PREPARATION FOR FUTURE LEARNING OF PROCEDURAL SKILLS

PREPARATION FOR FUTURE LEARNING OF PROCEDURAL SKILLS

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Lay Abstract

New doctors should be able to use learned skills to take care of patients, but also be able to solve new problems and learn new skills. We investigate how training medical students to perform one clinical procedure influences how they learn a second procedure. First, we compare the learning of students who are 1) taught how to do the procedure and expected to master it, 2) asked to invent the steps necessary to do the procedure before they are taught how to do it, and 3) taught how to do the procedure without being required to master it. Next, we compare how well the students learn to perform a second procedure. We found that students who learn a procedure and are expected to master the skill might be able to perform this procedure best, but no difference was found in how well they are able to learn a new procedure.

Abstract

Background: Competence in clinical practice involves effective application of previously-acquired knowledge and the ability to use knowledge adaptively for innovation across diverse clinical contexts. In the learning context, this adaptability is termed Preparation for Future Learning (PFL) and looks at the capacity of trainees to use knowledge and strategies to learn and solve new problems. We compared how three instructional designs impacted procedural skill acquisition and PFL, through assessment of transfer to learning a novel procedural skill.

Methods: We randomized 60 medical students to practice infant lumbar puncture (ILP) according to a Simulation-based Discovery Learning intervention (i.e. guided invention before expert instruction), a Simulation-based Mastery Learning condition (i.e., a stringent form of competency-based education), or a control sequence. In a second session, we assessed how well learners transferred strategies developed in the first session to learn a novel task – knee arthrocentesis (KA). We compared trainees' post-test ILP performance and PFL ability via a KA performance test.

Results: There was a significant effect of group on ILP checklist score after controlling for pre-test score, $F(2,56) = 3.202$, $p<0.05$. Post-intervention ILP checklist scores were statistically greater in the mastery group (93.03% ±2.02) compared to the control group (85.94% ±1.93). There was no significant effect of group on ILP global rating score. Though reliability of ratings was low, there was no significant effect of group on KA performance.

Conclusion: This work supports a benefit of mastery learning compared with non-mastery simulation-based instruction for procedural skill acquisition, but did not demonstrate a benefit for mastery learning over invention followed by direct instruction. Most participants in all groups were not competent to perform KA and no intervention showed clear benefit for PFL. Future work is required to guide development of learning interventions which support PFL given the expectation for trainees to problem solve and innovate.

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List of Abbreviations and Symbols

CBD: Competency-based education

PFL: Preparation for Future Learning

MPS: Minimum Passing Standard

SBML: Simulation Based Mastery Learning

ACLS: Advanced Cardiovascular Life Support

CBME: Competency based medical education

SBDL: Simulation Based Discovery Learning

CSF: Cerebral spinal fluid

POISE: Patient Outcomes in Simulation Education

ICC: Intraclass Correlation Coefficient

ANOVA: Analysis of Variance

LSD: Least Significant Difference

LP: Lumbar puncture

CL: Checklist

CI: Confidence interval

INSPIRE: International Network for Simulation-based Pediatric Innovation, Research and Education

Declaration of Academic Achievement

Andrea Fiume was responsible for the conception and design of the project; data collection of participants; leading intervention groups during data collection; running the statistical analyses and interpreting the data; and writing the thesis.

Drs. Lawrence Grierson, Ryan Brydges and Andrea Hunter supervised and provided guidance for the conception and design of the thesis; data collection, analysis and interpretation; and provided comments, edits, and approval of the written thesis.

Drs. Daisy Liu and Kendra Kosma helped lead the Mastery and control interventions during data collection.

Dr. Robin Mackin, Caroline Diorio, Willa Liao, Elana Hochstadter, and Meredith Austin-Appleton rated the quality of participants' video recorded lumbar punctures and Drs. Alexandra Saltman, Vanessa Ocampo, Stephanie Yang and Elishka Pek rated the quality of participants' video recorded knee arthrocentesis performance.

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Chapter 1 Introduction

1.1 Competence and Expertise in the Health Professions

The goal of health professions education and instruction for medical trainees is competence in clinical practice. An integral role of competent physician practice is the application of medical knowledge and skill for the provision of safe, patient-centered care within a physician's clinical scope of practice (Frank JR, Snell L, Sherbino J, 2015). Underpinning this competency is the acquisition of domain specific expertise which is developed through education and experience.

Traditional medical curricula have been organized according to a time-based structure planned around scheduled movement through pre-determined rotations. In this system, training has typically progressed through a fixed amount of time and culminated with a summative assessment of performance (Carraccio, Wolfsthal, Englander, Ferentz, & Martin, 2002). In contrast, competency based medical education (CBME) is recognized as an approach to health professions education which uses time as a resource for acquiring competencies. CBME has foundations in the broader competency-based education (CBE) which has been developed over the past 60 years and has been employed in the training of many professionals such as teachers, chiropractors, and social workers (Frank et al., 2010). CBME is an outcome-based approach to medical education which emphasizes competence as a prerequisite for progression through training. Competency-based curricula begin with identification of desired outcomes that are used to define the abilities needed by graduates to achieve these goals and the subsequent development of milestones, instructional methods, and assessment tools that allow for the development of the required knowledge, skills and attitudes among medical trainees (Frank et al., 2010). CBME may offer a more reliable path to the domain-specific expertise development required of medical trainees.

Health professionals must use and apply their previously acquired domain-specific knowledge and skills efficiently to provide quality patient care. However, beyond efficiency, the diverse and changing health care milieu requires that practitioners have the ability to use their foundational knowledge flexibly to develop novel or 'outside-the-box' solutions within the complex clinical context. This conceptualization of flexibility in practice and performance amongst health professionals is referred to as adaptive expertise (Bransford & Schwartz, 1999; Mylopoulos & Regehr, 2007). This concept will be explored in greater detail through this thesis and is reflected in recent implementations of CBME, such as Competence by Design (CBD) in Canada, which has shifted focus to adaptability beyond domain specific knowledge and expertise.

1.1.1 Competence by Design (CBD)

The Royal College of Physicians and Surgeons of Canada launched CBD in July 2017, with the goal to ensure competence of clinical trainees while teaching for excellence and encouraging ongoing learning and skill development throughout practice ("Competence by Design The rationale for change," 2018). Adherence to a strictly time-based model of training has been called into question and it has been argued that this training model may not most effectively fulfil the expectation for professional accountability in practice (Hodges, 2010). Instead, the CBD approach to training is intended to be outcomes-based and shifts the focus from time-based modules to a more flexible training environment which emphasizes accountability, flexibility and learner-centeredness. Within this learning framework, achievement of competence is assessed based on the identification of milestones and skills that learners achieve as they progress from novice to independent practitioner (Frank et al., 2010; Gruppen, Mangrulkar, & Kolars, 2012).

A particular impetus for change has been the acknowledgement that physicians need to be flexible and able to adapt to changing practice climates throughout their careers. As Hodges (2010) points out, education reform reports such as *Educating Physicians: A Call for Reform of Medical School and Residency* released by the Carnegie Foundation (Dooley-Hash, 2010) and *The Future of Medical Education in Canada Project* (Busing et al., 2015) point to the need to prepare physicians to practice with adaptability (e.g. the capacity to accommodate practice according to changing societal needs) and flexibility (e.g. the ability to rapidly adjust one's approach according to feedback). These tenets are reflected in the goals for postgraduate training articulated through the CBD framework, which aims to instill values of "professional responsibility, flexibility and adaptability; maintenance and enhancement of evolving competencies; and the overarching altruistic virtue of meeting societal needs, both as an individual and as a profession" (Maudsley et al., 2014). These views reflect the aim to prepare clinicians for practice through achievement of particular medical and specialty-related expertise, but also acknowledges the importance of flexibility in practice and learning.

1.2 Development of Expertise

Concepts of competence in medicine require acquisition of domain-specific knowledge and expertise. Much of the foundational science related to expertise development comes from domains outside of medicine and health professions education, with previous work in areas such as sports, music and chess (Ericsson, Charness, Feltovitch, & Hoffman, 2006). Definitions of expertise vary widely in the literature. In common, though, are notions of elite, peak, or exceptionally high levels of task or domain specific performance (Bourne, Kole, & Healy, 2014). Some authors have characterized expert performance as fluid, automatic behavior which occurs without conscious control (i.e. (Dreyfus, Dreyfus, & Zadeh, 1987). The view of expertise extensively studied and described by Ericsson, however, identifies expert performance as the behavior of individuals who are able to counteract automaticity through the development of complex mental representations which permit precise control of performance at increasingly high levels (Ericsson, 2008). In medicine and health professions education, this expertise can be conceptualized as superior objective performance, as evinced by criteria such as superior patient outcomes, for individual clinicians (Ericsson, 2015). This development of domain expertise is an important feature of the competent clinician.

1.2.1 Expertise and Deliberate Practice

A model of achievement of expertise based on prolonged and concentrated effort applied towards a specific skill set with strategic, focused, and goal-oriented activities – termed deliberate practice – has been described by Ericsson and others (Ericsson et al, 1993). According to this skill acquisition protocol, there are three primary elements which define practice as "deliberate" and are proposed to be necessary for expertise development within this model: (1) a clear, defined task, (2) provision of detailed and immediate feedback and (3) opportunities for incremental improvement through repetitive practice (Ericsson, 2008; Krackov & Pohl, 2011). This suggests that mere practice does not make perfect. Instead, deliberate practice requires work on the part of the learner to attend to and use feedback in repetitive practice with the aim of making incremental refinements of performance just beyond the learner's current level of performance (Ackerman, 1988; Ericsson, 2000; Ericsson, Nandagopal, & Roring, 2009). Within this approach, performance in a given domain is described to develop gradually. Novice performance improves to a degree that allows domain-specific activity participation, and performance of domain specific activities ultimately permits progression of performance to expert levels (Ericsson, 2015). The expert-performance approach with deliberate practice involves identification of the mental structures and representations that expert specialists have acquired and provision of training and feedback that specifically targets the trainee's development of the structures associated with this high-level target performance

(Ericsson, 2015). Practice environments which permit repetitive training and can facilitate the provision of regular and timely feedback are well suited to deliberate practice (Ericsson & Lehmann, 1996). In medicine, deliberate practice has been shown to positively impact skill acquisition as demonstrated by superior performance on OSCE results (Duvivier et al., 2011), and simulator performance (Issenberg, McGaghie, Petrusa, Gordon, & Scalese, 2005; Issenberg et al., 1999). The model proposed by Ericsson and Lehmann (1996) attributes expert performance to deliberate practice with the view that individual attributes such as intelligence, memory, and other cognitive abilities account for performance difference only among novices. There is evidence to suggest that emphasis on deliberate practice alone is insufficient to optimally understand the development of expertise and plan training programs with this goal. For instance, individual differences, and in particular working memory capacity, can influence expert performance in novel activities (Kulasegaram, Grierson, & Norman, 2013). Further work is required to fully elucidate the factors influencing the development of expertise to allow for optimal planning and implementation of curricula in the health professions.

Planning of curricula should also be influenced by the type of knowledge educators intend for learners to attain. For instance, Broudy (1977) discusses three aspects or types of knowing termed *replicative*, *applicative* and *interpretive*. The first aspect of knowing, replicative knowing, involves recall of learned information, as would be assessed in a standard memory test in school. The second aspect involves application of previously acquired knowledge to solve transfer problems. In contrast, interpretive knowing encompasses how learners are able to categorize, classify and infer, a component of "knowing with" which influences how learners approach problems based on previous experiences, but involves more than simple replication of those experiences. This is relevant to students' ability to learn and perform in future problem solving scenarios.

This final component of knowing is relevant when planning for training aimed at fostering optimal expertise development, while paying attention to the development of flexibility and adaptability among trainees. Given the pace of medical discovery and the complexity of clinical practice, it is well understood that medical school curricula cannot directly address all problems a student will face in clinical practice (Mylopoulos & Scardamalia, 2008). In light of this complexity, a fundamental goal of training in the health professions must be for the development of clinicians who are capable of adaptability throughout their career and prepared for innovation and flexibility in problem solving and learning in practice. Through this thesis, concepts of adaptive expertise (Mylopoulos & Woods, 2017) and Preparation for Future Learning (Bransford & Schwartz, 1999) will be reviewed in the context of goals of training in medical education and the impact of different educational interventions reflecting distinct educational paradigms will be explored in terms of their influence on the development of this type of expertise.

1.3 Adaptive Expertise

A critical feature of the performance of adaptive experts, is their ability to maintain an appropriate balance between efficient clinical care and the innovation required for effectively approaching a novel or challenging problem (Schwartz et al., 2005). Adaptive experts possess the capacity to recognize problems that present the opportunity to innovate, build knowledge, and enhance practice (Mylopoulos & Woods, 2009). The adaptive expert can be contrasted with the routine expert – a highly skilled technician who possesses domain specific skills, which are applied effectively and efficiently in practice but that cannot be adapted effectively in the face of a novel problem (Bransford, Brown, & Cocking, 2000). The adaptive expert is able to recognize when the factors that generally govern his or her performance do not apply to a particular problem or encounter (Gott, Hall, Pokorny, Dibble, & Glaser, 1992). Knowledge is a critical foundational element of expert performance in both components of adaptive expertise; through its direct and efficient application of known solutions and as the foundation for innovation in care delivery. The experienced clinician who has developed adaptive expertise is able to accurately identify the clinical situations in which routine and efficient application of knowledge is ideal or when innovation is required for the provision of quality patient care. Adaptive expertise demands both efficiency and innovation, with both components being essential aspects of expert performance. The skills of innovation and efficiency are viewed with equal importance and a critical component of the adaptive expert's performance is his or her ability to accurately distinguish contexts and problems necessitating either skill (Mylopoulos & Woods, 2017).

1.4 Preparation for Future Learning

Given the importance of continual acquisition and incorporation of new knowledge in the provision of quality patient care, understanding how to optimally foster the development of adaptive expertise through promotion of innovation in practice and learning is of primary importance to medical education researchers. For trainees, this adaptability has been conceived as *Preparation for Future Learning* (PFL), which describes the learner's capacity to use resources and strategies effectively and innovatively when problem solving in new learning situations (Bransford & Schwartz, 1999). The fundamental aim is to understand how trainees apply past knowledge and learning to solve novel problems. This is important as in new or complex situations, clinicians often find that problem solving on the basis of straightforward application of their knowledge is insufficient. Instead, foundational knowledge must be used flexibly through innovative problem solving. The construct of PFL is understood as a key competence of adaptive expertise (Bransford & Schwartz, 1999) and it has been argued that this flexibility is a specific learned skill set that can be fostered through training (Hatano & Inagaki, 1984; Mylopoulos & Regehr, 2009). There is a growing body of literature demonstrating that outcomes of innovation in clinical performance and learning are influenced by particular curricula and training principles.

In the field of medical education, studies have demonstrated that integration of basic and clinical sciences through the delivery of instruction that offers explicit links between clinical signs and symptoms and basic biomedical mechanisms can serve as a useful tool for students faced with difficult and non-routine clinical presentations (Lisk, Agur, & Woods, 2016) and can support the learning of new, related concepts (Mylopoulos & Woods, 2014). Educational paradigms and medical education programs that support PFL and trainees' development of adaptive expertise are thus likely to be of importance when the goal is to train clinicians to acquire the skills and attitudes necessary to engage in innovative problem solving during learning and clinical practice.

1.4.1 Definition of transfer in context of Adaptive Expertise and Preparation for Future Learning

Beyond transfer of knowledge and skill into new situations, adaptive expertise reflects the capacity to transfer strategies, attitudes and learning approaches in order to solve new problems. This reflects the ability to approach situations in which the individual does not have sufficient memories or schemas (i.e. knowledge and skill) to correctly solve a problem, but they have an established framework for approaching and making sense of the new problem (Schwartz, Bransford & Sears, 2005). This includes attending to the critical features of the new problem and framing the learning task. The focus of "transfer in" and "transfer out" as two equally important and necessary components in the process of solving new learning problems is what differentiates the view of transfer in the context of preparation for future learning and adaptive expertise from other definitions of transfer. "Transfer in" involves the use of previous learning, acknowledgement that what has been previously learned may be relevant in another context, and drawing on prior knowledge during learning to make comparisons and generalizations (Engle et al., 2012). "Transfer out" reflects how a learner makes use of a new learning resource in order to solve a target transfer problem (Schwartz, Bransford & Sears, 2005). In contrast to other approaches, such as literature focused on teaching for learning-to-learn which has advocated for domain specific learning strategies and the importance of educators knowing "how" to teach a particular subject matter (e.g. Klauer, 1988), this definition of transfer highlights the important role of content knowledge which shapes an individual's approach and interpretation of a new problems (Schwartz, Bransford & Sears, 2005). Thus, transfer in this context involves both content knowledge and more general problem solving approaches, with both components being necessary but individually insufficient for efficient, effective and flexible approach to new learning problems.

1.4.2 Measuring Preparation for Future Learning

Understanding the impact of educational paradigms on PFL is dependent on the ability to systematically evaluate it. Bransford and Schwartz (1999) proposed the double transfer design, a methodological approach to assessing the ability of trainees to solve novel problems adaptively that aims to evaluate and understand the learning trajectory of trainees. PFL assessments using the double transfer design seek to evaluate how learners use past knowledge and experiences when learning new material. Bransford and Schwartz (1999) propose that learning new material involves the process of *Transfer In and Transfer Out*. *Transfer In* refers to the practice of using past knowledge to understand new material and *Transfer Out* denotes that use of that newly acquired knowledge to perform a subsequent, related task (Bransford & Schwartz, 1999). PFL assessments using a double transfer design, thus involve an initial learning session with subsequent opportunity for learners to transfer this knowledge to a second learning task. On the basis of new information acquired through this second learning session, they are required to complete a final task or assessment of learning. This differs from the standard transfer methodology that requires learners to acquire a certain skill or body of knowledge and subsequently be tested on a related skill or body of knowledge without the requirement to learn new material before completion of the target transfer task (Schwartz et al., 2005).

Capacity for adaptability in training and preparation for future learning has not traditionally received significant attention in health professions education research. In particular, within the context of simulation-based learning, transfer has been traditionally conceptualized as the application of what is learned in one context (i.e., within a simulation) to another (i.e., to a real-world clinical scenario)

(Hamstra, Brydges, Hatala, Zendejas, & Cook, 2014). There has been recent calls for research and instruction which recognizes adaptability and preparation for future learning as a competency of health professions education (Mylopoulos, Brydges, Woods, Manzone, & Schwartz, 2016) and studies using the double transfer design to evaluate how prepared trainees are to learn from new material are gaining popularity (Brydges, Peets, Issenberg, & Regehr, 2013; Mylopoulos & Woods, 2014; Schwartz & Martin, 2004). PFL assessments have been previously used to measure the learning of procedural skills and have been shown to yield different results from a standard transfer assessment, which adds to the validity argument that PFL assessments are measuring a distinct process (Manzone, 2015; Mylopoulos & Woods, 2014; Schwartz et al., 2005). Studies employing the double transfer methodology also offer an important opportunity to further evaluate the factors influencing preparation for future learning and the development of adaptive expertise as well as the skills and behaviours that underlie it.

The majority of assessments used in research and clinical settings have been efficiency oriented and focused on traditional definitions of transfer. Without consideration of outcomes such as adaptive expertise and use of PFL assessments, the value of particular educational experiences which promote transfer of knowledge and problem solving frameworks may be missed (Schwartz, Lindgren & Lewis, 2009). Double transfer study designs offer an opportunity to evaluate preparation for future learning, since an individual's capacity for "Transfer in" and "Transfer out" of established and newly acquired schemas are operationalized through this design and thus well aligned with the definition of transfer applicable to preparation for future learning and adaptive expertise.

1.4.3 Designing instruction for developing Preparation for Future Learning

Educational psychologist Robert Gagne, best known for his theory on Conditions of Learning, proposed that different forms of instruction were best suited to different learning goals or outcomes (Gagne, 1962). Educational scientists with theoretical foundations from various educational paradigms have proposed and evaluated different instructional designs that might improve trainees' PFL abilities. In particular, *Mastery Learning* is an instructional design technique that researchers have hypothesized influences future learning ability. Research in the general education literature has demonstrated that students in well-implemented Mastery Learning programs reach higher levels of achievement and enhanced confidence in their learning ability (Anderson, 1994; Guskey & Pigott, 1988; Kulik, Kulik, & Bangert-Drowns, 1990). The development of strong positive attitudes towards learning has been proposed as the mechanism whereby early learning experiences influence subsequent learning (Bloom, 1977). Invention activities have also been proposed and evaluated as a useful instructional technique when the goal is preparing students to learn and problem solve in the future (Schwartz & Martin, 2004). These two educational approaches will be explored in greater detail.

1.5 Mastery Learning

Mastery learning is an especially stringent form of CBE through which students are expected to achieve uniform outcomes at the level of mastery, a much higher level of performance than competence or proficiency alone (McGaghie, 2015a). This educational approach has foundations in the research, practice and writings of early educational scientists dating back to the 1960s, with historical attempts to produce similar constructs documented as early as the 1920s (Block & Burns, 1976; B. Bloom, 1968). Mastery learning has recently gained traction in medical education research and program development.

1.5.1 Historical Perspective

The conceptual paradigm termed "Model of School Learning" forms the critical foundation for Mastery Learning approaches and was described by John Carroll (1963) as an attempt to outline the major factors influencing student success. The theoretical assertion was that a student's aptitude for a given task was predictive of his or her learning in a given time period and the amount of time he or she required to achieve a specified learning objective (Carroll, 1963). Thus, the degree of learning was a function of the time spent on learning versus the time required. In this model, learning time was suggested to be determined by the time students were allowed to focus on a particular learning task and their perseverance. Other factors influencing learning were suggested, including student aptitude (i.e. the amount of time required to learn a task to a given criterion level under ideal instructional conditions), the quality of instruction, and the ability to understand (i.e. the student's ability to profit from the instruction, a concept similar to general intelligence) (Block & Burns, 1976).

Bloom operationalized the conceptual model as Mastery Learning. These strategies promoted education through individualized instruction in order to meet the unique needs and characteristics of each learner. According to Bloom (1968), Mastery Learning approaches were dependent on the educators' ability to recognize when students had achieved mastery through the collection of evidence. Within this model, each learning objective had to be translated into an evaluable standard and criteria for advancement was established based on comparison of performance against a pre-determined benchmark, referred to as a Minimum Passing Standard (MPS). (Bloom, 1968). Bloom asserted that if students were normally distributed with respect to aptitude and each learner received optimal quality of instruction and the individualized learning time required, then a majority of students could be expected to attain mastery. Within this educational approach, time could therefore be used as a variable for individualization of education and to encourage all students to achieve success.

Within the Mastery Learning strategy, each educational component is taught with group-based methods and feedback and corrective instruction are provided based on results of brief, formative diagnostic tests at the end of each unit. These strategies built upon previous approaches by incorporating more precise and individualized feedback, including formative evaluations, and drawing on carefully described objectives for each unit. This strategy also incorporated a greater variety of directed feedback strategies and tools as compared to previous objectives-based teaching strategies (Block & Burns, 1976). A similar approach called the Personalized System of Instruction was introduced around the same time, but differed fundamentally in that students were required to pace themselves through carefully designed, self-instructional materials while the teacher provided support and individual assistance only when needed (Keller, 1968). This is contrasted with the group-based, teacher-led instruction that underlies Mastery Learning.

On the basis of early research on Mastery Learning, it was argued that in addition to facilitating high level achievement amongst the majority of students, the students educated through Mastery Learning curricula demonstrated greater interest in and more positive attitudes toward the topics learned. This was conceived as a particular strength of Mastery Learning and one of the key factors underlying improved school achievement in the long run (Bloom, 1973). Since that time, Mastery Learning approaches have been widely evaluated at the elementary, secondary, and post-secondary levels of education and results have been summarized through a number of meta analyses and systematic reviews (Guskey & Gates, 1986; Kulik et al., 1990). Through these reviews, Mastery programs have generally demonstrated positive outcomes, though effect sizes of Mastery Learning on student achievement vary considerably (Guskey & Gates, 1986) and may be higher for weaker students (Kulik et al., 1990). Mastery approaches have been shown to have positive effects on student attitudes toward learning (Guskey & Gates, 1986; Kulik et al., 1990) and can improve retention (Guskey & Gates, 1986), but may increase learning time (Kulik et al., 1990).

Although theoretical and empirical support for Mastery Learning exists, a number of critiques regarding these approaches have been raised in the literature. Challenges raised by the need for highly specific educational goals and a scarcity of diagnostic and assessment tools, as well as concern for increased teacher time and energy have been cited as factors limiting widespread implementation of mastery curricula (Tools, 1976). Unequal benefit of Mastery Learning for low achieving students and a shift in focus from coverage of a wider array of topics to mastery of a select few has also been raised as a critique of this educational approach (Slavin, 1987). Although these challenges and critiques were raised in the context of elementary and secondary school education, their consideration is prudent as Mastery Learning curricula are implemented and evaluated within the medical education context.

1.5.2 Mastery Learning in Medical education

Researchers from Northwestern University Feinberg School of Medicine including William McGaghie, Jeffrey Barsuk, and Diane Wayne, have been at the forefront of advancing Mastery Learning strategies in medical education and simulation. Mastery learning is described as a tool to ensure that “all learners accomplish all educational objectives or reach competency standards beyond proficiency levels with little or no variation in outcome” (Griswold-Theodorson et al., 2015). Seven primary criteria are outlined as necessary components of a Mastery Learning curriculum (Mcgaghie, Issenberg, Barsuk, & Wayne, 2014):

1. Baseline (i.e. diagnostic) testing;
2. Clear learning objectives, sequenced as units ordered by increasing difficulty;
3. Engagement in educational activities (e.g. deliberate skills practice, data interpretation, reading) that are focused on reaching the objectives;
4. The establishment of a minimum passing standard (e.g. test score, checklist score) for each educational unit;
5. Formative testing to gauge unit completion at a preset minimum passing mastery standard;
6. Advancement to the next educational unit given measured achievement at or above the mastery standard, or
7. Continued practice or study on an educational unit until the mastery standard is reached.

The potential value of Mastery Learning in health professions education has catalyzed a growing body of literature dedicated to its investigation. Cook and colleagues (2013) published a systematic review and meta-analysis of Mastery Learning for health professionals using technology-enhanced simulation. Overall, the authors identified 82 studies evaluating simulation based Mastery Learning for a variety of clinical topics including minimally invasive surgery, gastrointestinal or urological endoscopy, central or peripheral vascular access, airway management, and resuscitation training in medical students and post-graduate trainees. The authors found a pooled effect size of 1.29 (95% confidence interval [CI], 1.08–1.50; P < .001) for process skills, suggesting that Simulation-based Mastery Learning (SBML) is associated with substantial learning gains compared with no intervention. In addition, pooled effect sizes for studies comparing SBML with non-simulation instruction, such as lecture or video, were moderate to large in favor of SBML. Instruction with Mastery Learning models required more time and more repetitions than non-mastery approaches (Cook, Brydges, Zendejas, Hamstra, & Hatala, 2013). However, despite the historical and theoretical notion that Mastery Learning would positively influence attitudes towards learning and future learning ability, these studies reviewed learning outcomes for a particular clinical skill or procedure without attention to the impact on students' future learning ability.

A realist synthesis recently published by Griswold-Theodorson and colleagues (2015) sought to evaluate the translational educational outcomes of SBML. The authors included 14 studies that employed pre/post or cohort study designs and identified improvements in patient care processes and outcomes. In particular, improvements reported included superior performance of skills (such as hemodialysis catheter insertion, cardiac auscultation, and adherence to advanced cardiac life support guidelines) as well as improved performance of procedures (including transurethral resection of the prostate, laparoscopic fascial closure, colonoscopy, and laparoscopic surgery) and decreased patient discomfort. A number of studies demonstrated decreased procedural or operative time and a reduction in complication rates after implantation of SBML curricula. These results were described to represent advantages for the health and safety of individual patients as well as cost savings for hospitals and health care systems (Griswold-Theodorson et al., 2015), but again did not evaluate the impact on trainees' capacity for learning and problem solving in novel, related situations.

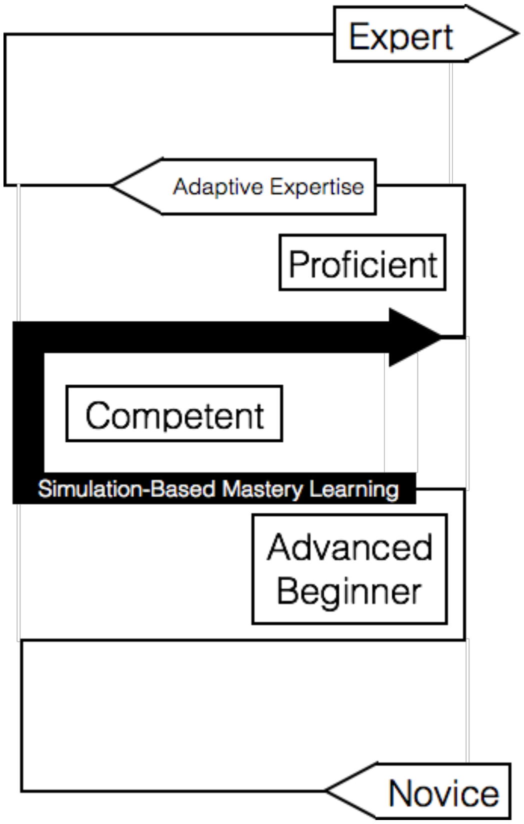

Figure 1: Role of SBML in skill acquisition. SBML in the simulation environment is thought to prepare learners to enter the clinical setting at a competent skill level. Adaptive expertise is described as essential to move to more proficient or expert levels of performance. Image adapted from Griswold-Theodorson et al, 2005.

1.6 Invention Activities

It has been argued that routine, focused instruction in problem solving is unlikely to prepare students for learning and problem solving in novel situations (Bransford & Schwartz, 1999) and invention activities have been proposed as valuable educational tools for preparing students for future learning (Schwartz & Martin, 2004). An invention activity refers a discovery-based or constructivist exercise designed to help students to recognize important structural features and create an organizational schema that enhances their ability to learn from being taught the expert interpretation (Schwartz & Martin, 2004). This teaching methodology is in keeping with the constructivist approach to learning that acknowledges a student's ability to create new knowledge outside of instruction and relies on the active construction of new knowledge based on a learner's prior experience. Constructivist learning approaches encourage student learning through active engagement with a learning problem and typically demand that students take initiative for their own learning through diagnosing their personal learning needs, formulating learning goals, identifying resources to achieve these goals, engaging in activity towards achievement of these goals, and evaluating learning outcomes (Spencer & Jordan, 1999). The development of problem solving skills and deep understanding are among the key goals of constructivist learning approaches. The expectation for active student learning also requires a reconceptualization of the role of teacher within the educational environment. Within constructivist learning theory, teachers are regarded as guides, monitors, coaches and facilitators as the student plays a principal role in mediating and controlling his own education (Jonassen, 1991).

The appropriate use of instructional techniques within this context is important and has been shown to have measurable educational benefits. For instance, there is a significant body of evidence supporting the educational benefits of discovery and active learning under the guidance of an instructor compared to unconstrained discovery (Schwartz & Bransford, 1998). Likewise, the timing of active learning activities in relation to direct instruction has been shown to have important educational implications. Providing students with the opportunity to generate knowledge about a domain (i.e. discovery learning), followed by direct instruction through a lecture or text, has shown promising educational effects and good learning outcomes when the goal is transfer of knowledge to novel situations(Bransford & Schwartz, 1999). The benefit of providing students with the opportunity to participate in invention or discovery activities prior to being exposed to direct instruction through learning resources has also been demonstrated to be effective at preparing students to learn in subsequent analyses (Kapur, 2010).

When invention activities are used to prepare students for future learning, they are described to be brief, highly-structured activities which engage the learner and simulate creativity in thinking and problem solving as a tool in preparation for explicit instruction and reinforcing practice. The expectation is that engagement in the invention activity will scaffold the learner to be able to detect important structural features of a given case and utilize that scaffolding in developing a deep understanding from direct, conventional teaching (Roll, Holmes, Day, & Bonn, 2012). The following features of a good invention activity have been proposed (adapted from: Adams, Wieman, & Dan, 2008):

1. Clear goal: The task should present a clear, challenging goal of trying to develop a compact and consistent description or representation of the "important features" across the cases. Typically, the description entails integrating several features in one representation.
2. Contrasting cases: The task should include multiple cases simultaneously, so students notice structure and structural variations that transcend superficial differences. Cases should systematically vary on key parameters so students try to see how these variations relate at a deeper, structural level.
3. Context: The task should involve things relatively familiar and meaningful to the students.
4. Level of difficulty: Students should have partial success, even if they do not come up with the true solution.
5. Avoid jargon
6. Try with a few students first and modify as needed before using with a class.
7. Collaboration: invention activities work best when done by pairs of students.

Well-designed invention activities have been shown to scaffold learning in a manner that prepares learners for future learning. Several mechanisms for enhanced future learning outcomes have been proposed including the cognitive effect of making learners more aware of knowledge gaps and motivational influences through enhanced curiosity and interest in learning related concepts (Belenky & Nokes-Malach, 2012; Glogger et al., 2013). The impact and mechanisms of discovery-based learning through invention activities on preparation for future learning amongst trainees in the health professions has not received significant research attention.

1.7 Approaches to Training in Medicine – Simulation

Traditional training programs in medicine have focused on the acquisition of theoretical knowledge, typically within a classroom setting, followed by practical training with real-world exposure to patients. This begins with students acquiring basic science knowledge in a preclinical training phase with the assumption that trainees will subsequently learn from experience in direct patient care. However, in the era of patient safety and competency based education, the traditional apprenticeship approach to procedural skill teaching and learning built on the model of “see one, do one, teach one” is insufficient and indefensible (Kotsis & Chung, 2013). Adherence to this educational model is no longer ideal for patient safety or the assurance of clinical competence. Therefore, learning environments that provide opportunity and exposure to situations and models that simulate clinical experiences and contexts provide a safe space for trainees to practice skills. These learning environments allow instructors to control learning conditions and provide trainees with timely and accurate feedback (Ericsson, 2015), which is important for procedural skill acquisition.

Systematic reviews of the literature have demonstrated that in comparison with no intervention, technology-enhanced simulation training has consistently produced large educational effects for knowledge, skill, and behavior-related outcomes and moderate effects for patient-related outcomes (Cook et al., 2011) and that outcomes measured on simulation-based assessments are generally directly correlated with patient-related outcomes (Brydges, Hatala, Zendejas, Erwin, & Cook, 2015). The simulation context is also well suited to the the effectiveness of instructional design features (Cook et al., 2013; Cook et al., 2011, 2012) and simulation-based procedural skills assessments are considered to be sensitive enough to detect learning and performance changes in the research context (Ilgen, Ma, Hatala, & Cook, 2015). This thesis will extend the traditional assessment of knowledge, skill, behavior and patient-related transfer outcomes to evaluate the impact of simulation based training interventions reflecting different educational approaches on trainees' ability to learn a new simulated task.

1.8 Summary

Exploration of the literature supporting CBME, and CBD in particular, has highlighted the importance of efficient application of domain-specific knowledge and skills as well as the ability to flexibly use and apply knowledge in learning and performance in modern conceptualizations of the competent practitioner. The PFL assessment has been introduced as an outcome measure to assess trainees' innovation, in addition to the efficiency which is traditionally captured through post-test performance assessments, retention tests and standard transfer assessments. Scientists guided by different educational frameworks have proposed and evaluated various instructional designs that might improve trainees' PFL abilities. For instance, behavioral scientists have proposed long term educational benefits associated with mastery learning curricula, with the expectation for high level and uniform performance outcomes among trainees who are thought to develop more positive attitudes and interest towards topics being learned. Further, constructivist learning approaches, including those involving invention activities, have been proposed as a mechanism to prepare trainees for innovation, flexibility, and adaptability in future learning and performance scenarios through exposure to educational interventions which permit the construction of knowledge and emphasize a deep understanding of concepts.

Since discovery-based constructivist approaches and outcomes-based Mastery Learning approaches have both been related to the development of adaptability and future learning ability, we believe the two educational approaches should be compared, with PFL as a primary outcome. The following section will provide a more in-depth description of the study aims and accompanying hypotheses. The significance of this work will also be discussed.

Chapter 2 Research Aims and Hypotheses

2.1 Objectives

This thesis investigates the effects of SBML and Simulation Based Discovery Learning (SBDL) followed by direct instruction on procedural skill acquisition and PFL in a simulation-based training context. In particular, it evaluates these interventions based on novice medical trainees' skill acquisition of lumbar puncture (LP) technique and double transfer to knee arthrocentesis learning and performance on a task trainer. The research study was designed to satisfy two primary research aims:

1. To compare the impact of an SBDL intervention versus a SBML curriculum and non-mastery "Observe-then-practice" curriculum on trainees' skill acquisition.

2. To use a PFL assessment in the health professions simulation-based training context to assess how mastery interventions influence future learning of procedural skills as compared to a SBDL curriculum or a non-mastery "Observe-then-practice" curriculum.

2.2 Hypothesis

We hypothesize that all groups will perform better at post-test as compared to pre-test with improvements in mean checklist and Global Rating Scale (GRS) scores expected for all groups. Related to the first aim, the study includes pre-test and post-assessments to test the hypothesis:

Hypothesis 1a: Participation in a SBML curriculum will result in higher mean checklist and GRS scores as compared to the other two groups at Post-test.

Hypothesis 1b: Participation in a SBDL curriculum will result in greater variability in trainees' post-test outcomes (greater range and standard deviation (SD) around mean LP and GRS scores).

We hypothesize that compared to participants in the other groups, trainees in the SBDL group will demonstrate enhanced learning as demonstrated by higher mean GRS scores on the PFL assessment, which would provide support for using constructivist approaches when designing education aimed at developing adaptive expertise.

These hypotheses are based on the results of previous studies which have demonstrated improved procedural skill outcomes among trainees receiving simulation based instruction using a mastery model compared with non-mastery approaches for procedures such as endotracheal intubation, airway management, laparoscopic cholecystectomy, and intravenous catheterization (Brydges, Carnahan, Rose, & Dubrowski, 2010; Domuracki, Moule, Owen, Kostandoff, & Plummer, 2009; Gauger et al., 2010; Stewart, Paris, Pelton, & Garretson, 1984; Stratton et al., 1991). A recent meta analysis of SBML for health professionals reported results in favor of mastery learning for process outcomes, including global ratings, with a large pooled effect size (Cook et al., 2013). This would also be consistent with the central tenant of mastery learning approaches which expect learners to achieve uniform outcomes at a high performance level (McGaghie, 2015a). Greater variability in outcomes following SBDL is anticipated given the introduction of variability in initial practice for participants in this intervention group and the shorter amount of time dedicated to deliberate practice with constructive feedback amongst these participants.

Related to the second aim, the study includes double transfer assessments to one additional hypothesis:

Hypothesis 2: Participation in a SBDL curriculum will have a significant, positive impact on trainee's performance on the double transfer task.

Hypothesis 2 is the main focus of this thesis and builds off of the extensive work in educational psychology (Schwartz & Martin, 2004) and health professions education (Mylopoulos et al., 2016) literature reviewed in the introduction.

2.3 Significance

This thesis adds to the literature and understanding of the educational mechanisms and related instructional design that enhances novice health professional trainees' PFL. Evidence of improved PFL ability following simulation based training reflecting a particular educational paradigm (i.e. SBML - an especially stringent form of CBME; or SBDL "Do-then-See" sequence - self-regulated, hands-on learning before expert instruction) would provide support for type of instruction when the goal is adaptability in future learning scenarios. This work may also contribute to the evidence supporting the conceptual and methodological validity of PFL assessments in health professions education research.

Chapter 3 Methodology

3.1 Overview of Study Design

We used a randomized between-subjects design to compare performance according to intervention group: the SBDL "Do-then-See" group, the SBML group, or a control group. In addition, we used a PFL double transfer design requiring all participants to complete pre-test, post-test, and double transfer assessments. Specifically, participants completed an initial practice phase (delivered according to their group assignment) which included the pre-test, group specific instruction and practice, and the post-test. They subsequently returned approximately two weeks later to complete the second learning and testing phase, which included the double transfer assessment that was common to all groups. See Figure 2 below.

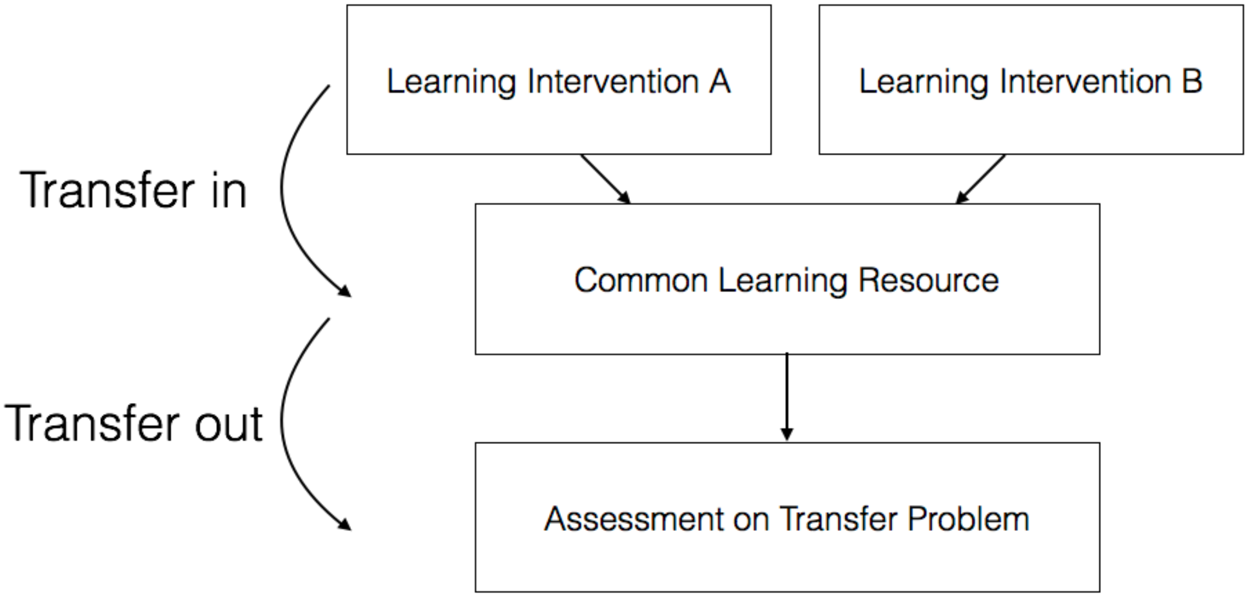

Figure 2: Overview of the double transfer protocol used in the thesis. Adapted from (Schwartz et al., 2005)

3.2 Participants, Recruitment and Group Assignment

Approval for conduct of this study was obtained from the University of Toronto Health Sciences Research Ethics Board and the Hamilton Integrated Research Ethics Board. We recruited 64 pre-clerkship (year one and two) undergraduate medical students from the University of Toronto and McMaster University. The study was conducted outside of the existing medical school curricula. Initial contact with potential participants was made via a LISTSERV email through the Faculty of Medicine Registrar at each institution. Students interested in participating in the study were asked to contact the graduate student investigator to receive additional information about the study and to schedule a time for participation. We sent further study information to interested students, including the time commitment, study location, and a data collection schedule. Recruitment occurred on a first come first-served basis. Inclusion required that participants had never performed a successful LP on a live or simulated adult, child, or infant and was contingent on participants' availability to attend the two sessions 2-3 weeks apart. Written informed consent was obtained prior to the start of the first session. All students who volunteered for the study received a $20 honorarium in the form of a gift certificate at the time of study completion.

As the 64 participants confirmed their participation dates and times, they were randomly assigned a computer generated participant code that anonymized their identity. Participants were randomly assigned to one of the three interventions, two experimental groups, the SBDL "Do-then-See" group and the SBML group, and the non-mastery control group.

3.2.1 Sample Size Calculation

Evidence from previous studies suggesting an educationally meaningful difference of 1.0 unit on a 5-point global rating scale (Brydges, Nair, Ma, Shanks,

& Hatala, 2012), was used in the derivation of our sample size. Accounting for a standard deviation of ~1.0, an alpha level of 0.05 and a desired power of 0.80, power analysis for a one-way ANOVA test was conducted in G*Power and yielded a total sample size of 48 participants, or approximately 16 participants per group (Faul et al., 2013). We then aimed to collect 20 participants per group to account for attrition.

3.3 Simulated Procedural Skill

Participants performed simulated infant LP on a part-task trainer for practice and testing purposes during the study. Participants were asked to perform the procedure with the infant positioned in the lateral decubitus position. The Simulab LumbarPunctureBaby trainer was used which simulates a two week old baby and has identifiable anatomic features including an iliac crest, umbilicus, L3-L5 vertebra and gluteal fold ("LumbarPunctureBaby System Training Package," 2017); Figure 3.

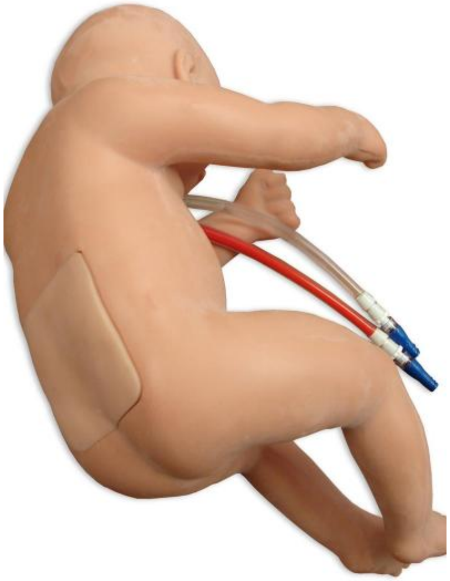

Figure 3: LumbarPunctureBaby Model from Simulab, Seattle, WA (“LumbarPunctureBaby System Training Package,” 2017)

Given inconsistency of fluid withdrawal despite appropriate positioning and technique observed during pre-investigation trials with the task trainers, it was decided that the task trainer would not be filled with fluid representing cerebral spinal fluid and participants would not be graded on successful acquisition of a fluid sample.

3.4 Protocol and Intervention Design

3.4.1 Session 1: Initial Practice Session

The initial practice session began with participant completion of a baseline demographic questionnaire (Appendix A). Following this, participants performed a video recorded simulated infant LP pretest. Next, participants received group specific instruction and practice over a period of approximately 2 hours. At the end of the first session, all participants completed a simulated infant LP post-test. All procedural skills assessments were video recorded using two cameras, one capturing a wide-angle and the other capturing an up-close view of the participants' hand movements and equipment use (e.g., orientation of the needle). Participants were blind to individual items on the checklist and GRS during testing and training sessions.

An overview of the study design is presented here (Figure 4)

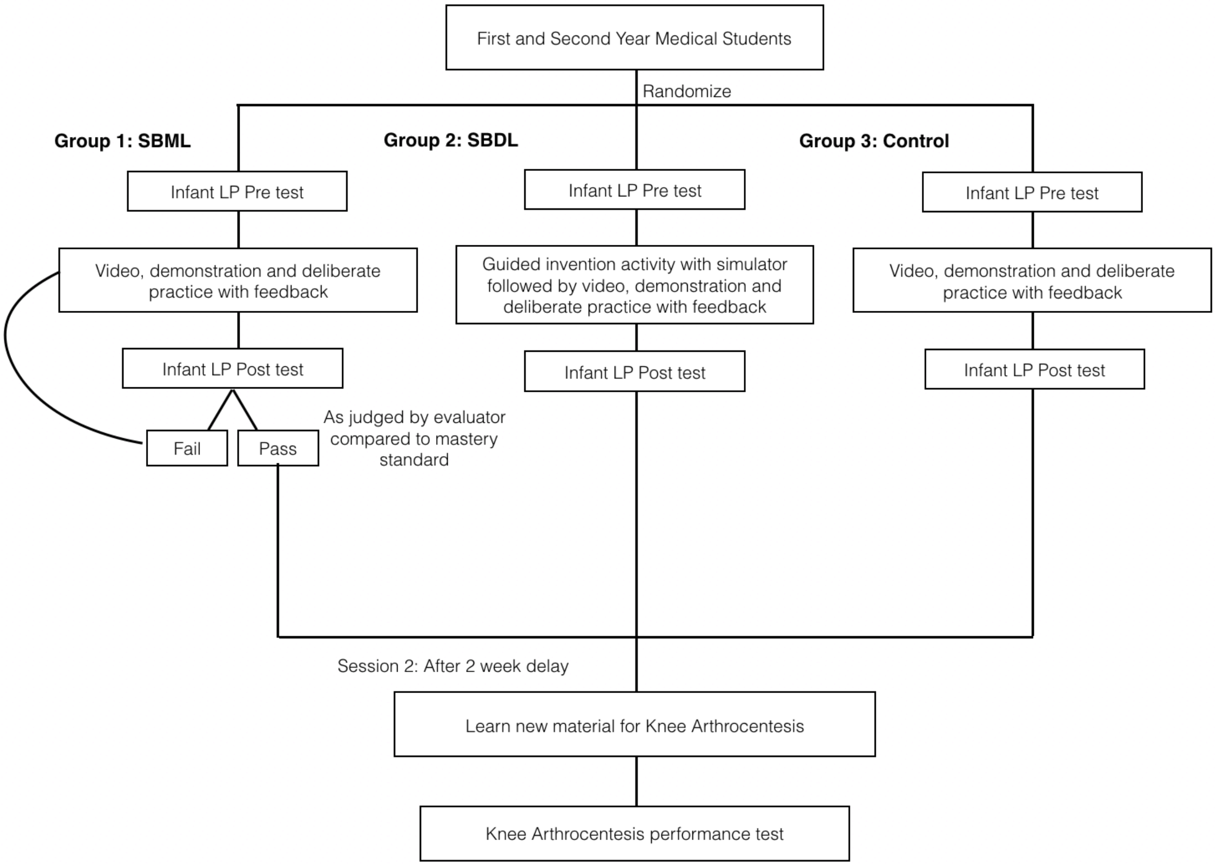

Figure 4: Overview of Study Design

3.4.2 Intervention Group Design

The three educational interventions used in this study were designed to reflect standards for simulation based training highlighted in the competency based Mastery Learning literature and the constructivist literature focusing on invention, as well as popular non-mastery simulation curricula.

3.4.2.1 SBML Intervention

After undergoing the procedural skills pre-test examination, participants randomized to the SBML intervention completed a 2-hour education session featuring an educational video on infant LP, an interactive infant LP demonstration, and deliberate practice with directed feedback (Ericsson, 2004). During this time, participants practiced repetitively within groups of 3-6 students with individualized verbal feedback provided by a trained pediatrician or senior pediatric resident instructor. Immediately after the intervention, participants were required to meet or exceed a MPS on a procedural skill assessment (post-test) using the subcomponent checklist developed by the Patient Outcomes in Simulation Education (POISE) investigators (Gerard et al., 2013). Participants who did not achieve the MPS engaged in more deliberate practice and were retested until the MPS was reached.

3.4.2.2 Establishment of the Minimum Passing Standard

The MPS was established through application of the item-based Mastery Angoff Method (Downing, Tekian, & Yudkowsky, 2006; Yudkowsky, Park, Lineberry, Knox, & Ritter, 2015), which asks experts to indicate the probability that a student well-prepared to succeed in the next level of training (i.e. first supervised infant LP on a patient in this context) would perform each item on the checklist correctly. A panel of experts in performance of infant lumbar puncture was posed the question, "For each checklist item, please provide the probability (as a percentage) of a well prepared medical student accomplishing this item after repeated practice with the model." Responses were recorded and averaged to establish the MPS. This cutoff was then compared to existing data regarding for infant LP performance assessed using the same checklist, consistent with the "proficient group approach" to standard setting (Gallagher, 2012; Gallagher et al., 2005). This approach to standard setting uses known performance scores recorded from a reference group with appropriate expertise to guide establishment of the passing standard.

3.4.2.3 SBDL Intervention

Following the procedural skills pre-test examination, participants randomized to the SBDL intervention worked in groups of 3-6 students for 30 minutes to practice and 'invent' strategies for performing an infant LP on a task trainer. Participants were given an explanatory document (Appendix B) to work through the invention activity and students were guided through the activity by a trained instructor. They subsequently observed the educational video on infant LP and an interactive infant LP demonstration, and participated in deliberate practice with directed feedback. Immediately after the intervention, participants completed a video-recorded procedural skill assessment (post-test) but were not required to meet or exceed a MPS. The total education session lasted for 2 hours.

Guiding materials for this group were developed in accordance with the features of strong invention activities proposed by Adams and colleagues (2008). The following table (Table 1) outlines how each of the proposed criteria were operationalized in our study intervention (Adams et al., 2008)

Invention Characteristic	**Category**	**Instruction**
Clear goal	Instruction to Participant	Please practice performing the skill of lumbar puncture. Your goal is to collect cerebral spinal fluid (CSF) from the L4/5 or L5/S1 interspace using proper sterile technique. This task is performed with the patient in the lateral decubitus [side lying] or sitting position – today we will practice the skill with the patient positioned in lateral decubitus. Aim to develop an efficient, reproducible strategy that would be effective in the simulation and clinical settings. Discard your sharps in a safe manner. To complete this task, you will need to be able to: - Landmark - Use proper sterile technique

		- Collect CSF while minimizing tissue trauma
Contrasting cases	Instruction to Participant	1. Consider the features (patient position, body habitus, etc.) that would impact the effectiveness of each strategy you invent. 2. Consider the impact of variations in your technique (methods for holding the need, different insertion angles and depths, needle bevel position, etc.) that would impact the effectiveness of each strategy you invent. 3. After each attempt think about how your strategy relates to your original expectation of how the procedure should be performed and what the outcome will be. 4. Include an analysis of how this attempt is similar or different from your previous attempt as well as your original hypothesis. 5. With each attempt, try to explain the steps you are taking and technique you are using.
Context	Instruction to Participant	Your CSF collection will allow analysis of the sample in the laboratory
Level of difficulty	Study Design	The LP task is not too difficult. Even a 'wrong' solution could yield a CSF sample

Avoid jargon	Study Design/Instruction to Participant	Where necessary, any jargon used was accompanied with a definition
Design cycle	Study Design	These materials were pilot tested with a group of pre-clerkship medical students
Collaboration	Study Design	Students will work in small groups during the invention and practice phases of the intervention

Table 1: Application of criteria for design of good invention activities to the SBDL intervention

3.4.2.4 Control Intervention

Similar to the SBML group, participants randomized to the control group completed a 2-hour education session featuring an educational video on infant LP, an interactive infant LP demonstration, and deliberate practice with directed feedback. During this time, participants practiced repetitively within groups of 3-6 students with individualized verbal feedback provided by a trained pediatrician or senior pediatric resident instructor. Immediately after the intervention, participants completed a video-recorded procedural skill assessment (post-test) but were not required to meet or exceed a MPS. The total education session lasted for 2 hours.

3.4.3 Common Intervention Materials

As highlighted above, in addition to the group specific intervention elements, all participants watched an educational video on infant LP, participated in an interactive infant LP demonstration, and engaged in deliberate practice with directed feedback.

3.4.3.1 Infant Lumbar Puncture Video Demonstration

Participants were taught the expert interpretation of the infant LP procedure through observation of the POISE network's Infant LP Procedure Video (Auerbach, Chang, Krantz, Ching, Pusic, Kessler, Nguyen, Penesetti, 2011). This is a nine-minute instructional video containing information on the necessary equipment, discrete steps, contraindications, and troubleshooting for the infant LP procedure. This video provides learners with expert modeling and a clear description of the component steps of an infant LP, focusing on psychomotor skills. This video was developed with the intention to provide novice providers with an introduction to the infant LP procedure and develop their knowledge, skills and confidence related to the procedure.

3.4.3.2 Infant Lumbar Puncture Expert Demonstration

All participants were given the opportunity to observe a live performance of the infant LP procedure by a pediatrician certified by the Royal College of Physicians and Surgeons of Canada (expert modeling). During this demonstration, the instructor reviewed the steps of the procedure as demonstrated in the video, oriented participants to the part-task training model and equipment being used, and highlighted components of the procedure which would be assessed. Participants were invited to ask for any procedural or conceptual clarifications during or following the demonstration.

3.4.3.3 Deliberate practice with Directed Feedback

Following demonstration of the infant LP technique, participants in each group engaged in deliberate practice with directed feedback (Ericsson, 2004). Participants were required to observe their peers practice and receive feedback when it was not their turn to work hands-on with the task trainer. Consistent with the features of deliberate practice highlighted by Ericcson (2004), participants were instructed to practice and develop expertise in infant LP, a well-defined task. The instructor was present to provide detailed and immediate feedback on performance. During this hands-on practice session, participants were able to repetitively practice the infant LP procedure.

3.5 Session 2: Preparation for Future Learning

All participants were asked to return for a second study session approximately 2 weeks after the first. As highlighted previously, the double transfer design was used which involves a second learning session of new material before the completion of a target transfer problem. Consistent with other studies employing the double transfer study design (Manzone, 2015), all participants worked independently during the second training session. During this session, all participants were asked to independently learn and demonstrate the technique for a diagnostic knee arthrocentesis. This procedure was selected as an ideal PFL transfer task as it has many conceptual and procedural similarities to LP, but also requires acquisition of a new procedural technique and awareness of different anatomic features. During this learning activity, no instructors were available and all participants experienced this second session as an unsupervised learning activity.

3.5.1 Double Transfer Task Training Materials

Prior to completing a video-recorded procedural skill assessment (PFL-transfer test), all participants were given a maximum of 30 minutes to read an article and watch an instructional video highlighting the procedure for diagnostic knee arthrocentesis. We selected the Knee Arthrocentesis video and article from the series of Videos in Clinical Medicine from The New England Journal of Medicine (Thomsen, Shen, Shaffer, & Setnik, 2006) as these materials are clear and succinct. This module provides written and graphic instructions for diagnostic knee arthrocentesis including indications, contraindications, necessary equipment and discrete steps, as well as a video demonstration of knee arthrocentesis technique. Participants were given free access to the part-task knee model to practice the knee arthrocentesis technique. For the purpose of practice and testing, participants were given the following additional written instructions:

- This is a left adult knee
- Please use the medial approach
- Do not inject lidocaine into the model (skip this step)
- Use alcohol swab for “cleansing agent”
- Do not stick bandage to model
- Do not use skin marking pen (skip this step)

- You do not need to wear full sterile equipment, only gloves

When the 30 minutes passed, or the participant asked to move on, they were asked to perform a single video-recorded trial of diagnostic knee arthrocentesis on the same part-task knee model. Participants' performance on this final trial was scored and taken as a measure of how well their initial educational intervention prepared them to learn this related procedural skill on their own.

3.5.2 Model

The part-task Knee Arthrocentesis module (Simulab, Seattle, WA; ("Arthrocentesis Model," 2017) was used for the double transfer task training and assessment. This task trainer allows learners to practice proper landmarking and needle insertion for the collection of knee synovial fluid on a model with high anatomic fidelity (Figure 5).

Figure 5: Arthrocentesis Model from Simulab, Seattle, WA ("Arthrocentesis Model," 2017)

3.6 Instructor Training

3.6.1 Training for SBML

All instructors for the SBML group were trained according to the International Network for Simulation-based Pediatric Innovation, Research and Education (INSPIRE) infant LP instructor's guide and instructional video which is intended to prepare instructors to conduct a Mastery Learning session, demonstrate expert modeling of the procedure, utilize a Mastery Learning checklist to guide formative feedback, and coach learners through repetitive practice (Auerbach et al., 2014; Auerbach, Chang, Krantz, Ching, Pusic, Kessler, Nguyen, Penesetti, 2011). Instructors were given specific instruction on how to make decisions regarding achievement of a MPS. Training occurred before each instructor facilitated a study group and consisted of viewing the video, reviewing the written instruction guide and discussing completion of forms with the graduate student investigator. The training document for SBML instructors is shown here (Appendix C).

3.6.2 Training for SBDL

All instructors for the SBDL group were pre-trained regarding the principles of the constructivist approach to learning and guided discovery with a didactic description from the graduate student investigator and review of a SBDL instructor guide (see Appendix D). In addition, instructors were trained to demonstrate expert modeling of the procedure and coach learners through deliberate practice with directed feedback. Instructors were advised not to provide feedback during the final video-recorded procedural skill assessment.

3.6.3 Training for control group

All instructors for the control group were trained according to a modification of the INSPIRE infant LP instructor's guide and instructional video. Instructors were trained to demonstrate expert modeling of the procedure, utilize a Mastery Learning checklist to guide formative feedback, and coach learners through repetitive practice (Auerbach, et al., 2014; Auerbach, Chang, Krantz, Ching, Pusic,]Kessler, Nguyen, Penesetti, 2011) but were advised not to score or provide feedback during the final video-recorded procedural skill assessment.

3.7 Outcome Measures

3.7.1 Demographic Questionnaire

All participants completed a demographic questionnaire which focused on previous educational experiences, experience with problem based learning, exposure to simulation-based training, and previous experience with real and simulated LP (Appendix A).

3.7.2 Lumbar Puncture Performance

3.7.2.1 Global Rating Scale (GRS)

As our primary measure of participants' performance of infant LP, we used a GRS which has been used in previous simulation-based studies of LP education and has promising validity evidence. This scale consists of four subscales, namely respect for tissue, time and motion, instrument handling, flow of procedure, and knowledge of specific procedure, in addition to an overall performance rating, all scored on a 5-point likert scale (Brydges et al., 2012); Appendix E). This tool was derived from the objective structured assessment of technical skill (OSATS) GRS which has has been widely used in the assessment of procedural and technical skills (Martin et al., 1997). All assessment tools were converted into an electronic format to permit capture of data electronically using Google forms (e.g., Appendix F).

The average of the five component scales of the GRS was calculated for each rater and an intra-class correlation coefficient (ICC) was calculated to ensure inter-rater reliability was acceptable (i.e., ICC > 0.70). Once reliability was confirmed, the average GRS score across both raters was calculated and the combined score was used in all analyses.

3.7.2.2 Mastery Checklist

In addition, we used a task-specific checklist instrument (Appendix G) developed and validated by the POISE researchers (Gerard et al., 2013) and translated into a tool for assessment of mastery (Auerbach et al., 2014). The SBML instructor rated participants' performance using this instrument at the time of the final video-recorded procedural skill assessment (post-test) for the purpose of making a decision regarding achievement of a MPS. To permit comparison of performance and maintain rater blinding, the infant LP checklist and GRS was also used to measure performance at pre-and post-test for participants in all groups independently and in duplicate by two pediatricians or senior pediatric residents who were blinded to the participant's group of allocation, based on review of video-recordings.

3.7.3 Knee Arthrocentesis Performance

3.7.3.1 GRS

As our primary measure of participants' performance on the knee arthrocentesis double transfer task, we used the same 5 component global rating scale as was used for rating LP performance (Brydges et al., 2012), Appendix H). Validity evidence exists for use of OSATS-derived GRSs in assessment of knee arthrocentesis performance (Walzak et al., 2015). There is growing support for GRS as the preferred tool for competency assessment since checklists may lack specificity and do not always effectively rule out incompetence (Ma et al., 2012; Walzak et al., 2015). GRS has emerged as a standard in performance-based assessment.

3.8 Rater Orientation

Pediatricians and senior pediatric residents with competence in infant LP technique were selected as raters of LP performance for this study, and knee arthrocentesis performance was rated by senior rheumatology residents. All raters were trained by the graduate student investigator prior to independently rating the video-recorded procedural assessments. Rater orientation took place over one hour and consisted of a didactic session followed by rating 3 randomly selected videos examples of LP and knee arthrocentesis. Prior to watching any videos, definitions of poor and competent performance were reviewed with raters in the context of an undergraduate pre-clerkship trainee:

- **Poor (1,2):** The participant could only be trusted to perform the procedure in the clinical context with high levels of hands on guidance from a more senior clinician. *More practice* in the simulation setting is required.
- **Competent (3):** The participant could be trusted to perform the procedure in the *clinical context while supervised* by a more senior clinician, but does not require hands on guidance. This participant would be ready for supervised practice with a patient.
- **Superior (4,5):** The participant could be trusted to perform the procedure in the *clinical context with little to no supervision*.

The raters then independently scored each of the videos before comparing their ratings and discussing any disagreements in order to come to a consensus score. This process was intended to establish a shared mental model of "competent" performance in the study context amongst the raters. We did not use the ratings of these videos in the ICC reliability calculation, but did include them in the remaining analyses.

3.9 Data Analysis

All statistical analyses were conducted using SPSS Statistics Version 21. (SPSS, Inc., Chicago, IL).

3.9.1 Baseline Questionnaire Data

Descriptive statistics for demographic data were calculated and separate one-way analyses of variance (ANOVAs) and the chi-square statistic were used to compare demographic features as well as previous exposure to LP and simulation-based training among participants in each group.

3.9.2 Lumbar Puncture Performance Data

LP checklist scores were calculated based on ratings provided by two blinded raters for each pre- and post-test performance. Overall GRS scores were also calculated based on the average score assigned by each rater in each of the five GRS sub-components. Inter-rater reliability was calculated using an ICC and following confirmation of acceptable reliability (i.e. ICC > 0.7), the checklist scores and overall GRS scores were combined to yield a mean checklist score and GRS score at pre-test and post-test for each participant. Instructor ratings were not used in the establishment of post-test performance scores since they were unblinded and available for participants only in the SBML group.

Separate univariate ANCOVA analyses with pre-test scores as a covariate were used to determine whether there were any significant differences between intervention groups at post-test captured with the checklist score and GRS. Post hoc analyses were performed with Tukey's Least Significant Difference (LSD) to decompose any significant effects involving more than 2 means. Performance variability between groups was compared through evaluation of standard error around the mean for each group.

3.9.3 Knee Arthrocentesis Performance Data

Overall knee arthrocentesis GRS scores were also calculated based on the average score assigned by each rater in each of the five GRS sub-components. Inter-rater reliability was calculated using an ICC and following confirmation of acceptable reliability (i.e. ICC > 0.7), GRS-subcomponent scores were combined to yield a mean GRS score for each participant.

To assess our main outcome of interest, one-way ANOVA was used to determine whether there were any significant differences between intervention groups in knee arthrocentesis performance.

Chapter 4 Results

4.1 Participant Demographics and Baseline Questionnaire

A total of 60 participants had complete study data, with 20 in the SBML group, 18 in the SBDL group, and 22 in the control group. Participants included 51 first year medical students (85%) and 9 second year medical students. Thirty-two of the participants (53%) were medical students at McMaster University with the remaining 28 participants studying at the University of Toronto. There were 39 females (65%). The majority (56 participants, 93%) were right handed.

The demographic data for each group are presented below in Table 2. There were a greater proportion of second year medical students in the SBDL group. The baseline questionnaire data revealed that there were no significant differences between the groups for previous experience with LP, other simulated procedures or sterile technique training. All participants had previous problem based learning experience.

	Gender	**Year of Training***	**Handedness**	**Age – mean (range)**
SBML (n=20)	5 male (25%) 15 female (75%)	19 first year (95%) 1 second year (5%)	18 right (90%) 2 left (10%)	23.4 (21-32)
SBDL (n=18)	6 male (33%) 12 female (67%)	12 first year (67%) 6 second year (33%)	17 right (94%) 1 left (6%)	23.3 (21-28)
Control (n=22)	10 male (46%) 12 female (54%)	20 first year (91%) 2 second year (9%)	21 right (95%) 1 left (5%)	23.2 (21-26)
Overall (n=60)	21 male (35%) 39 female (65%)	51 first year (85%) 9 second year (15%)	56 right (93%) 4 left (7%)	23.3 (21-32)

*χ2 = 6.9162, p = 0.031489. No significant difference for all other variables across the groups

Table 2: Participant demographics as distributed across the three interventions.

	Previous LP Teaching	**Observed Previous LP**	**Previous Sterile Technique Training**	**Other Previous Simulation Training**
SBML (n=20)	19 No (95%) 1 Yes (5%)	17 No (85%) 3 Yes (15%)	8 No (40%) 12 Yes (60%)	13 No (65%) 7 Yes (35%)
SBDL (n=18)	15 No (83%) 3 Yes (17%)	15 No (83%) 3 Yes (17%	9 No (50%) 9 Yes (50%)	11 No (61%) 7 Yes (39%)
Control (n=22)	16 No (73%) 6 Yes (27%)	17 No (77%) 5 Yes (23%)	11 No (50%) 11 Yes (50%)	12 No (54%) 10 Yes (46%)
Overall (n=60)	51 No (85%) 9 Yes (15%)	48 No (80%) 12 Yes (20%)	28 No (47%) 32 Yes (53%)	36 No (60%) 24 Yes (40%)

No significant difference for all other variables across the groups

Table 3: Participant Experience data as distributed between the three interventions.

4.2 Lumbar Puncture Results

4.2.1 Rating Reliability

Intraclass correlation coefficient revealed good consistency among raters for GRS and excellent consistency for CL scores. For GRS, the ICC was 0.879 (95% CI 0.826-0.916) and for CL, the ICC was 0.959 (95% CI 0.940 to 0.971). With confirmation of acceptable inter-rater reliability, a mean score for each of the LP outcomes was calculated for each participant at pre-test and post-test.

4.2.2 Simulation Based Mastery Learning Group

4.2.2.1 Establishment of the Minimum Passing Standard

A panel of 6 clinical experts determined the MPS using the mastery Angoff (item-based) standard setting method. Expert responses are summarized in Table 4. The mean of the Angoff scores was calculated to be 86% and used as the MPS; this translated to a maximum of 2 items missed on the checklist. Though this mastery standard surpassed the mean checklist score recorded among experts (i.e. pediatric emergency medicine, neonatology and hematology staff or fellows with >50 LPs) in a study assessing validity of this tool (Gerard et al., 2013), it was lower than the MPS of 100% used in previous studies employing this checklist (D. Kessler et al., 2015; D. O. Kessler, Auerbach, Pusic, Tunik, & Foltin, 2011).

Expert Panelist	Plans insertion site	Prepares for procedure	Discusses consent process	Discusses analgesia	Cleanses	Maintains sterility	Instructs holder	Proper interspace	Midline of back	Inserted perpendicular	Advances Toward umbilicus	Advances one motion	Stylet removed	Makes corrections	Acquires fluid	Removes needle	Discards sharps
1	100	100	100	100	100	100	100	100	100	100	75	75	75	50	75	100	100
2	90	85	95	80	95	90	95	90	85	80	80	75	70	70	50	70	90
3	90	60	25	50	90	90	60	90	90	90	90	90	60	60	90	80	60
4	100	90	95	80	90	90	100	100	100	100	100	80	90	100	90	100	100
5	85	75	75	75	90	70	70	85	90	75	75	65	80	75	65	90	90
6	100	90	95	80	90	90	100	100	100	100	100	80	90	100	75	100	100

Table 4: Expert opinions regarding the probability (expressed as percent) of a well prepared medical student accomplishing each Infant Lumbar Puncture checklist item after repeated practice with the model; Used for establishment of the Minimum Passing Standard (MPS) according to the Mastery Angoff method.

Despite the fact that MPS was expected to reflect achievement of a mastery standard, a GRS score of 3 or greater was assigned to a participant with a combined total CL score of less than 86% in 9 cases. A GRS score of less than 3 (i.e. reflected incompetent performance) was assigned to 6 participants with total CL scores of at least 86% (i.e. reflecting achievement of the mastery standard).

4.2.2.2 Simulation Based Mastery Learning Group Outcomes

Eight participants (40%) in the SBML group failed to meet the MPS at initial posttest. They subsequently underwent additional deliberate practice and were retested. All participants reached the MPS within 1 hour of further practice. The maximum number of post-test trials before meeting the MPS was 3. There was agreement on achievement of the MPS between the instructor and blinded raters for all but 3 of the SBML participants.

4.2.3 Lumbar Puncture Checklist Scores

Data are mean ± standard error, unless otherwise stated. The average pre-test and post-test CL scores for the SBML group were 13.96% (± 3.51%) and 92.76% (±1.40%); the SBDL group were 13.83% (±2.50%) and 88.68% (±2.06%); and the control were 17.46% (±3.23%) and 86.43% (±2.57%); see Figure 6. The largest range of post-test scores (55.88-100%) was seen for the control group, as compared to the SBML group (78.86-100%) and the SBDL group (68.75-100.00%). The distribution of final checklist scores by group is depicted in Figure 6.

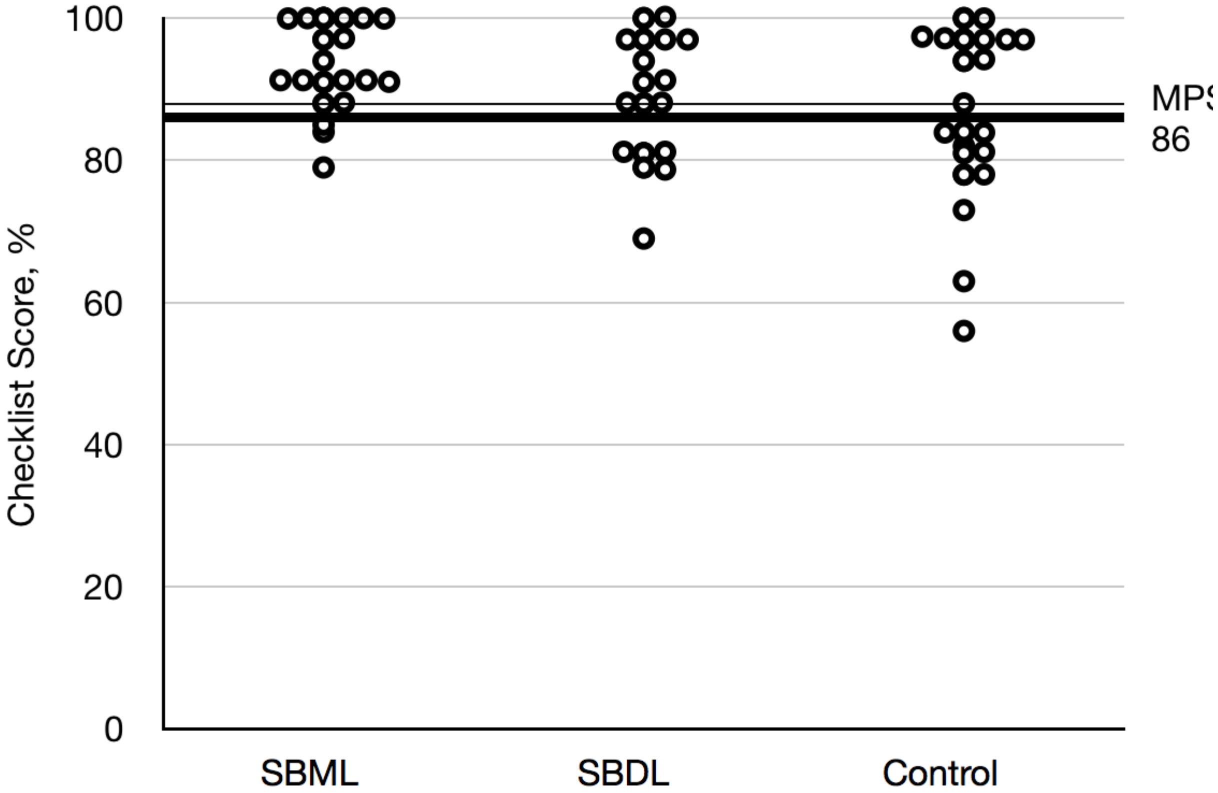

Figure 6: Infant lumbar puncture (checklist) final post-test performance of participants according to group of randomization.

There was a significant effect of group on LP checklist score after controlling for pre-test score, F(2,56) = 3.202, $p < 0.05$, partial η2 = 0.103.

Post hoc analysis was performed with a Tukey LSD test. Data are adjusted mean ± standard error, unless otherwise stated. Post-intervention LP checklist scores were statistically significantly greater in the mastery group (93.03 ±2.02%) compared to the control group (85.94 ±1.93%), a mean difference of 7.1% (95%

CI, 1.5 to 12.7%), p<05. There were no other statistically significant differences in post-intervention LP checklist scores between groups (see Table 5).

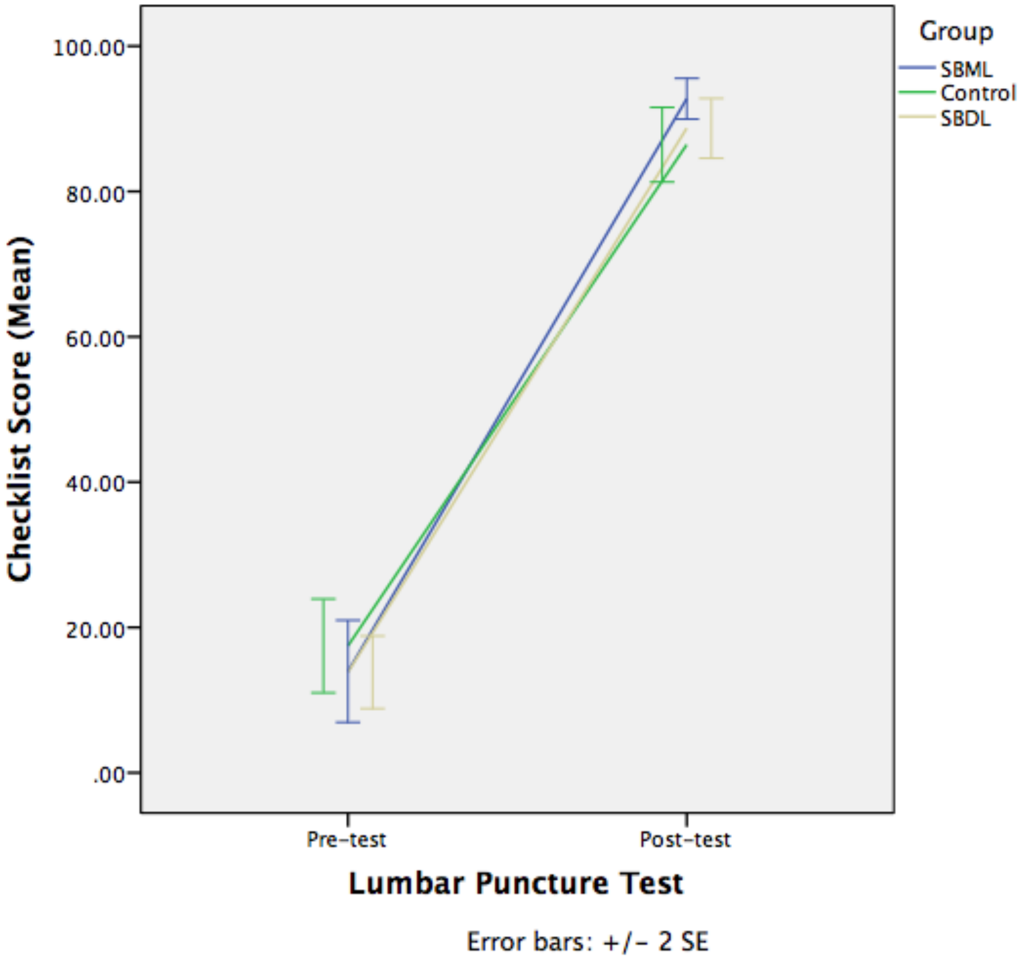

Figure 7: Mean Lumbar Puncture Checklist scores at pre-test and post-test across intervention groups. Error bars represent the standard error.

		Unadjusted		Adjusted	
	N	M (%)	SE (%)	M(%)	SE(%)
SBML	20	92.76	1.40	93.03	2.02
SBDL	18	88.68	2.06	88.98	2.13
Control	22	86.43	2.57	85.94	1.93

Table 5. Adjusted and Unadjusted Intervention Means and Variability for Post-Intervention Lumbar Puncture Checklist score with Pre-intervention checklist score as a Covariate.
Note. N = number of participants, M = Mean, SE = Standard Error, SBML = Simulation Based Mastery Learning, SBDL = Simulation based discovery learning

4.2.4 Lumbar Puncture GRS Scores

The average pre-test and post-test GRS scores for the SBML group were 1.20 (± 0.09) and 3.52 (±0.12); the SBDL group were 1.41 (±0.08) and 3.28 (±0.17); and the control were 1.34 (±0.09) and 3.16 (±0.15); see Figure 8. The largest range of GRS scores (1.9-4.4) was seen for the control group, as compared to the SBML group (2.5-4.4 and the SBDL group (2.2-4.5).

There was no significant effect of group on LP GRS after controlling for pre-test GRS score, F(2,56) = 2.272, p = 0.113, partial η2 = 0.075. Adjusted and unadjusted mean scores across intervention groups are presented in table 6.

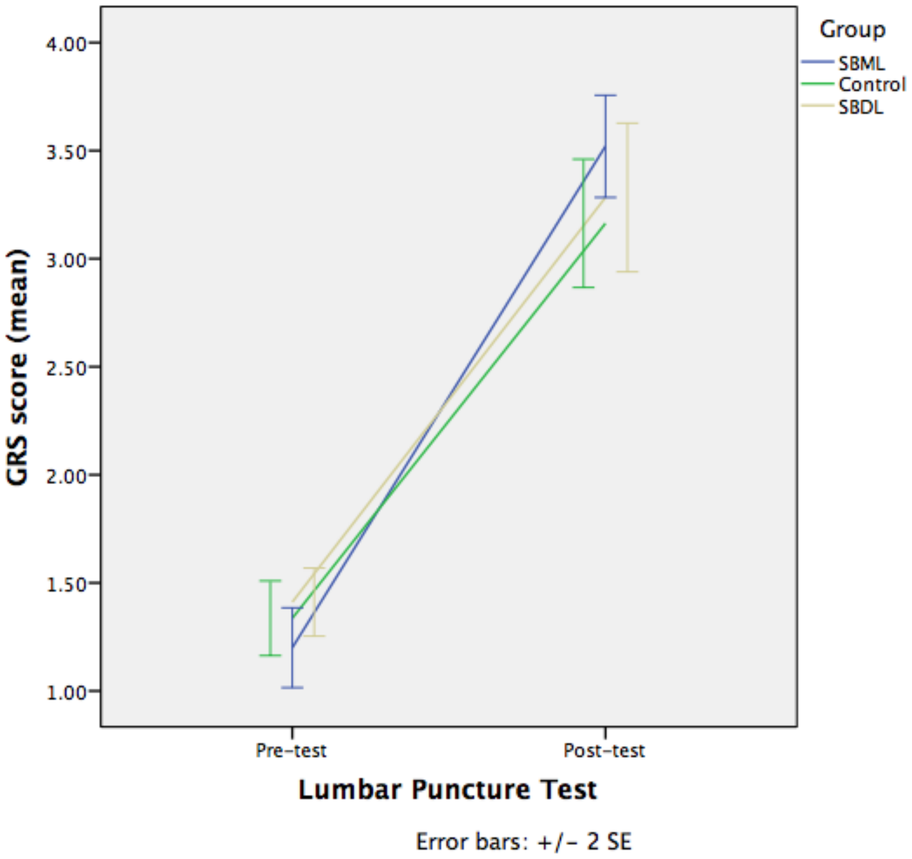

Figure 8: Mean Lumbar Puncture GRS scores at pre-test and post-test across intervention groups. Error bars represent the standard error.

		Unadjusted		Adjusted	
	N	M	SE	M	SE
SBML	20	3.52	.12	3.57	.15
SBDL	18	3.28	.17	3.24	.15
Control	22	3.16	.15	3.15	.14

Table 6. Adjusted and Unadjusted Intervention Means and Variability for Post-Intervention Lumbar Puncture Global Rating Scale (GRS) score with Pre-intervention GRS score as a Covariate.

Note. N = number of participants, M = Mean, SE = Standard Error, SBML = Simulation Based Mastery Learning, SBDL = Simulation based discovery learning

4.3 PFL: Knee Arthrocentesis Results

The PFL session took place an average of 16 days after the initial learning session (range 9-22 days). All participants completed the secondary learning task and PFL assessment within 30 minutes.

4.3.1 Knee Arthrocentesis GRS Rater Reliability

Intraclass correlation coefficient revealed disagreement among raters for knee arthrocentesis GRS scores. The ICC was -0.186 (95% CI -9.80-0.290). The lack of acceptable inter-rater reliability rendered combining knee arthrocentesis outcomes to calculate a single score for each participant problematic.

4.3.2 Knee Arthrocentesis GRS Scores

Recognizing limitations in reliability of ratings, a mean GRS score was calculated for each participant for the knee arthrocentesis performance. Mean scores for the SBML group were 2.52 (±0.47), SBDL group were 2.44 (±0.64), and control group were 2.3 (±.45). There was no statistically significant difference between groups as determined by one-way ANOVA (F(2,57) = 0.938, p = 0.397).

	N	M	SE	Minimum	Maximum
SBML	20	2.52	0.11	1.70	3.60
SBDL	18	2.44	0.15	1.40	3.20
Control	22	2.30	0.10	1.60	3.30

Table 7. Means and Variability for Knee Arthrocentesis Global Rating Scale (GRS) score

Note. N = number of participants, M = Mean, SE = Standard Error, SBML = Simulation Based Mastery Learning, SBDL = Simulation based discovery learning

Chapter 5 Discussion

This study examined the effects of simulation-based instruction according to a mastery learning, discovery learning or non-mastery curriculum on infant LP skill acquisition and PFL of the knee arthrocentesis procedure in a simulation-based training context for novice learners. The following discussion highlights interpretations of study results in the context of existing literature and discusses their implications for researchers and educators in health professions education. First, the lumbar puncture performance data will be explored, highlighting potential interpretations that can be drawn from the presence (and absence) of differences in post-instruction outcomes observed among participants in each of the three intervention-groups. Next, the main outcome of knee arthrocentesis performance will be reviewed and the finding of unexpected challenges with reliability of ratings and no significant difference on the PFL double transfer test will be discussed in the context of existing literature. Together, the results suggest that participation in a mastery learning curriculum may offer some gains in procedural skill performance of a target task, but there were no benefits seen in how prepared students were to learn a novel procedural technique. This chapter will close with an exploration of the study limitations and directions for future research will be discussed.

This thesis contributes to expansive literature on SBML but is the first study, to our knowledge, to assess PFL as an outcome of this educational intervention. Assessment of performance after student engagement with educational materials for a novel learning task is important given that mastery learning approaches are assumed to enhance future learning ability (B. S. Bloom, 1973). This work is also unique in its application of the constructivist principle of invention as a pre-training tool for procedural skill development in HPE. This builds on previous work which has demonstrated performance benefits for learning and applying new statistical concepts after students were given the opportunity to invent solutions to statistical problems prior to being shown the expert approach (Schwartz & Martin, 2004). This work seeks to examine whether the benefit of invention activities realized in the cognitive domain can be generalized to procedural skills training within the simulation context, through application of PFL methodology and assessments.

5.1 Initial learning task processes and outcomes

5.1.1 Establishment of the MPS

In design of the SBML intervention, the mastery-learning Angoff approach (Yudkowsky et al., 2015) was used to establish the MPS. While this is one of the standard setting approaches widely used and advocated for in the SBML literature, an approach to mastery standard setting which draws on performance data that include past examinees' performance in subsequent learning experiences is favored (O'Malley, Keng, & Miles, 2012; Yudkowsky et al., 2015). We were unable to establish a MPS on the basis of past performance as data is not available for trainees at a similar level of training (i.e. pre-clinical medical students). Of note, the MPS used in this study differs from previous studies which have defined mastery as independent performance of all items on the same subcomponent skills checklist (e.g. Kessler et al., 2015; Kessler, Auerbach, Pusic, Tunik, & Foltin, 2011). Differing mastery standards may be appropriate given that these studies were conducted with interns and residents, for whom a higher performance standard might be expected.

Interestingly, although the MPS was established based on standards derived from an expert panel for expected performance of a medical student trainee well prepared to perform at the next level of training, there was discrepancy noted for some participants who were recorded to have achieved MPS based on checklist scores, and yet demonstrated performance below the level of competence as rated on the GRS. There are a number of possible explanations for this finding. First, use of a minimum checklist score to determine mastery does not take into account the relative impact of a procedural error or omission on success of the procedure or potential patient harm. However, these types of errors would be likely to strongly influence a participants' score on the GRS. It is possible that standard setting according to the patient safety approach may better reflect achievement of competence on the GRS. The patient safety approach to standard setting requires identification of checklist items that correspond with dimensions such as safety, procedural outcome, or patient comfort and the requirement for such essential items to be achieved before a learner is deemed to have achieved mastery (Yudkowsky, Tumuluru, Casey, Herlich, & Ledonne, 2014). Achievement of competence and performance at the MPS may better coincide if standards are set taking into account relative importance of checklist items in the future.

5.1.2 Lumbar Puncture Performance and Learning

Results of pre-test assessments demonstrated that participants were true novices, with mean checklist scores of less than twenty percent in all groups and mean GRS scores between 1 and 2. As anticipated, performance on post-test assessments was significantly higher than pre-test scores in all groups. This is consistent with other simulation literature which has demonstrated benefits of simulation-based curricula for procedural skills, especially when the instructional design involves deliberate practice (McGaghie, Issenberg, Cohen, Barsuk, & Wayne, 2011). Participants in all intervention groups received instruction and the opportunity to engage in deliberate practice involving a well defined learning objective, with appropriate level of difficulty and the opportunity for focused, repetitive practice. During this practice, participants received feedback and direction from instructors and were able to incorporate the feedback in order to correct errors and improve performance through additional practice trials. These features are consistent with elements of deliberate practice (Ericsson, 2004).

With pre-test scores as a covariate, a significant effect of group on LP checklist scores was seen at post-test. Post hoc analyses demonstrated that LP checklist scores were statistically significantly higher among participants in the SBML group as compared to the control group. However, no significant effect of group on LP GRS was observed. This is partially consistent with hypothesis 1A, which anticipated that participation in a SBML curriculum would have a significant, positive impact on trainees' post-test LP checklist and GRS scores. The higher checklist scores among participants in the SBML group as compared to the control group is consistent with the mastery learning literature which has demonstrated a large educational benefit of SBML compared with non-mastery simulation based instruction (Cook et al., 2013). However, there was no significant difference seen in performance of the SBML group as compared to the SBDL group at post-test and no educational benefit for SBML in comparison to the other learning interventions was demonstrated using the GRS. This pattern of findings has important implications for how decisions regarding procedural skill teaching are made in the clinical setting. First, given that performance gains from mastery learning curricula were found to be modest and reflected only in checklist, but not GRS scores, the additional resources required to implement mastery learning interventions should be considered. Mastery learning curricula have been shown to take more time (Cook et al., 2013), require instructor training, and necessitate the establishment of defensible passing standards (Yudkowsky et al., 2015) which might require more resources than alternative training approaches. However, these costs may be offset by improved patient-related outcomes and clinical cost-savings reported after SBML of procedural skills (Cohen et al., 2010; Mcgaghie et al., 2014). It has yet to be determined whether similar benefits would be realized following SBDL for procedural skills and a cost-benefit comparison of the two interventions would be of value.

Since previous work has demonstrated educational benefits of SBML in comparison with no intervention and non-mastery instruction (Cook et al., 2013), the finding that the SBML group did not outperform participants in the SBDL group warrants further consideration. Participants in the SBDL group engaged in an invention activity in which they were asked to develop and trial strategies for performing infant LP prior to receiving didactic instruction consisting of an educational video on infant LP and an interactive infant LP demonstration and having the opportunity to engage in deliberate practice with directed feedback. This type of pre-training has been shown to be beneficial for preparing students to learn the expert approach and has been termed *productive failure*. Productive failure refers to learner engagement in problem solving activities involving concepts which have not yet been taught followed by direct instruction and training related to the concept of interest (Kapur, 2008). In these activities, learners are typically unsuccessful in arriving at the correct solution and performance in the short term may be impeded. However, use of prior knowledge to generate solutions, regardless of their accuracy, has been shown to be beneficial in preparing students to ultimately receive instruction from experts (Kapur & Bielaczyc, 2012; Schwartz & Martin, 2004). While the productive failure literature has been primarily studied in the context of cognitive tasks such as mathematics and statistics learning, other forms of pre-training involving basic or foundational skills, as well as mental rehearsal, have been shown to enhance learning in subsequent simulation based training (Cook et al., 2013). Discovery-based training prior to didactic instruction and deliberate practice may offer educational benefits similar to mastery learning, or could be further evaluated as a mechanism to enhance the educational benefit of mastery learning curricula in the simulation context. As will be discussed further, this equivalence in training outcomes also highlights the potential value of PFL assessments as an important outcome of differentiation between training approaches.

The greatest variance in performance at post-test was observed for checklist and GRS scores among participants in the control group. This is at odds with hypothesis 1B, which anticipated that this pattern of findings would be observed for participants in the SBDL group. The large range in post-test scores for control group participants suggests that the intervention produced less uniform achievement among trainees. Participants in this intervention were not subject to the same requirement for achievement of a MPS as the trainees in the SBML group and as such, there was no opportunity for additional instruction, practice and feedback if achievement was suboptimal at the end of the timed training session. Engagement in an invention activity prior to direct instruction was initially hypothesized to increase variability in performance. However, it may be that engagement in this constructivist activity actually more uniformly prepared students to learn from the direct instruction and deliberate practice which followed. There was the least variability in performance, both in checklist score and GRS, among participants trained according to the SBML intervention. This finding is expected, since mastery curricula are intended to ensure that all learners ultimately perform at a high level of achievement with little or no variation in outcome by personalizing the amount of time needed to achieve this level of performance (McGaghie, 2015b; Sheng & Lifeng, 2012).

5.1.3 Discussion of Intervention-specific findings

Interpretation of study results in the context of existing literature in SBML offers some important evidence of ecological validity of the intervention and highlights some deviations from previous findings that will be discussed. First, 8 participants (40%) in the SBML group failed to meet the MPS at the initial post-test. Participants required a maximum of 3 performance assessments before the MPS was achieved and this required no more than 1 hour of additional instruction and testing time, which is in keeping with existing SBML literature (Barsuk et al., 2012, 2015; Wayne, Barsuk, O'Leary, Fudala, & McGaghie, 2008). There was agreement on achievement of the MPS between the instructor and blinded raters for all but 3 of the SBML participants. For two of these participants, there was agreement between one of the blinded raters and the instructor that the MPS had been achieved, but the average CL score assigned by the blinded raters fell slightly below the MPS. For the third participant, both blinded raters scored performance below the MPS. Review of this video-recorded performance showed that the participant initially forgot two steps but later remembered and demonstrated the appropriate technique; the initial instructor recorded these steps as having been completed successfully while the blinded raters did not. This variability in assessment of mastery performance achievement may have diluted the effect of the mastery intervention on LP performance outcomes as well as the knee arthrocentesis transfer task.

5.2 PFL

Recognizing limitations in interpretation of knee arthrocentesis performance outcomes, this study revealed no significant difference in performance on the PFL assessment between participants according to group of initial infant LP instruction. Review of performance on the double transfer task revealed that the majority of participants in all groups were not competent to perform the knee arthrocentesis task at the end of the independent training and practice session. While these findings should be interpreted with significant caution, this pattern of results may indicate that regardless of the initial training intervention, participants were inadequately prepared to learn from the novel material. This highlights the difficulty trainees face in the transfer of knowledge and learning skills to new problems, the type of knowing that Broudy (1977) referred to as interpretive. This differs from replicative knowing, involving the use of knowledge in the same context in which it was acquired and rehearsed and applicative knowing, involving the use of acquired rules and procedures in a new context (i.e. the type of knowing captured in standard transfer assessments) (Broudy, 1977). These findings are in conflict with investigations performed in the cognitive domain which have, for example, demonstrated benefits of engagement in invention activities for subsequent learning of statistics concepts (Schwartz & Martin, 2004). However, even for purely cognitive tasks, invention activities have not uniformly been shown to enhance future learning over direct instruction (Belenky & Nokes, 2009; Matlen & Klahr, 2009). Interestingly, previous thesis work aimed at evaluating the mechanisms and cognitive processes underlying structured invention tasks as a tool to prepare students for future learning found that invention activities were less successful at preparing low-achieving students for future learning (Roll, 2009). It is possible that some degree of prior knowledge is needed for successful invention as preparation for learning, and the novice medical student participants in this study did not possess the requisite prior knowledge and skills to benefit from the invention activity. However, it is also possible that a true difference in PFL ability exists, but was not detected on account of study limitations. This possibility will be explored further in the limitation section which follows.

5.2.1 PFL Assessments in the Simulation Context

While there is a strong literature base in educational psychology (Bransford & Schwartz, 1999) and medical education (Mylopoulos & Woods, 2014, 2017) focused on the theoretical understanding and practical application of adaptive expertise and PFL, studies evaluating the goal of preparing learners for future development of procedural skills in the simulation context are in their infancy. Previous graduate student work by Julian Manzone used the double transfer methodology to compare how initial instruction in a simulation setting involving (i) self-regulated learning with supports (i.e. explanation about influence of practice schedules on learning, list of process goals, and interviewing aimed at promoting different types of knowing), (ii) self-regulated learning without supports, and (iii) one-on-one instructor-led training (involving didactic teaching, demonstration of the technique and feedback during practice) influenced PFL of endotracheal intubation skill on a simulator (Manzone, 2015).

This project builds on the previous application of PFL assessments in the simulation context. While this study design has implications for researchers who might seek to identify benefits of interventions which might not otherwise be detectable using traditional assessment approaches and standard transfer tests, the overall poor performance on the double transfer task and lack of reliability in ratings assigned to the PFL task performance serves as a reminder of the intricacies involved in selection of appropriate double transfer tasks, learning materials and assessment methods. These challenges should be considered and mitigated in future work which aims at contributing to the collection of validity evidence for PFL assessments and using these methodologies to compare the impacts of educational approaches on future learning ability.

As the practical methodological aspects of the use of PFL assessments in the simulation context are optimized, educators may begin to use these tools as one component of the evolving system for assessment within new competency-based curricula. This may represent an important tool given that the skills of flexibility and innovation in learning and practice may not be effectively evaluated using traditional assessment mechanisms (Bransford & Schwartz, 1999). And ultimately, as research employing PFL assessments contributes to a greater understanding of the benefits of particular instructional approaches for future learning ability, faculty development aimed at teaching principles of the particular educational interventions and paradigms found to be beneficial for the development of knowledge, skills and attitudes that support lifelong learning will be necessary.

5.3 Limitations

This thesis has a number of limitations that are important to highlight and consider when interpreting study results. First, a significant unexpected finding was very poor agreement between raters in assignment of knee arthrocentesis GRS scores. This disagreement was present despite rater orientation including an exercise intended to facilitate development of a shared mental model regarding the definition of competence in this context. Disagreement in rater scores impeded our ability to reliably combine scores to produce an average performance rating for each participant. Producing a combined average score for each participant despite poor agreement between individual raters significantly impeded the reliability of our outcome data for the PFL assessment and as such, the finding of no significant differences in PFL among participants based on group of initial instruction should be interpreted with significant caution.

Potential sources of error and poor reliability include limitations in selection of the knee arthrocentesis assessment tool given the level of expertise of study participants and rater-related factors. First, while GRSs are commonly used for the assessment of procedural skill performance, limited validity evidence exists for the knee arthrocentesis GRS in the simulation context for novice medical student trainees. It is possible that the tool rendered it challenging for raters to discriminate performance among this group of novice learners and it may not have been sensitive enough to detect any true differences in knee arthrocentesis performance. While GRS have more discriminate value at higher levels of expertise (Ilgen et al., 2015), a more systematic assessment framework may have yielded performance assessments with greater validity for this novice group. Use of a subcomponent checklist might also offer the opportunity to evaluate exactly what knowledge and procedural skills (e.g. landmarking, sterility, etc.) are transferred between the performance tasks.

The selection of raters for knee-arthrocentesis performance may have also impacted the reliability of scoring. Though senior rheumatology trainees were recruited as raters for the assessment of performance on the double transfer task, assessment of novice trainee performance of knee arthrocentesis may not be a significant component of their daily work and thus more intensive training may have been required to facilitate development of a shared mental model regarding rating using the GRS and assessment of competent performance in this context. However, there are inherent differences in raters and training has not been shown to be consistently beneficial in the literature (Gingerich, Kogan, Yeates, Govaerts, & Holmboe, 2014). These sources of error and variability in ratings warrant further consideration and mitigation in future work.

With regards to the study interventions and ecological validity of the educational paradigms they are meant to represent, a couple of additional factors require emphasizing. This study is novel with respect to evaluation of a simulation-based guided invention curriculum. While design of this intervention drew upon literature regarding discovery learning, invention activities, and constructivist approaches to learning in general, much of the existing evidence came from research in fields outside of medical education and was focused primarily on cognitive tasks such as mathematics and statistics learning (e.g. Schwartz & Martin, 2004). As such, evidence informing optimal design of a guided invention activity for the purpose of procedural skill learning was not available. It was expected that guided invention would encourage participants to focus on land-marking, use of proper sterile technique, and technical skill which would facilitate deep learning of the procedure. While informal observations of participant engagement during the group invention activity supported these aims, participants did not seem to transfer this approach to the new learning task. Future work to optimize this constructivist intervention and formally evaluate how students approach the invention activity and subsequent learning task is required in order to definitively assess the impact of curricula involving discovery and expert instruction on procedural skill acquisition and transfer of knowledge and strategies to learning and performance of a novel procedure.

Next, further consideration of unexpected findings related to disagreement between raters in assessment of achievement of the MPS for some participants, and participant achievement of the MPS despite earning average GRS scores below the level of competence, raises important considerations for how SBML curricula are applied in research and clinical settings. These discrepancies may have reduced our power to detect differences in performance of the initial procedural skill and would have impaired our ability to detect a true difference in PFL among participants randomized to this intervention. Since reliable and reproducible assessment of performance is a key component of SBML curricula, issues of reliability raised in this study warrant further attention so that assessment practices may be optimized to ensure defensible and reliable demonstration of competence and mastery.

Finally, consideration of how participants learned, practiced and ultimately performed the knee arthrocentesis transfer task raises a potential caution for researchers selecting transfer tasks in studies of PFL. Although this procedure was selected on the basis of some procedural and conceptual similarities with infant LP, it is possible that this procedure may not have been optimal as a PFL task, since a fluid sample could be obtained from the task trainer relatively easily and even in the presence of significant procedural errors. This might have influenced how participants engaged with the task trainer during practice as well as outcomes on the transfer task. Since performance among participants in all groups was poor on the transfer task, it is possible that participants were driven to focus on outcome rather than the important conceptual and technical aspects of the procedure once they determined how easily a fluid sample could be obtained from the model. It is possible that participants may have more reliably drawn on the knowledge, skill and approaches learned during the initial learning session in the face of a simulated procedural skill which was perceived to be more challenging.

5.4 Future Directions

Analysis of the study findings and consideration of the initial conception of research questions and study methodology for this work raise a number of interesting questions and problems which warrant attention and investigation through future work. Additionally, future work aimed at optimizing the PFL assessment in the simulation-based procedural skill context would be beneficial. To this end, unanswered questions regarding the learning materials, assessment task, and optimal rating tools for PFL assessments remain. For instance, this study used a written article and instructional video as instructional materials for the transfer procedure as well as unsupervised, unguided practice with the knee arthrocentesis simulated model. However, the optimal instructional materials and practice conditions for use in PFL assessments have not been established. Further, students worked with these materials and were given control over the total training time used and how they engaged with these resources. In addition to evaluating learning based on performance on the final procedural skill assessment, it may also be important to capture differences in the manner in which trainees engage with learning materials provided for the novel procedure. This would also contribute to a greater understanding of behaviors that relate to PFL ability and influence performance of a newly learned procedural skill.

As discussed in the previous section, this study used knee arthrocentesis as the double transfer task. This clinical procedure was selected given the presence of some procedural and conceptual similarities with the initial training procedure, LP. As future work employing the PFL assessment in the context of simulation-based procedural skill learning is performed, it will be important to identify the optimal characteristics of the transfer task to guide researchers in selecting procedures to use in these type of assessments. Likewise, participants in this study engaged with the novel learning materials and underwent the PFL assessment approximately 2 weeks after initial training sessions. This schedule was selected based on convenience and may not reflect the optimal timing of PFL assessment. Since decay in procedural skills is expected with time (Lammers et al., 2008) and PFL and adaptive expertise incorporate the transfer and application of previously acquired knowledge and learning skills (Schwartz et al., 2005), timing of double transfer assessments may impact results and study of the durability of strategies and behaviours that prepare trainees for future learning are warranted.

This study used a GRS to assess the outcome of learning of a novel procedural skill. While this methodology is beneficial in comparing learning interventions which might influence future learning ability, it would also be beneficial to evaluate the learning curve and learning process data as trainees practice and perform a novel procedural skill. For instance, analysis of variance in total learning time, the number of attempts required to achieve mastery, and differences in the types of errors trainees make while learning the novel procedure would be interesting outcomes to study in order to more fully understand the impact of various educational interventions on future learning ability.

With the aim to provide guidance to clinical teachers and curriculum designers on the optimal design of teaching interventions when the goal is for innovation and flexibility in problem solving and learning in practice, future work could build on this study to use the PFL assessment to compare the impact of other educational interventions. In particular, systematically changing instructional design elements known to impact learning and skill acquisition would be beneficial. Since outcomes of adaptability and preparedness to learn are not captured in traditional medical education outcomes (Mylopoulos et al., 2016), PFL assessments could be used to identify interventions and educational design features which contribute to the development of knowledge and learning skills which favorably impact future learning and might therefore be preferred in health professions education curriculum design, even when other learning outcomes are equal. Identification and implementation of these teaching and learning strategies would be particularly important in the context of CBME, and CBD in particular, given that the aim is to train clinicians who are prepared for practice with particular medical and specialty-specific expertise, but also are capable of flexibility in practice and learning (Frank et al., 2010).

6. Conclusions

This thesis has demonstrated that while engagement in a simulation-based mastery learning curriculum may have some benefit for learning of specific procedural steps as captured on an infant lumbar puncture subcomponent checklist, participation in a simulation-based educational intervention involving deliberate practice with or without the requirement for achievement of a mastery standard, and participation in invention activities prior to direct instruction and deliberate practice all result in significant improvements in procedural skill performance. Our results indicate that these interventions do not differ in impact on PFL, as captured using a simulated double transfer task. This work also highlights several practical methodological aspects of the use of PFL assessments in the simulation context and has study design implications for researchers who might seek to use PFL assessments to identify benefits of interventions which might not otherwise be detectable using traditional assessment approaches and standard transfer tests. Finally, this work highlights the challenges novice trainees face for the transfer of knowledge and skills to new procedural learning problems, and further work is required to design learning interventions which well support PFL when the goal of training is aimed at developing adaptive expertise.

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Appendices

Appendix A: Demographic Questionnaire: Lumbar Puncture

Age: ________
Gender: Male / Female
Handedness: R L

Please list previous undergraduate and postgraduate

School	Program	Degree

What year of medical school are you in: _________________

Have you ever received didactic teaching on Lumbar Puncture (e.g. participated in a lecture, bedside teaching, or watched an instructional video on LP)?
Yes / No
If yes, number of hours of instruction: ____________hrs

Have you ever received simulation training on Lumbar Puncture?
Yes / No
If yes, number of hours of practice: ____________hrs

Have you ever received simulation training on other procedures? Yes / No
If yes, which procedures? ____

How many hours of simulation training have you completed? ____________hrs
Have you observed a simulated technique? _____
Performed a simulated technique? ______

Have you ever observed or performed a Lumbar Puncture in a clinical setting (e.g. on a real patient)?
Yes / No
If yes, how many times have you:

Observed an LP? _____
Performed an LP? ______
Successfully completed an LP? _______

Have you had previous PBL experience?
Yes / No

Have you previously had formal training in sterile technique?
Yes / No

Appendix B: Participant Instructions for SBDL Group

<u>Instructions to Participant:</u> Please practice performing the skill of lumbar puncture. Your goal is to collect cerebral spinal fluid (CSF) from the L4/5 or L5/S1 interspace using proper sterile technique. This task is performed with the patient in the lateral decubitus [side lying] or sitting position – today we will practice the skill with the patient positioned in lateral decubitus. Aim to develop an efficient, reproducible strategy that would be effective in the simulation and clinical settings. Your CSF collection will allow analysis of the sample in the laboratory. Discard your sharps in a safe manner.

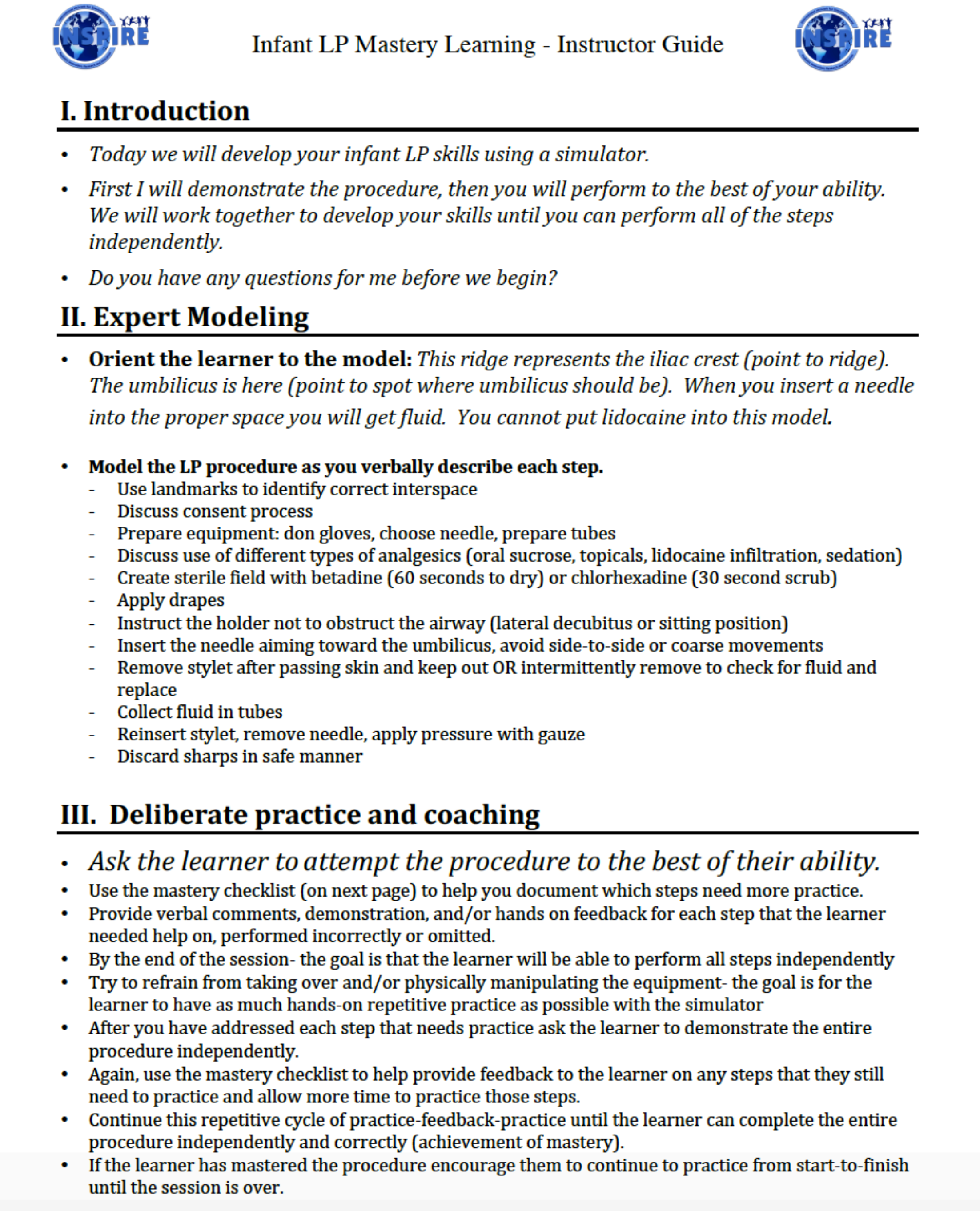
To complete this task, you will need to be able to:

- Landmark
- Use proper sterile technique
- Collect CSF while minimizing tissue trauma

As you invent strategies to perform a lumbar puncture, think about the following guiding statements:

Consider the features (patient position, body habitus, etc.) that would impact the effectiveness of each strategy you invent.
Consider the impact of variations in your technique (methods for holding the need, different insertion angles and depths, needle bevel position, etc.) that would impact the effectiveness of each strategy you invent.
After each attempt think about how your strategy relates to your original expectation of how the procedure should be performed and what the outcome will be.
Include an analysis of how this attempt is similar or different from your previous attempt as well as your original hypothesis.
With each attempt, try to explain the steps you are taking and technique you are using.

Appendix C: Mastery Learning Instructor Guidelines



Infant LP Mastery Learning - Instructor Guide

I. Introduction

- *Today we will develop your infant LP skills using a simulator.*
- *First I will demonstrate the procedure, then you will perform to the best of your ability. We will work together to develop your skills until you can perform all of the steps independently.*
- *Do you have any questions for me before we begin?*

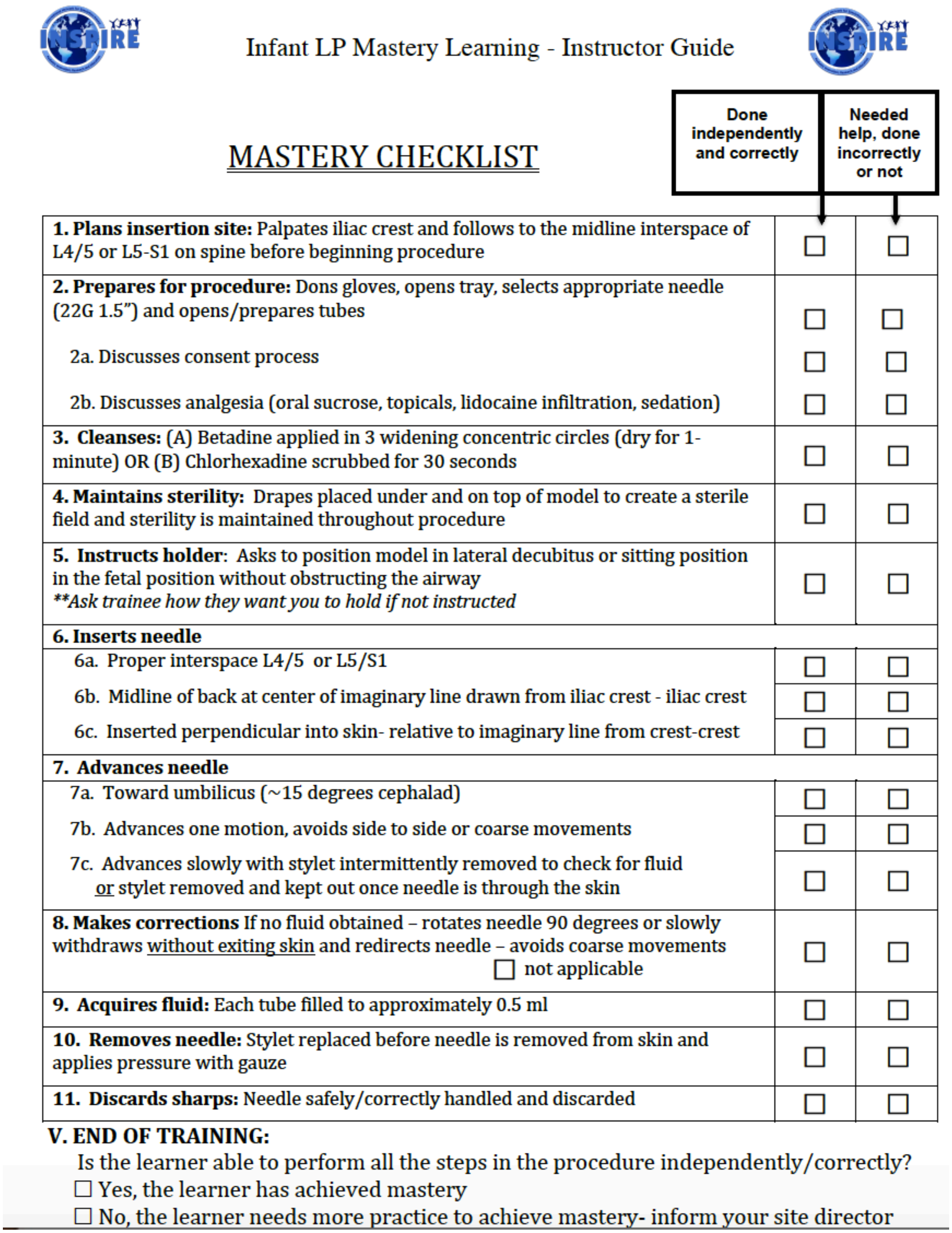
II. Expert Modeling

- **Orient the learner to the model:** *This ridge represents the iliac crest (point to ridge). The umbilicus is here (point to spot where umbilicus should be). When you insert a needle into the proper space you will get fluid. You cannot put lidocaine into this model.*

- **Model the LP procedure as you verbally describe each step.**
  - Use landmarks to identify correct interspace
  - Discuss consent process
  - Prepare equipment: don gloves, choose needle, prepare tubes
  - Discuss use of different types of analgesics (oral sucrose, topicals, lidocaine infiltration, sedation)
  - Create sterile field with betadine (60 seconds to dry) or chlorhexadine (30 second scrub)
  - Apply drapes
  - Instruct the holder not to obstruct the airway (lateral decubitus or sitting position)
  - Insert the needle aiming toward the umbilicus, avoid side-to-side or coarse movements
  - Remove stylet after passing skin and keep out OR intermittently remove to check for fluid and replace
  - Collect fluid in tubes
  - Reinsert stylet, remove needle, apply pressure with gauze
  - Discard sharps in safe manner

III. Deliberate practice and coaching

- *Ask the learner to attempt the procedure to the best of their ability.*
- Use the mastery checklist (on next page) to help you document which steps need more practice.
- Provide verbal comments, demonstration, and/or hands on feedback for each step that the learner needed help on, performed incorrectly or omitted.
- By the end of the session- the goal is that the learner will be able to perform all steps independently
- Try to refrain from taking over and/or physically manipulating the equipment- the goal is for the learner to have as much hands-on repetitive practice as possible with the simulator
- After you have addressed each step that needs practice ask the learner to demonstrate the entire procedure independently.
- Again, use the mastery checklist to help provide feedback to the learner on any steps that they still need to practice and allow more time to practice those steps.
- Continue this repetitive cycle of practice-feedback-practice until the learner can complete the entire procedure independently and correctly (achievement of mastery).
- If the learner has mastered the procedure encourage them to continue to practice from start-to-finish until the session is over.



Infant LP Mastery Learning - Instructor Guide

MASTERY CHECKLIST

	Done independently and correctly	Needed help, done incorrectly or not
1. Plans insertion site: Palpates iliac crest and follows to the midline interspace of L4/5 or L5-S1 on spine before beginning procedure	☐	☐
2. Prepares for procedure: Dons gloves, opens tray, selects appropriate needle (22G 1.5”) and opens/prepares tubes	☐	☐
2a. Discusses consent process	☐	☐
2b. Discusses analgesia (oral sucrose, topicals, lidocaine infiltration, sedation)	☐	☐
3. Cleanses: (A) Betadine applied in 3 widening concentric circles (dry for 1-minute) OR (B) Chlorhexadine scrubbed for 30 seconds	☐	☐
4. Maintains sterility: Drapes placed under and on top of model to create a sterile field and sterility is maintained throughout procedure	☐	☐
5. Instructs holder: Asks to position model in lateral decubitus or sitting position in the fetal position without obstructing the airway ***Ask trainee how they want you to hold if not instructed*	☐	☐
6. Inserts needle		
6a. Proper interspace L4/5 or L5/S1	☐	☐
6b. Midline of back at center of imaginary line drawn from iliac crest - iliac crest	☐	☐
6c. Inserted perpendicular into skin- relative to imaginary line from crest-crest	☐	☐
7. Advances needle		
7a. Toward umbilicus (~15 degrees cephalad)	☐	☐
7b. Advances one motion, avoids side to side or coarse movements	☐	☐
7c. Advances slowly with stylet intermittently removed to check for fluid <u>or</u> stylet removed and kept out once needle is through the skin	☐	☐
8. Makes corrections If no fluid obtained – rotates needle 90 degrees or slowly withdraws <u>without exiting skin</u> and redirects needle – avoids coarse movements ☐ not applicable	☐	☐
9. Acquires fluid: Each tube filled to approximately 0.5 ml	☐	☐
10. Removes needle: Stylet replaced before needle is removed from skin and applies pressure with gauze	☐	☐
11. Discards sharps: Needle safely/correctly handled and discarded	☐	☐

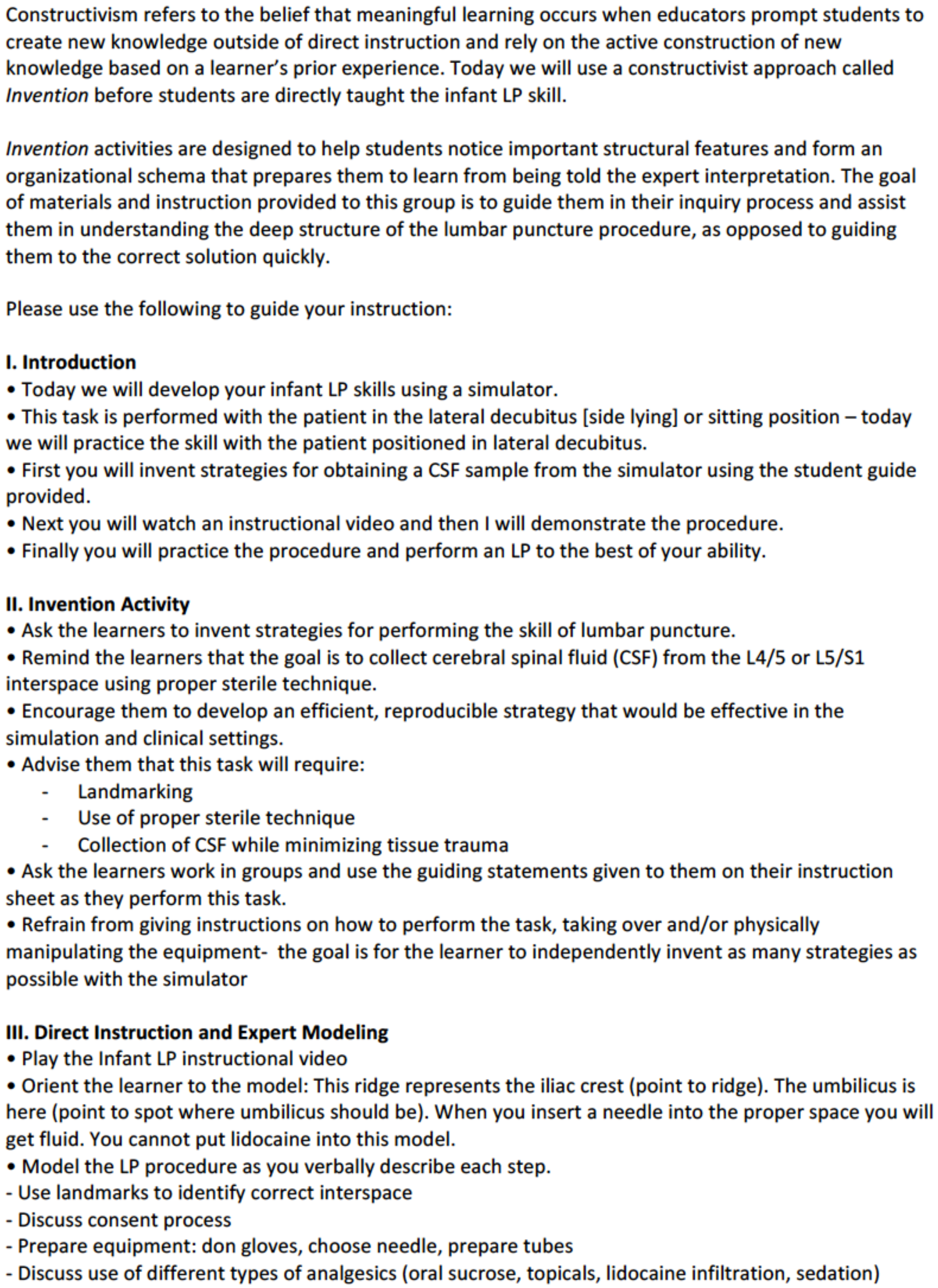
V. END OF TRAINING:

Is the learner able to perform all the steps in the procedure independently/correctly?

☐ Yes, the learner has achieved mastery

☐ No, the learner needs more practice to achieve mastery- inform your site director

Appendix D: SBDL Instructor Guidelines



Constructivism refers to the belief that meaningful learning occurs when educators prompt students to create new knowledge outside of direct instruction and rely on the active construction of new knowledge based on a learner's prior experience. Today we will use a constructivist approach called *Invention* before students are directly taught the infant LP skill.

Invention activities are designed to help students notice important structural features and form an organizational schema that prepares them to learn from being told the expert interpretation. The goal of materials and instruction provided to this group is to guide them in their inquiry process and assist them in understanding the deep structure of the lumbar puncture procedure, as opposed to guiding them to the correct solution quickly.

Please use the following to guide your instruction:

I. Introduction

- Today we will develop your infant LP skills using a simulator.
- This task is performed with the patient in the lateral decubitus [side lying] or sitting position – today we will practice the skill with the patient positioned in lateral decubitus.
- First you will invent strategies for obtaining a CSF sample from the simulator using the student guide provided.
- Next you will watch an instructional video and then I will demonstrate the procedure.
- Finally you will practice the procedure and perform an LP to the best of your ability.

II. Invention Activity

- Ask the learners to invent strategies for performing the skill of lumbar puncture.
- Remind the learners that the goal is to collect cerebral spinal fluid (CSF) from the L4/5 or L5/S1 interspace using proper sterile technique.
- Encourage them to develop an efficient, reproducible strategy that would be effective in the simulation and clinical settings.
- Advise them that this task will require:
    - Landmarking
    - Use of proper sterile technique
    - Collection of CSF while minimizing tissue trauma
- Ask the learners work in groups and use the guiding statements given to them on their instruction sheet as they perform this task.
- Refrain from giving instructions on how to perform the task, taking over and/or physically manipulating the equipment- the goal is for the learner to independently invent as many strategies as possible with the simulator

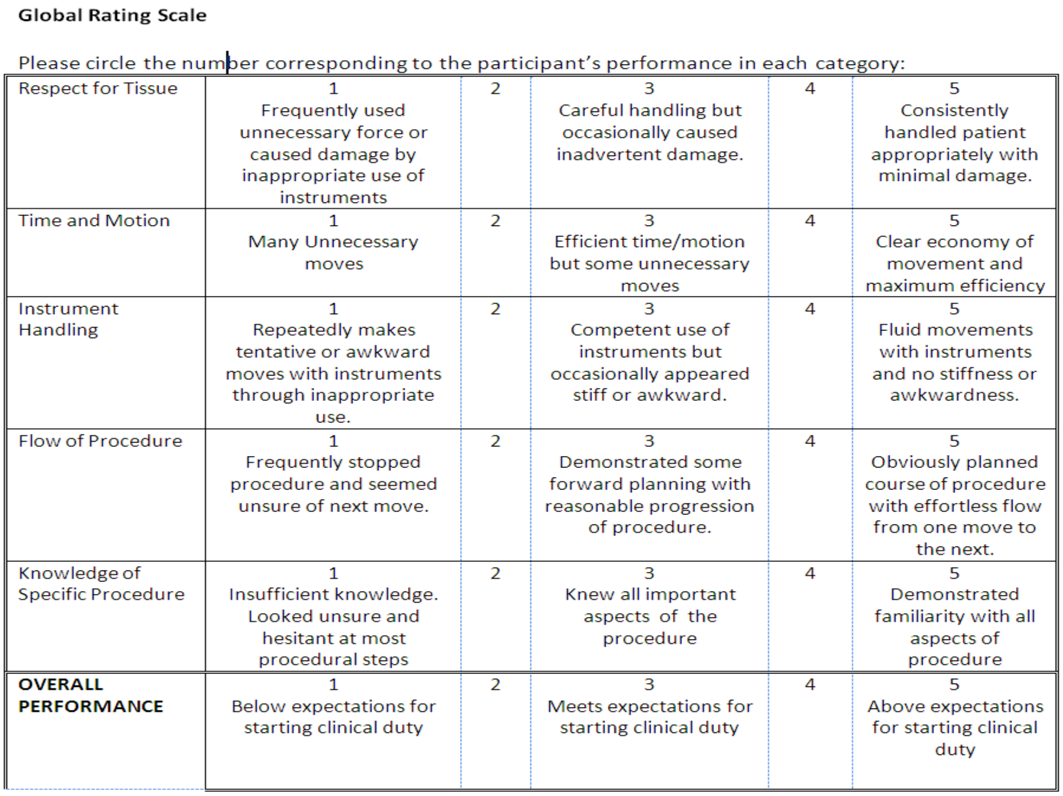
III. Direct Instruction and Expert Modeling

- Play the Infant LP instructional video
- Orient the learner to the model: This ridge represents the iliac crest (point to ridge). The umbilicus is here (point to spot where umbilicus should be). When you insert a needle into the proper space you will get fluid. You cannot put lidocaine into this model.
- Model the LP procedure as you verbally describe each step.

- Use landmarks to identify correct interspace
- Discuss consent process
- Prepare equipment: don gloves, choose needle, prepare tubes
- Discuss use of different types of analgesics (oral sucrose, topicals, lidocaine infiltration, sedation)

- Create sterile field with betadine (60 seconds to dry) or chlorhexidine (30 second scrub)
- Apply drapes
- Instruct the holder not to obstruct the airway (lateral decubitus or sitting position)
- Insert the needle aiming toward the umbilicus, avoid side-to-side or coarse movements
- Remove stylet after passing skin and keep out OR intermittently remove to check for fluid and replace
- Collect fluid in tubes
- Reinsert stylet, remove needle, apply pressure with gauze
- Discard sharps in safe manner

Appendix E: LP GRS (from Brydges et al, 2012)

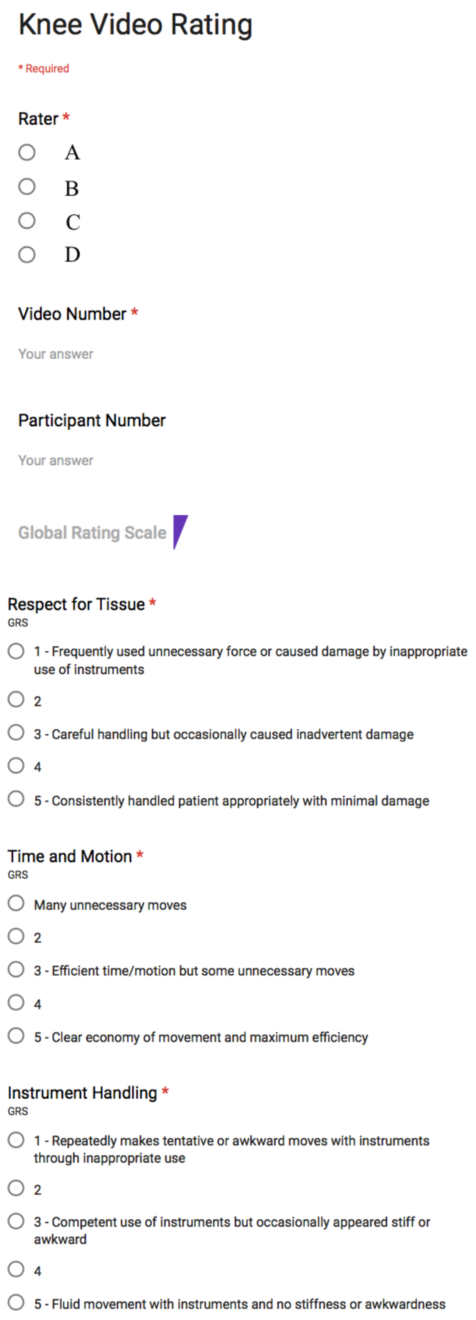


Global Rating Scale

Please circle the number corresponding to the participant's performance in each category:

Respect for Tissue	1 Frequently used unnecessary force or caused damage by inappropriate use of instruments	2	3 Careful handling but occasionally caused inadvertent damage.	4	5 Consistently handled patient appropriately with minimal damage.
Time and Motion	1 Many Unnecessary moves	2	3 Efficient time/motion but some unnecessary moves	4	5 Clear economy of movement and maximum efficiency
Instrument Handling	1 Repeatedly makes tentative or awkward moves with instruments through inappropriate use.	2	3 Competent use of instruments but occasionally appeared stiff or awkward.	4	5 Fluid movements with instruments and no stiffness or awkwardness.
Flow of Procedure	1 Frequently stopped procedure and seemed unsure of next move.	2	3 Demonstrated some forward planning with reasonable progression of procedure.	4	5 Obviously planned course of procedure with effortless flow from one move to the next.
Knowledge of Specific Procedure	1 Insufficient knowledge. Looked unsure and hesitant at most procedural steps	2	3 Knew all important aspects of the procedure	4	5 Demonstrated familiarity with all aspects of procedure
OVERALL PERFORMANCE	1 Below expectations for starting clinical duty	2	3 Meets expectations for starting clinical duty	4	5 Above expectations for starting clinical duty

Appendix F: Knee Arthrocentesis Google Form



Knee Video Rating

* Required

Rater *

○ A
○ B
○ C
○ D

Video Number *

Your answer

Participant Number

Your answer

Global Rating Scale

Respect for Tissue *
GRS

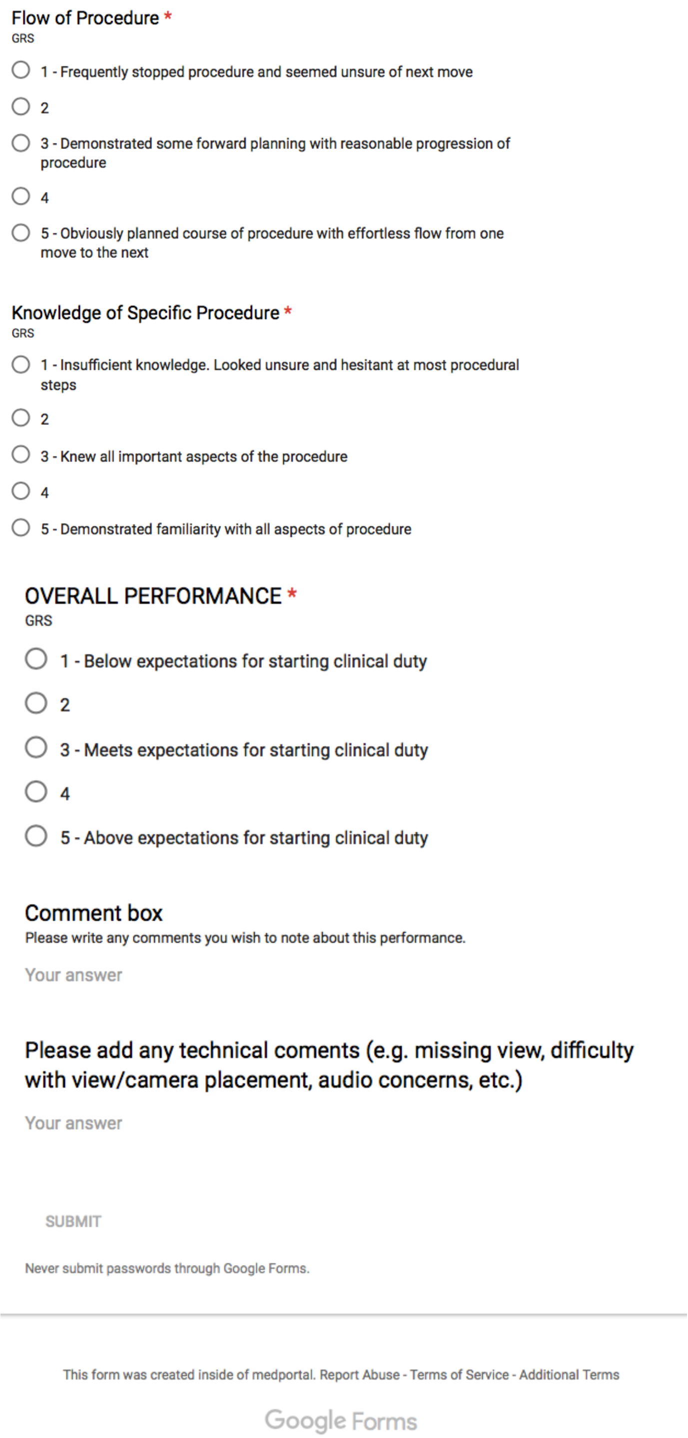
○ 1 - Frequently used unnecessary force or caused damage by inappropriate use of instruments
○ 2
○ 3 - Careful handling but occasionally caused inadvertent damage
○ 4
○ 5 - Consistently handled patient appropriately with minimal damage

Time and Motion *
GRS

○ Many unnecessary moves
○ 2
○ 3 - Efficient time/motion but some unnecessary moves
○ 4
○ 5 - Clear economy of movement and maximum efficiency

Instrument Handling *
GRS

○ 1 - Repeatedly makes tentative or awkward moves with instruments through inappropriate use
○ 2
○ 3 - Competent use of instruments but occasionally appeared stiff or awkward
○ 4
○ 5 - Fluid movement with instruments and no stiffness or awkwardness



Flow of Procedure *

GRS

○ 1 - Frequently stopped procedure and seemed unsure of next move

○ 2

○ 3 - Demonstrated some forward planning with reasonable progression of procedure

○ 4

○ 5 - Obviously planned course of procedure with effortless flow from one move to the next

Knowledge of Specific Procedure *

GRS

○ 1 - Insufficient knowledge. Looked unsure and hesitant at most procedural steps

○ 2

○ 3 - Knew all important aspects of the procedure

○ 4

○ 5 - Demonstrated familiarity with all aspects of procedure

OVERALL PERFORMANCE *

GRS

○ 1 - Below expectations for starting clinical duty

○ 2

○ 3 - Meets expectations for starting clinical duty

○ 4

○ 5 - Above expectations for starting clinical duty

Comment box

Please write any comments you wish to note about this performance.

Your answer

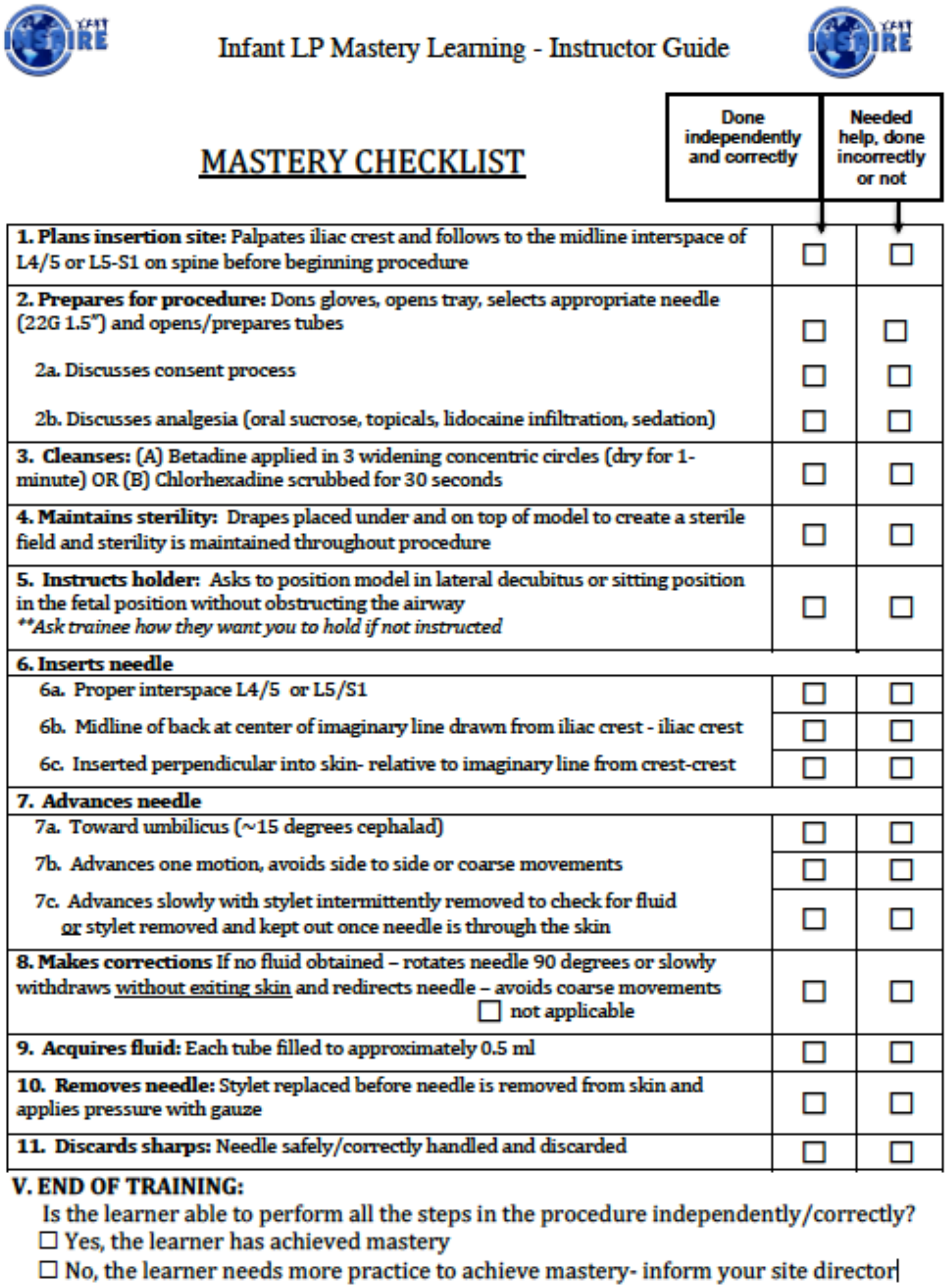
Please add any technical coments (e.g. missing view, difficulty with view/camera placement, audio concerns, etc.)

Your answer

Never submit passwords through Google Forms.

This form was created inside of medportal. Report Abuse - Terms of Service - Additional Terms

Appendix G: Mastery Learning Lumbar Puncture Checklist



Infant LP Mastery Learning - Instructor Guide

MASTERY CHECKLIST

	Done independently and correctly	Needed help, done incorrectly or not
1. Plans insertion site: Palpates iliac crest and follows to the midline interspace of L4/5 or L5-S1 on spine before beginning procedure	☐	☐
2. Prepares for procedure: Dons gloves, opens tray, selects appropriate needle (22G 1.5") and opens/prepares tubes	☐	☐
2a. Discusses consent process	☐	☐
2b. Discusses analgesia (oral sucrose, topicals, lidocaine infiltration, sedation)	☐	☐
3. Cleanses: (A) Betadine applied in 3 widening concentric circles (dry for 1-minute) OR (B) Chlorhexadine scrubbed for 30 seconds	☐	☐
4. Maintains sterility: Drapes placed under and on top of model to create a sterile field and sterility is maintained throughout procedure	☐	☐
5. Instructs holder: Asks to position model in lateral decubitus or sitting position in the fetal position without obstructing the airway ***Ask trainee how they want you to hold if not instructed*	☐	☐
6. Inserts needle		
6a. Proper interspace L4/5 or L5/S1	☐	☐
6b. Midline of back at center of imaginary line drawn from iliac crest - iliac crest	☐	☐
6c. Inserted perpendicular into skin- relative to imaginary line from crest-crest	☐	☐
7. Advances needle		
7a. Toward umbilicus (~15 degrees cephalad)	☐	☐
7b. Advances one motion, avoids side to side or coarse movements	☐	☐
7c. Advances slowly with stylet intermittently removed to check for fluid or stylet removed and kept out once needle is through the skin	☐	☐
8. Makes corrections If no fluid obtained – rotates needle 90 degrees or slowly withdraws without exiting skin and redirects needle – avoids coarse movements ☐ not applicable	☐	☐
9. Acquires fluid: Each tube filled to approximately 0.5 ml	☐	☐
10. Removes needle: Stylet replaced before needle is removed from skin and applies pressure with gauze	☐	☐
11. Discards sharps: Needle safely/correctly handled and discarded	☐	☐

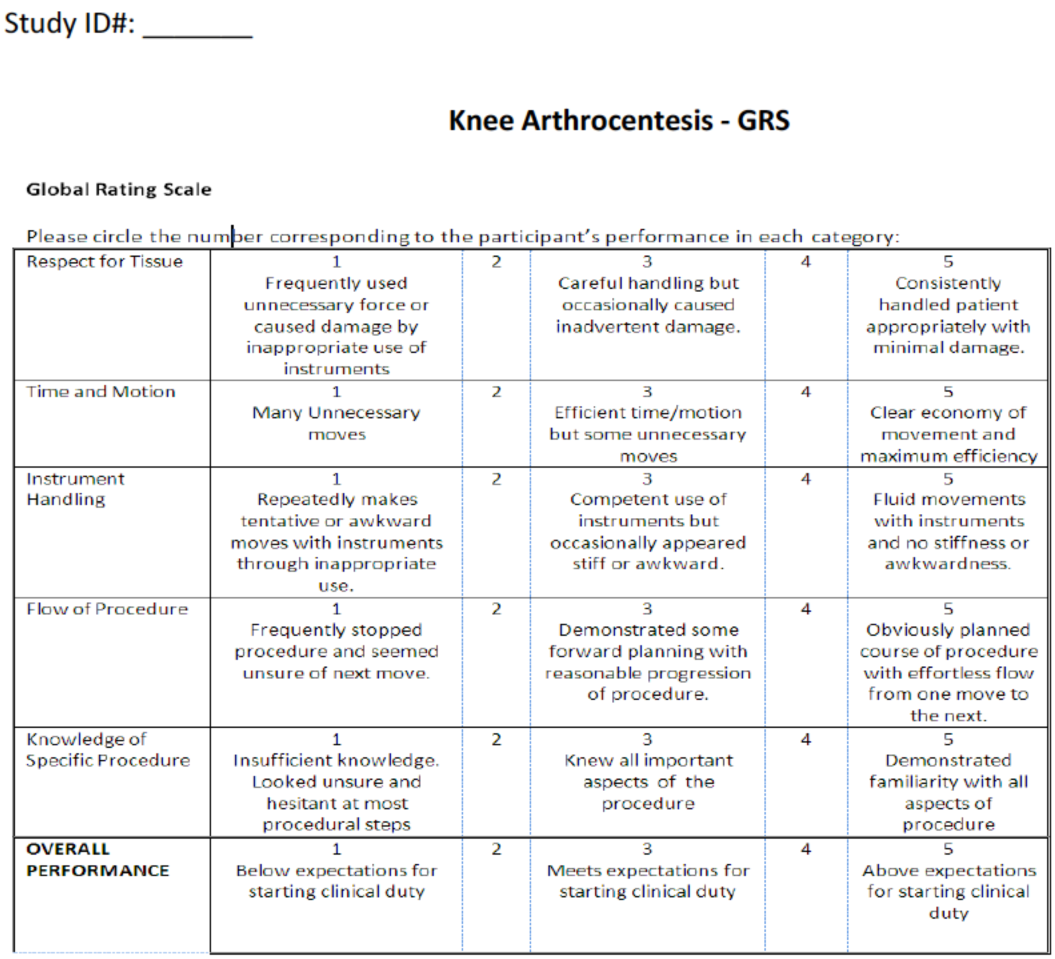
V. END OF TRAINING:

Is the learner able to perform all the steps in the procedure independently/correctly?

☐ Yes, the learner has achieved mastery

☐ No, the learner needs more practice to achieve mastery- inform your site director

Appendix H: Knee Arthrocentesis Global Rating Scale



Study ID#: ________

Knee Arthrocentesis - GRS

Global Rating Scale

Please circle the number corresponding to the participant's performance in each category:

Respect for Tissue	1 Frequently used unnecessary force or caused damage by inappropriate use of instruments	2	3 Careful handling but occasionally caused inadvertent damage.	4	5 Consistently handled patient appropriately with minimal damage.
Time and Motion	1 Many Unnecessary moves	2	3 Efficient time/motion but some unnecessary moves	4	5 Clear economy of movement and maximum efficiency
Instrument Handling	1 Repeatedly makes tentative or awkward moves with instruments through inappropriate use.	2	3 Competent use of instruments but occasionally appeared stiff or awkward.	4	5 Fluid movements with instruments and no stiffness or awkwardness.
Flow of Procedure	1 Frequently stopped procedure and seemed unsure of next move.	2	3 Demonstrated some forward planning with reasonable progression of procedure.	4	5 Obviously planned course of procedure with effortless flow from one move to the next.
Knowledge of Specific Procedure	1 Insufficient knowledge. Looked unsure and hesitant at most procedural steps	2	3 Knew all important aspects of the procedure	4	5 Demonstrated familiarity with all aspects of procedure
OVERALL PERFORMANCE	1 Below expectations for starting clinical duty	2	3 Meets expectations for starting clinical duty	4	5 Above expectations for starting clinical duty