLE (Chapter 4 – Using Mental Imagery to Expand the Simulation Learning Environment: A Randomized Pilot Study). In view of the cost and access limitations to the simulation environment, MI practice strategies are able to access the skill learning process without the need of overt physical practice and may provide a promising extension to the SLE (Al-Ghareeb & Cooper, 2016; Arora et al., 2010).

In this investigation, participants were randomly assigned to two groups using either physical (PP) or MI practice strategies to develop an ultrasound-guided needling skill (primary skill) in novice student registered nurse anesthetists. Although both groups significantly improved their time-to-complete scores on performing the skill, the PP group showed significantly better scoring when compared to the MI group for the primary skill. When adding a secondary task to the testing of the primary skill, there was no significant score difference between the PP and MI group. Although physical practice remains an effective and the most commonly used practice strategy to develop psychomotor skills, mental imagery practice is also an effective learning strategy and may be incorporated into the design of the SLE to supplement physical practice outside the simulation learning environment where costs and accessibility limit its use.

In this same investigation, I also explored the use of a secondary memory task to determine if a three-week skill development period was sufficient to develop automatized schemata of the ultrasound-guided needling skill. Even though both groups showed significant improvement in their time-to-complete score (primary skill) from pre- to post-testing, both groups showed a significant prolongation of the time-to-complete the primary skill when the secondary task was added at both the pre- and post-tests. These results may indicate that even though initial skill development had occurred, working memory resources were still being used to perform the primary skill in both the PP and the MI practice groups. This was also supported by the fact that the two subjective cognitive load measures did not show a significant improvement from pre- to post-testing. I proposed that the three-week skill development period may not be a sufficient time period to create automatized schemata for the primary skill using either physical or mental practice strategies. These results suggest that initial skill development is possible over short periods of practice, but learners may still be using WM resources to guide performance. When a clinical situation arises where WM resources are needed to process additional information during performance, skill performance may be degraded.

True learning occurs when the learner creates robust schemata from new information and experience or revises existing schemata (Leahy & Sweller, 2008).

Educators designing SLEs must plan for adequate evaluation of the learners' skill development. Incorporating cognitive load measures into performance evaluations will help simulation designers identify learners who have created automatized schemata and those who still need additional practice opportunities. For those learners still needing additional practice opportunities to facilitate creation of robust automatized schemata, MI may be one such strategy to increase the effectiveness of simulation-based skill development.

**Recommendations for Future Research**

Using the results of the experimental pilot investigation just described, I suggested that the use of mental imagery may be an effective adjunct practice strategy to develop psychomotor skills, although inference of those results was limited by a small sample size and a lack of power. As with any unique empirical investigation, replication is a necessary strategy to obtain accurate values of effect sizes and to be able to make accurate generalizations of the results to other contexts or populations (Cook, 2014).

The study had a unique component that hasn't been found in the literature to date. There have been no studies that have explored the use of MI techniques with ultrasound-guided needling skill development. The ultrasound-guided needling skill is a sensorimotor adaptation task, requiring the learner to adapt motor plans according to sensory feedback during skill performance. This type of skill differs from sequence-learning tasks where the learner must remember a certain sequence of steps to complete the skill. There are differences in task specificity between sequence-learning and sensorimotor adaptation tasks. Skill development and task variability may be differentially affected by alternative skill practice strategies such as MI (Stark-Inbar, Raza, Taylor, & Ivry, 2017). In view of these differences, future research should focus on the types of tasks when using MI techniques.

Another empirical approach may explore altering the duration of the skill development period to discover an effective length of the skill development period for the learner to develop robust schemata for the skill. As many psychomotor skills differ in their complexity, requirements for sensory feedback, and novelty; researchers and educators may find it difficult to determine the optimal skill development duration to promote true skill learning. I plan to re-evaluate the participants' skill performance at approximately seven months to explore differences in the retention of the ultrasound-guided needling skill between the two practice groups. Follow-up or retention assessments should be an integral part of all skill learning studies due to the understanding that skill development occurs in two phases - an initial, fast phase and a slow, permanent phase (Kantak & Winstein, 2012; Stefanidis et al., 2007). Retention and robust schemata creation of a skill may be more pronounced if the skill development period extends farther into the slow learning phase.

In a critical review of the integration of MI strategies in rehabilitation programs, Malouin, Jackson, and Richards (2013) concluded that it is difficult to determine an optimal time frame or practice strategy composition (PP:MI ratio) to develop specific skills. Allami, Paulignan, Brovelli, and Boussaoud, (2008) compared differing rates of MI and PP to performance outcomes and found that imagery is an effective practice adjunct and may possibly be able to replace some physical practice in motor skill development. A group of researchers, trying to determine the optimal practice time for novice learners to achieve competency in ultrasound needle visualization, found that there was wide variability to achieve competent performance (Barrington, Wong, Slater, Ivanusic, & Ovens, 2012). Barrington and his colleagues added that identifying learners who are not developing competence is also an important principle of skill training. Although it may be challenging to design the optimal skill practice period, the educator must be able to identify those learners who are slow at developing the skill adequately and institute additional instruction and practice. Identifying poorly progressing learners can be effectively accomplished with improved evaluative tools based on cognitive loading. One important principle uncovered from the literature is the principle that MI can be accomplished anywhere and does not require access to the simulation environment or costly training equipment. As a result, MI has significant potential benefits for skill development in the health care professions.

The current study compared physical practice strategies to mental imagery practice with only two opportunities to physically perform the skill once during the entire skill development period. Participants' skill development may benefit from a more extended physical practice experience when combined with MI techniques. Because the ultrasound-guided needling skill requires sensory feedback to direct performance, extending the physical practice of this skill may encode more complete feedback information into the developing schemata and produce more accurate cognitive representations of the skill upon which the learner can build during MI practice. This extended type of a physical practice period would also parallel commonly used skill practice experiences in many current simulation-learning environments.

Researchers have proposed that there is inter-individual variability in mental imaging ability (Guillot et al., 2008, 2009). In the reported study, only half of the participants ($n$ = 12) used MI during the skill development period, but there may have been significant differences in their MI ability to affect the results. Researchers continue to disentangle the effects of the variability of MI ability by exploring the neural mechanisms of MI. Imaging ability and skill development are associated with differing areas of brain activation (Blefari, Sulzer, Hepp-Reymond, Kollias, & Gassert, 2015). Investigations exploring the use of MI should also include measurements of MI ability to compare imaging ability with skill development.

Neal (2016) reviewed a critical analysis of an evidence-based assessment of US use in regional anesthesia and pain medicine. He found that although US is effective in reducing the incidence of local anesthetic systemic toxicity (LAST) and hemi-diaphragmatic paresis (HDP), there is no significant evidence to show that US is any better than other nerve localization techniques in preventing nerve injury from needle damage. These equivocal results may demonstrate that US-guidance during regional anesthesia is a fairly novel technique and practitioners may not be using US effectively due to a lack of sufficient skill development. Anecdotal evidence by this author and other US instructors has shown that many practitioners are not maintaining continuous ultrasound visualization of the block needle during the procedure. This lack of continuous visualization reflects an inadequate skill development during training. As we optimize the design of the SLE for at least this skill, future research may more fully support all of the proposed benefits of US-guided regional anesthesia techniques.

**Conclusions and Implications for Teaching**

Ethical ideals and public demands for competent health care services exert external pressures on educators to design SLEs that promote learner skill development to ensure safe and competent care prior to entering the actual patient care environment (Kohn, Corrigan, & Donaldson, 2000). This evolving educational paradigm contrasts with the continued use of the apprenticeship model in some health professions training in which novice practitioners develop procedural skills practicing on actual patients (Halsted, 1904). The apprenticeship model is no longer an appropriate model for training (Grantchov & Reznick, 2008). In view of this shifting educational paradigm in skill development teaching, the information presented in these three exploratory papers may have important implications for educators designing simulation-based skill learning experiences in health professions education.

The skill learning process can be favorably or unfavorably affected by the design of the learning environment. The simulation educator must thoughtfully approach the design with a thorough understanding of the complexity of this environment and the important integration and interactive functionality of the essential components that facilitate skill learning. There has been much research on the individual components and factors which comprise simulation learning. These three papers explored how many of these components work together to facilitate learning. The SLE is a unique learning environment in which the learner and educator must closely interact to facilitate learning, which is unlike the more diffuse interaction commonly experienced in the classroom. Design features that optimize this close interaction are crucial to the learning experience. Beyond understanding the neurophysiological foundations of skill learning, the educator must be kind, non-threatening, and completely engaged in the learning experience and with the learner. Educators should be expert listeners to hear what the learner is experiencing and be able to support effective cognitive processes being used during the development of psychomotor and clinical reasoning skills. The learner can optimize skill learning by actively engaging in the learning experience. In simulation environments, learners perform skills in front of an educator and often their peers. This can produce anxiety which may lead to impaired learning and performance. An informed and engaged educator can attenuate factors leading to high anxiety and learner disengagement by designing the SLE appropriately and continuously assessing the environment. If needed, the educator should be able to individually adjust the learning experience to meet each learner's needs.

The construction of robust skill schemata is a complex cognitive process, but essential to skill development, retention, and transfer of skills to the patient care setting. The ultimate goal of nurse anesthesia skill training is to prepare the learner to provide safe and competent care in a dynamic care environment. Each clinical setting has unique situational factors to which the learner must attend and cognitively process during the performance of a skill. If the practitioner has to actively think about performing a skill, the unique and sometimes complex situational factors inherent in these patient care situations may overwhelm the practitioner's cognitive resources. This may lead to impaired performance and poor patient outcomes. By using automatized schemata to perform the skill, the learner will have sufficient cognitive resources to process these situational factors. Cognitively processing these unique factors each time the skill is performed adds experiential information to the existing schemata and may be an important factor facilitating the development of clinical reasoning skills. The overall goal of the educator designing an effective skill learning environment should be to facilitate optimal skill development in each learner who can then enter clinical practice and provide safe, efficient, and competent care to every patient. This important goal may be accomplished through a thorough understanding of the learning environment, the neurophysiological foundation of the skill learning process, and innovative educational strategies that increase the effectiveness of skill development.

**References**

Al-Ghareeb, A., Cooper, S. J. (2016). Barriers and enablers to the use of high-frequency patient simulation manikins in nurse education: An integrative review. *Nurse Education Today, 36,* 281-286. doi:10.1016/j.ecns.2017.05.015

Allami, N., Paulignan, Y., Brovelli, A., & Boussaoud, D. (2008). Visuo-motor learning with combination of different rates of motor imagery and physical practice. *Experimental Brain Research, 184,* 105=113. doi:10.1007/s00221-007-1086-x

Arora, S., Aggarwal, R., Sevdalis, N., Moran, A., Sirimanna, P., Kneebone, R., Darzi, A. (2010). Development and validation of mental practice as a training strategy for laparoscopic surgery. *Surgical Endoscopy, 24,* 179-187. doi:10.1007/s00464-009-0624-y

Barrington, M. J., Wong, D. M., Slater, B., Invanusic, J. J., & Ovens, M. (2012). Ultrasound-guided regional anesthesia: How much practice do novices require before achieving competency in ultrasound needle visualization using a cadaver model. *Regional Anesthesia and Pain Medicine, 37,* 334-339. doi:10.1097/AAP.0b013e3182475fba

Beal, M. D., Kinnear, J., Anderson, C. R., Martin, T. D., Wambolt, R., & Hooper, L. (2017). The effectiveness of medical simulation in teaching medical students critical care medicine: A systematic review and meta-analysis. *Simulation in Healthc*are, *12*, 104-16. doi:10.1097/SIH.0000000000000189

Blefari, M. L., Sulzer, J., Hepp-Reymond, M., Kollias, S., & Gassert, R. (2015). Improvement in precision grip force control with self-modulation of primary motor cortex during motor imagery. *Frontiers in Behavioral Neuroscience, 9,* 1-11. doi:10.3389/fnbeh.2015.00018

Cahill, L. C., McGaugh, J. L., & Weinberger, N. M. (2001). The neurobiology of learning and memory: Some reminders to remember. *TRENDS in Neurosciences, 24,* 578-581.

Chang, C. (2013). Medical simulation is needed in anesthesia training to achieve patient safety. *Korean Journal of Anesthesiology, 64,* 204-211. doi:10.4097/kjae.2013.64.3.204

Clapper, T. C. (2010). Beyond Knowles: What those conducting simulation need to know about adult learning theory. *Clinical Simulation in Nursing, 6,* e7-e14. doi:10.1016\j.ecns.2009.07.003

Cook, D. A. (2014). How much evidence does it take? A cumulative meta-analysis of outcomes of simulation-based education. *Medical Education, 48,* 750-760. doi:10.1111/medu.12473

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited and why? *Current Directions in Psychological Sciences, 19,* 51-57. doi:10.1177/0963721409359277

Derakshan, N., & Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance: New developments from attentional control theory. *European Psychologist, 14,* 168-176. doi:10.1027/1016-9040.14.2.168

Dreifuerst, K. T. (2009). The essentials of debriefing in simulation learning: A conceptual analysis. *Nursing Education Perspectives, 30,* 109-114. PMid:19476076

Fisher, R. (2016). Designing the simulation learning environment: An active engagement model. *Journal of Nursing Education and Practice, 6(3),* 6-14. doi:10.5430\jnep.v6n3p6

Grantcharov, T. P., & Reznick, R. K. (2008). Teaching procedural skills. *British Medical Journal, 336,* 1129-31. doi:10.1136/bmj.39517.686956.47

Guillot, A., Collet, C., Nguyen, V. A., Malouin, F., Richards, C., & Doyon, J. (2008). Functional neuroanatomical networks associated with expertise in motor imagery. *Neuroimage, 41,* 1471-1483. doi:10.1016/j.neuroimage.2008.03.042

Guillot, A., Collet, C., Nguyen, V. A., Malouin, F., Richards, C., & Doyon, J. (2009). Brain activity during visual versus kinesthetic imagery: An fMRI study. *Human Brain Mapping, 30,* 2157-2172. doi:10.1002/hbm.20658

Halsted, W. S. (1904). The training of the surgeon. *Bulletin of Johns Hopkins Hospital, 15,* 265-275.

Kantak, S. S., & Winstein, C. J. (2012). Learning-performance distinction and memory processes for motor skills: A focused review and perspective. *Behavioral Brain Research, 228,* 219-231. doi:10.1016/j.bbr.2011.11.028

Kohn, L. T., Corrigan, J., & Donaldson, M. S. (2000). To err is human: Building a safer health system. Institute of Medicine (IOM). Washington, D.C., National Academy Press 2000.

Leahy, W., & Sweller, J. (2008). The imagination effect increases with an increased intrinsic cognitive load. *Applied Cognitive Psychology, 22,* 273-283. doi:10.1002/acp.1373

Malouin, F., Jackson, P. L., & Richards, C. L. (2013). Towards the integration of mental practice in rehabilitation programs: A critical review. *Frontiers in Human Neuroscience, 7,* 1-20. doi:10.3389/fnhum.2013.00576

Neal, J. M. (2016). Ultrasound-guided regional anesthesia and patient safety: Update of an evidence-based analysis. *Regional Anesthesia and Pain Medicine, 41,* 195-204. doi:10.1097/AAP.0000000000000295

Paas, F., Ayers, P. (2014). Cognitive load theory: A broader view on the role of memory in learning and education. *European Psychologist*, *26,* 191-195. doi:10.1007/s10648-014-9263-5

Shin, S., Park, J., & Kim, J. (2015). Effectiveness of patient simulation in nursing education: Metanalysis. *Nursing Education Today, 35,* 176-82. doi:10.1016/j.net.2014.09.009

Stark-Inbar, A., Raza, M., Taylor, J. A., and Ivry, R. B. (2017). Individual differences in implicit motor learning: Task specificity in sensorimotor adaptation and sequence learning. *Journal of Neurophysiology*, *117,* 412-428. doi:10.1152/jn.01141.2015

Stefanidis, D., Scerbo, M. W., Korndorffer Jr., J. R., & Scott, D. J. (2007). Redefining simulator proficiency using automaticity theory. *American Journal of Surgery, 193,* 502-506. doi:10.1016/j.amjsurg.2006.11.010

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*, 257-285.