Simulation-Based Medical Education in Pediatrics

Joseph O. Lopreiato, MD, MPH; Taylor Sawyer, DO, MEd

From the Uniformed Services University of the Health Sciences, Bethesda, Md (Dr Lopreiato); and University of Washington School of Medicine and Seattle Children's Hospital, Seattle, Wash (Dr Sawyer)
The authors declare that they have no conflict of interest. The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Department of Defense or the Uniformed Services University of the Health Sciences.
Address correspondence to Joseph O. Lopreiato, MD, MPH, Uniformed Services University of the Health Sciences, Val G. Hemming Simulation Center, 4301 Jones Bridge Rd, Bethesda, MD 20814 (e-mail: Joe.Lopreiato@simcen.usuhs.edu).
Received for publication August 9, 2014; accepted October 27, 2014.

ABSTRACT

The use of simulation-based medical education (SBME) in pediatrics has grown rapidly over the past 2 decades and is expected to continue to grow. Similar to other instructional formats used in medical education, SBME is an instructional methodology that facilitates learning. Successful use of SBME in pediatrics requires attention to basic educational principles, including the incorporation of clear learning objectives. To facilitate learning during simulation the psychological safety of the participants must be ensured, and when done correctly, SBME is a powerful tool to enhance patient safety in pediatrics. Here we provide an overview of SBME in pediatrics and review key topics in the field. We first review the tools of the trade and examine various types of simulators used in pediatric SBME, including human patient simulators, task trainers, standardized patients, and virtual reality simulation. Then we explore several uses of simulation that have been shown to lead to effective learning, including curriculum integration, feedback and debriefing, deliberate practice, mastery learning, and range of difficulty and clinical variation. Examples of how these practices have been successfully used in pediatrics are provided. Finally, we discuss the future of pediatric SBME. As a community, pediatric simulation educators and researchers have been a leading force in the advancement of simulation in medicine. As the use of SBME in pediatrics expands, we hope this perspective will serve as a guide for those interested in improving the state of pediatric SBME.

KEYWORDS: curriculum integration; mannequin; pediatric medical education; simulation; standardized patients; task trainer

ACADEMIC PEDIATRICS 2015;15:134–142

SIMULATION-BASED MEDICAL EDUCATION (SBME) has been defined as any educational activity that utilizes simulation aides to replicate clinical scenarios.[1] At its most basic, SBME uses simulators, or human beings, to serve as an alternative to real patients, and it provides an educational environment in which educators can create realistic yet well-controlled clinical experiences that simulate real-life patient care. SBME is a form of experiential learning and is thus an excellent homologue to the experiential learning gained during real-life clinical encounters. A recent meta-analysis showed that simulation is a highly effective instructional modality for pediatric education.[2]

Similar to other instructional formats used in medical education (eg, bedside teaching, lectures), SBME is an instructional methodology that facilitates learning. However, a unique aspect of SBME is that the interactions of learners during and after the simulation experience contribute significantly to the final learning gains derived from the experience. To facilitate learning during simulation, the psychological safety of the participants must be ensured.[3] Psychological safety refers to the feeling among learners that it is safe to experiment and to make mistakes as a way to learn. When done correctly, SBME is a powerful tool to enhance patient safety in medicine, including pediatrics.[4] Table 1 provides a brief overview of what SBME is and what it is not on the basis of these premises.

The use of SBME in pediatrics has grown over the past 2 decades. As a result of many factors. Perhaps the most significant is the increasing focus in medicine on patient safety and the ability that SBME provides for trainees to make mistakes and learn from them without the fear of harming patients.[4,5] Another factor is the continued need for skill acquisition and practice in the face of limitations in clinical exposures as a result of duty-hour restrictions. Additional factors include the desire for training program directors to acquire measureable learning outcomes on their trainee's performance and the need to provide just-in-time training. All of these factors have conspired to create an ideal environment for the growth of simulation in pediatrics today.

In this review, we provide an overview of SBME methodologies and review several key topics in the field of SBME. We will highlight the various types of simulators that can be used in pediatric SBME followed by a discussion of several key principles. Then we explore several

Published by Elsevier Inc. on behalf of the Academic Pediatric Association

Table 1. Simulation-Based Medical Education

Simulation is…
- A tool for learning.
- A learning event with goals and objectives.
- A safe place to learn.
- A tool to enhance patient safety.

Simulation is not…
- A replacement for clinical experiences.
- Something that just happens.
- A place to belittle or embarrass learners.
- The answer to all our problems.

key principles of effective learning when using simulation methods. Where applicable, we provide references of how these learning methods have been successfully applied to pediatric simulation. Finally, we discuss the future of pediatric SBME and the expected changes that will take place. An important caveat of this report is that there is not a unique pediatric simulation theory that differs in principle from adult or other simulation. Rather, we focus on how the field of pediatric SBME can adapt general simulation principles to the unique contexts found in caring for children.

Types of Simulators Used in Pediatric SBME

There are 4 types of simulation methods used in pediatric SBME: human patient simulators, task trainers, standardized patients, and virtual reality. These types of simulators should be thought of as tools an educator can use to facilitate learning. As with any educational tool, each type of simulator has unique characteristics that make it beneficial for use to fulfill specific educational objectives or to evaluate clinical competency at various levels.

Human Patient Simulators

One of the most commonly used simulation modalities in pediatric SBME is a whole-body human patient simulator. These pediatric simulators are designed to provide an accurate anatomic representation of pediatric patients at various ages, from a premature infant to a young child. Late teen and young adult patients can feasibly be simulated using adult simulators. Modern pediatric simulators can display physiologic signs and physical cues, including variant heart rate; pulse strength; blood pressure; visible cyanosis; visible chest rise; increased work of breathing; adventitial breath sounds; bowel sounds; pupillary constriction/dilation; seizurelike movements; secretions from eye, nose, and mouth; and urination. These various physiologic signs can be remotely controlled by an operator through the use a computer control module or handheld remote. Most pediatric simulators also allow the ability to perform a wide variety of medical procedures including airway maneuvers (bag-valve mask ventilation, intubation, needle cricothyrotomy), various forms of vascular access (intravenous access, interosseous access), and pediatric life support procedures (cardioversion, defibrillation).

Many simulation reports refer to modern computer-controlled simulators as high fidelity. Simulator fidelity has traditionally been used to describe the degree to which the simulator looks, feels, and acts like a human patient.[6] Some experts, however, have suggested more specific terms to describe fidelity, including engineering fidelity, referring to whether the simulation looks realistic, and psychological fidelity, referring to whether the simulator can accurately simulate the critical elements and demand the specific behaviors required to complete a task.[7] When describing computer controlled simulators we prefer the term “high technology” over “high fidelity,” as each specific simulator may or may not poses a high degree of either engineering or psychological fidelity. Although some simulation scenarios may benefit from a high-technology simulator capable of displaying many physiologic cues, in most cases, beneficial learning environments can be achieved and learning outcomes demonstrated using simpler low-technology simulators with basic functions, such as the ability to do chest compressions or insert an airway or intravenous line. On the basis of available research, there little evidence to suggest that high-technology simulators provide significant educational benefits over less expensive and low-technology simulators.[6–8] Some evidence suggests that the level of simulation fidelity (engineering, psychological) should be matched to learners’ levels along the continuum of training, with low levels of fidelity used for novice and early-stage learners and higher levels applied to scenarios for more advanced learners.[9]

Advances in electronics have led to the development of smaller, more portable human patient simulators that can replicate newborn, infant, and child physiology. Some pediatric-specific examples of learning activities that can now be conducted using SBME include newborn delivery simulations, pediatric cardiopulmonary arrest simulations, and simulations involving diagnosis and evaluation based on physiologic cues provided by the simulator (eg, severe asthma, septic shock, seizure)[10–12] In these scenarios, the simulator creates the focal point of team-based interactions and treatment decisions, as the patient does in real life. The simulator also provides an integrated model upon which medically appropriate procedures can be performed, and the coordination among and communication between team members can be practiced.

Given the complexities of manipulating a modern high-technology simulator, conducting a simulation using this type of device generally requires a specific person assigned to operate it: a simulation operations specialist. Close coordination between the facilitator conducting the simulation and the operations specialist running the simulator is required to ensure that appropriate changes are made to the physiology of the simulator as the simulation progresses. Alternatively, a high-technology simulator can be preprogrammed with specific changes in physiology (eg, heart rate, saturations, blood pressure) driven by participant actions or inactions within a specific span of time (eg, heart rate drops from 100 to 30 bpm over 1 minute if tension pneumothorax is not relieved with needle decompression by 5 minutes into the scenario). Additionally, some modern high-technology simulators can recognize the administration of specific medications and respond with preprogrammed physiologic changes (eg, automatic increased heart rate and blood pressure in response to intravenous epinephrine). This type of preprogramming decreases the amount of on-the-fly adjustments required during the simulation and can ensure standardization of simulator responses across learning events. The variety, functionality, and level of complexity of high-technology simulators used in pediatric SBME continues to increase.

Task Trainers

Task trainers are partial-body simulators that are used for training in specific tasks and procedural skills. Commonly used task trainers in pediatrics include endotracheal intubation simulators, lumbar puncture simulators, and intravenous catheter trainers. The use of task trainers allows learners to repeatedly practice a specific procedural skill until proficiency is attained. The task-focused nature of this type of simulator allows educators to dedicate time to education on one specific procedural skill or to set up several simulation stations, with a different task trainer at each, that participants can rotate through in order to practice a variety of procedural skills.

Task trainers are generally less expensive and easier to maintain than the high-technology simulators discussed above, and they typically do not include computerized controls. Many of them, however, do possess a high degree of engineering and/or psychological fidelity, such as the inclusion of reservoirs for artificial bodily fluids (blood, spinal fluid) in order to provide positive feedback to learners and allow confirmation of procedural success. Using task trainers to conduct procedural skill training avoids reliance on the use of the more expensive high-technology simulators. As an example, for neonatal intubation training, it would be advantageous to use an intubation head, costing several hundred dollars, for trainees to use initially to practice intubation, rather than risking damaging the airway of a several-thousand-dollar high-technology neonatal simulator. Once learners have proved some proficiency at neonatal intubation, they could be allowed to perform intubation on the high-technology simulator as part of a newborn delivery scenario requiring endotracheal intubation. Task trainers are intended for use to teach a specific skill (or set of skills), but they can be used in combination with human patient simulators and standardized patients as part of a hybrid simulation.

Evidence supports an association between procedural skill training using task trainers and improved clinical proficiency at procedural skills. Studies involving internal medicine residents and adult patients have proven a link between procedural skills training using simulation and improved patient outcomes during central venous catheter insertion, hemodialysis catheter insertion, paracentesis, and lumbar puncture.[13–17] In pediatrics, the use of an infant lumbar task trainer has been associated with improvements in pediatric residents' ability to obtain cerebrospinal fluid during real infant lumbar punctures.[18] An important aspect of these studies is the incorporation of proven instructional techniques during the procedural skills training, such as deliberate practice and mastery learning. Over time, the engineering and psychological fidelity of pediatric task trainers have improved significantly, and further improvements are expected in the future.

Standardized Patients

Standardized, or simulated, patients (SPs) are well accepted and widely used in medical education. SPs are humans who are recruited and trained to portray patients in a reliable and consistent manner. The use of SPs to conduct objective structured clinical examinations has been in practice since the 1960s and is perhaps the most widely used method of assessing clinical competency in health care education today.[19,20] SPs are used across the continuum of medical education, from medical school to graduate medical education, to assess select competencies in patient care, interpersonal communications, and professionalism.[21–24] Since 2005, SPs have been a part of the United States Medical Licensing Examination, Step II, clinical skills evaluation.

During simulation involving SPs, the SP acts as the patient and is able to provide a medical history and undergo a physical examination. Physical exam signs can be simulated by the SP (eg, cough, wheezing, abdominal pain) or can be created with special effects makeup or moulage (eg, rash, ecchymosis). The SP reactions and interactions during the simulation can be scripted in order to ensure standardization of responses and guarantee the ability to equally evaluate learners participating in the simulations. For all SPs, standards of practice and protocols exist, and the Association of Standardized Patient Educators has been created to foster excellence in SP training and utilization (http://www.aspeducators.org/).

Simulations involving SPs have expanded from their origins in undergraduate medical education to graduate medical education as a means to assess select competencies in patient care, interpersonal communications, and professionalism. The use of children as SPs has been used to assess resident skills in history taking, communication, physical examination, telephone medicine, and transitions of care.[21,23,24] Depending on the learning goals and objectives, excellent SBME scenarios can be created that utilize child SPs. Using children as SPs provides the ability to evaluate trainee interactions with the child in a realistic setting. In most cases, an adult SP acts as the parent, and a child or teen SP acts as the patient. Pediatric simulations involving adult SPs can also include parental counseling or difficult conversations, such as end-of-life discussions.[22] Training of children as SPs can usually be arranged through the local medical school, many of which have trained SP educators that can help recruit and train child SPs for your program.

VIRTUAL REALITY SIMULATORS

Virtual reality (VR) simulators use a computer screen, or another type of graphic user interface, to create simulated patients and patient care environments. As indicated by the name, the interactions that take place are virtual in that learners interact with patients via a computer interface in an electronically rendered environment, rather than a physical simulator. Computer interfaces for VR simulation can include a keyboard and mouse, or a haptic interface that can simulate things like instrument handles, intravenous needles, or laryngoscope handles. With the integration of haptic interfaces, VR simulators have the capacity to promote the acquisition of a full range of cognitive, technical, and behavioral skills.

In pediatrics, research has shown that VR simulation is associated with improvements in cognitive knowledge and clinical skills.[25,26] Extensive work has been done to create responsive virtual humans and virtual pediatric SPs using advanced computer technology and computer game graphic engines.[27] The use of such virtual pediatric SPs provides great promise for the ability to conduct standardized training and objectively evaluate performance via computer anywhere in the world, without requiring expensive physical simulators and simulation facilities. Research involving a screen-based simulator to evaluate cognitive skills involved in pediatric advanced life support (PALS) found that the technology could supplement traditional curricula by facilitating frequent knowledge assessments as part of a PALS competency maintenance program.[28] The American Heart Association has recently introduced HeartCode PALS, a Web-based, self-directed program that teaches health care providers the knowledge and skills needed to recognize and prevent cardiopulmonary arrest in infants and children as part of the standard PALS curriculum. Unlike the field of surgery, where a wealth of research reports have linked VR simulation with improved surgical skill, there is currently limited research on the use of VR simulation in the acquisition of procedural skills in pediatrics. However, with advances in VR simulation, and with increasing use of VR in pediatrics, research investigating pediatric procedural skills acquisition and maintenance is expected to increase in the future.

HYBRID SIMULATIONS

Hybrid simulations involve the melding or simultaneous use of 2 or more methods of simulation. Examples include the use of an SP who has an intravenous catheter task trainer attached to his or her arm, a team training scenario involving a pneumothorax during which the mannequin is used during the initial diagnostic steps but a chest tube task trainer is used during the chest tube placement, or a scenario involving a pediatric cardiopulmonary arrest where a human patient simulator is used for the resuscitation and an SP is employed as a parent. Using hybrid simulation leverages the relative strengths and overcomes some of the specific weaknesses of the simulators discussed above. Using a mix of mannequins, task trainers, SPs, and VR simulators, educators can create an extensive variety of multimodal and interactive simulation experiences that can foster a range of difficulty and clinical variation. A potential downside of hybrid simulations is the difficulty in maintaining a sense of realism when moving between multiple devices that collectively are meant to represent a single human being.

USING SIMULATION FOR EFFECTIVE LEARNING

Conducting SBME requires 3 key assets: people (educators, learners), time (planning, conducting, evaluating), and resources (simulators, equipment).[29] Learners participating in simulation experiences should get high value for the degree of investment that instructors and facilities put into their simulation programs. Additionally, the learning environment within which SBME takes place must be carefully constructed in order to maximize the learning benefits experienced by simulation participants. A key tenet of SBME is the establishment of a safe learning environment for participants, as well as the promotion of the idea that within the simulation learning environment, it is safe to make, talk about, and learn from mistakes.

On the basis of the review of the literature, Motola et al[30] identified several key principles that lead to effective learning in SBME. These general principles of effective SBME also pertain to effective pediatric SBME. We focus on 5 principles identified by Motola et al that, if used correctly, can lead to effective learning and can provide value to pediatric SBME learning experiences. Table 2 provides an overview of these principles with examples.

CURRICULUM INTEGRATION AND LEARNING OBJECTIVES

Integrating SBME into the curriculum is a multistep process.[31,32] To effectively integrate simulation, it is critical to do a gap analysis of the established curriculum to decide which clinical skills are not currently being adequately addressed. High-risk and low-volume clinical scenarios, such as neonatal and pediatric resuscitations, are best suited for simulation because the skills needed in these scenarios are rarely practiced during clinical care and can be practiced frequently without endangering patients using simulation. Once the high-value scenarios are identified as needing integration into the curriculum, the next step is to create specific, measurable, and valid learning objectives. SBME begins with learning objectives—the knowledge, skills, and behaviors expected of learners in a simulation scenario. In our experience, many simulation objectives are vague or are not written down. Learning objectives should be clear, specific, and measurable. An easy rule of thumb is to start with the end in mind, then pick the simulation mode most likely to meet those objectives. Building longitudinally on the learning objectives so that medical students do basic tasks, interns do more sophisticated tasks, and senior residents do the most sophisticated tasks is important to maintain engagement throughout the duration of training. Once the learning objectives are created, the educator can decide, in consultation with the simulation center staff, which simulators to use. Some objectives may require the use of hybrid

Table 2. Using Simulation for Effective Learning

Principle	Description	Example
Curriculum integration	Integrating simulation as part of the overall curricular plan to include clear learning objectives	A pediatric septic shock simulation is included as part of the emergency medicine rotation to reinforce diagnosis and treatment of septic shock.
Feedback and debriefing	Including a structured debriefing immediately after a simulation, conducted using an accepted approach which ensures the psychological safety of the participants	After a simulated pediatric cardiac arrest scenario the residents are lead through a facilitated discussion of what occurred during the simulation by an attending. Feedback on ways performance could be improved in the future is provided.
Deliberate practice	Allowing residents the ability to practice a procedural skill with directed feedback until they are proficient	Pediatric residents participated in an airway skills training session wherein they are allowed to intubate a task trainer repeatedly while receiving directive feedback on their performance from an attending.
Mastery learning	Practicing a skill to a level where coaching is not necessary and performance has achieved a mastery level	During an airway skills session, residents undergo baseline testing before receiving standardized instruction and deliberate practice with focused feedback. After significant deliberate practice the residents undergo a posttest to confirm performance at a predefined mastery level using a valid and reliable airway skills assessment tool.
Range of difficulty and clinical variation	Varying the complexity of simulation scenarios on the basis of the year group of residents involved and including a variety of problems to be solved in a scenario	During the course of pediatric residency, residents participate in simulation of escalating intensity and difficulty as they progress from first, second to third year. Additionally, after proficiency is attained in one scenario, the scenario is changed to avoid repetition and monotony.

simulation. The final step is the construction of the assessment system, which flows from the learning objectives and tasks required. This may involve analysis of the time needed to complete a task, task performance score on a validated checklist, or the comments of an SP after a clinical encounter. It is important that learning objectives be specified for each simulation experience and that simulation experiences fit into the larger curricular goals for the learners' level. This rule should apply regardless of the simulation modality used and is in keeping with accepted educational principles of instruction. Conducting SBME without clearly defined learning objectives and without dedicated integration into the overall curricular plan risks wasting time and resources.

Feedback and Debriefing

Simulation-based learning has its foundation in Kolb's theory of experiential learning.[33] Kolb's framework includes 4 phases: concrete experience, reflective observation, abstract conceptualism, and active experimentation. In this context, learning takes place in the reflective and conceptualization phases, wherein learners critically review their current performance and develop a plan of action to affect future performance.[33] In order for experiential learning through SBME to be effective, 2 concepts must be integrated. The first concept is psychological safety. Psychological safety is the tone that the facilitator sets within the simulation-based learning session. A good facilitator makes it clear that during simulation, mistakes will be made and that no one is perfect. The goal of the session is learning, not intimidation or humiliation. These types of statements ensure that the learning environment is safe for experimentation, risk taking, and learning. The second concept is the importance of debriefing. Debriefing is a process in which learners are guided by a facilitator to reflect on their actions in the simulation, with the goal of developing plans for improved performances in future experiences. During the simulation debriefing, learners reflect and conceptualize their actions and consider modifications that can be experimented with in subsequent simulations and in real life. Consequently, the critical learning involved with the simulation experience takes place during the debriefing session after a simulation scenario rather than during the simulation itself.

In a review of best practices in simulation, debriefing was the factor most cited in successful learning.[31] Examples of debriefing methods that have been used with success in pediatric SBME are the debriefing with good judgment method, described by Rudolph et al,[3] and the after-action review method, described by Sawyer and Deering.[34] Both methods provide conversational frameworks within which learners can review their actions during the simulation and reflect on what actions went well and which ones require change. The facilitator's role during debriefing is to guide the conversation, to work to determine the rationale for the participant's actions, and to assist in changing the mental framework that led to suboptimal performance.[3] Debriefing is not a session in which only the do's and don'ts are dictated by the instructor. The debriefing process works best when learners are provided the opportunity to self-discover the alterations needed in their actions that will result in improved performance in the future. These learner-centered interactions and self-analyses are unique features of SBME and are one of the reasons that pediatrics has embraced SBME as an educational modality.[2] Unlike didactic lectures and other teacher-centered learning experiences, SBME provides a unique environment in which the learners can work cooperatively to improve their own performance as well as that of their team members.

Given the importance of debriefing in SBME, planning for the simulation experience should include setting aside adequate time for debriefing.[34] In general, the debriefing session should take as long as needed to cover all the important learning objectives of the simulation and to correct any identified performance or knowledge gaps. This may take up to twice as long as the simulation scenario itself. Many simulation scenarios are video recorded. Some instructors use a playback of the video as part of the debriefing time, a type of debriefing called video-enhanced debriefing. Whether the use of video enhances the debriefing session is unclear.[35–37] As a quality assurance measure, an assessment tool has been developed that allows observers to grade the quality of debriefing.[38] This tool can be used to provide feedback to facilitators on the quality of their debriefing skills.

DELIBERATE PRACTICE

The concept that practice makes perfect has been around for ages. However, as pointed out by the legendary football coach Vince Lombardi, “Practice does not make perfect. Only perfect practice makes perfect.” Deliberate practice is a method to help perfect the practice experience. Deliberate practice is defined as “the repetitive performance of a cognitive or psychomotor task in a focused domain, coupled with rigorous skills assessment.”[30] It is a highly effective form of learning and is grounded in instructional research and information processing theories of skill acquisition. An example of deliberate practice is batting practice in Little League. The batter takes many swings at the ball in a simulated game under the watchful eye of a coach who gives feedback and instruction during the practice. On the basis of the coach’s years of experience and expertise at batting, he is able to provide focused and specific feedback to the batter in order to improve the swing. Using this same basic framework, one could easily envision a senior resident or attending physician allowing a new intern to deliberately practice lumbar punctures on a task trainer while providing focused feedback and coaching. Ericsson[39] studied the achievement of expertise in sports, music, and medicine. He found that the number of times a skill is deliberately practiced is directly tied to the acquisition and maintenance of expert performance. He concluded that deliberate practice is a better predictor of superior expert performance than any other method.[40] McGaghie et al[41] conducted a meta-analysis of 20 years of literature on simulation research and showed that in head-to-head comparisons, SBME with deliberate practice was more beneficial than traditional clinical education in achieving specific clinical skill acquisition goals.

When designing simulation scenarios and procedural skills training sessions, pediatric simulation educators should utilize deliberate practice when possible. A simulation scenario is often run only once, followed by debriefing to learners about the actions they should and should not have taken. Because of time constraints, the simulation scenario ends without allowing participants to demonstrate that they have changed their behavior on the basis of the feedback. More effective learning occurs when the simulation experience is repeated and the participants are allowed to use the insight provided by the facilitator. In this way, learners can gain confidence and demonstrate improved performance. This is much preferred to the usual “one and done” type of simulation scenario. If the simulation uses SPs for formative purposes, it is also preferable to have several stations in which the same or similar clinical skills are being taught. For example, in a simulation experience involving history taking or physical examination, learners move from station to station, receiving feedback on their performance at each station, and then can use that feedback to change their behavior at the next station. Another example is a group of residents participating in newborn resuscitation simulations who are allowed to repeat a meconium delivery scenario again after they failed to suction the trachea during their first simulation. In all these examples, a key ingredient is the ability for repeated practice and the provision of expert feedback aimed at improving performance, which forms the basis of deliberate practice.[40,41]

MASTERY LEARNING

Mastery learning is an extension of deliberate practice methodology, wherein learners practice a technical or behavior skill until such time that they can do it without coaching at a mastery level. Mastery learning involves a complex series of 5 steps: baseline testing, standardized instruction, deliberate practice, focused feedback, and post-testing.[41,42] The objective of mastery learning is for all learners to demonstrate competence. During the mastery learning session, the skill or behavior is first demonstrated to learners by an instructor, and then learners are allowed to practice the skill. Deliberate practice, with focused formative feedback, is used to optimize the quality of the practice. Increasing levels of difficulty are incorporated to assist learners in solidifying their skills. Mastery is obtained when the skill can be performed without coaching to a predefined and objectively determined passing or mastery standard.

Careful planning and consideration should be undertaken before conducting simulation-based mastery learning activities. Critical steps for educators to consider include determining which technical or behavioral skills should be trained to a mastery standard, finding or developing an assessment tool to rate performance, determining the minimum passing score on the assessment tool that defines mastery, and conducting rater training to ensure the appropriate use of the assessment tool. Procedural skills and resuscitation are perhaps the best-studied application of mastery learning methodology. Simulation-based mastery learning has been applied with great success to several procedural skills in medicine, including central venous catheter insertion, paracentesis, hemodialysis catheter insertion, lumbar puncture, thoracentesis, and advanced cardiac life support.[13–17,43] Barsuk et al[44] studied the duration of the retention of technical skills after mastery level and reported that skills can last up to 1 year. However, careful attention must be paid to the methodology in which the mastery learning session is conducted to ensure the durability of skills is achieved.[45,46] A recent review demonstrated that simulation-based mastery learning is a powerful educational tool that has had documented translational outcomes in terms of improved patient care practices, patient outcomes, and collateral effects.[47]

Range of Difficulty and Clinical Variation

Incorporating a range of difficulty and clinical variation into simulation experiences is an important principle that leads to effective learning in SBME. Simulation experiences can be designed for many levels of learners, from novices to experts. Conducting SBME with various levels of complexities built in can aid learners in building action plans to accommodate the wide variety of clinical variations and complexity encountered in the real clinical world. Designing clinical variation into simulation experiences has been examined in several contexts.[48–52] Some pediatric examples are worth noting. Sawyer et al[51] included escalating levels of clinical difficulty in a study of the effect of deliberate practice on neonatal resuscitation performance. Residents involved in the study exhibited progressive improvements in technical performance over the course of 3 simulated neonatal resuscitations, despite the increasing clinical difficulty of the resuscitations. Eich et al[52] found a close correlation between the difficulty of the pediatric anesthesia simulation scenarios and the candidates' own perceptions of their learning effect. By incorporating a range of difficulty and clinical variation into simulation experience, pediatric educators can continue to challenge learners over the course of their training and push them to achieve the next higher level of performance.

Future Directions for SBME in Pediatrics

Despite its long history, SBME in pediatrics is still in a growth phase, and the use of SBME in pediatrics is expected to increase significantly over the next decade. As outcomes-based medical education becomes more prevalent, the need to demonstrate and accurately evaluate knowledge, skills, and behaviors becomes more important. In the future, all medical specialties, including pediatrics, will likely require simulation-based assessments as a measure of competency during training and continued retention of competency as part of maintenance of certification.[53]

As technology improves, the next generation of pediatric simulators and task trainers will have higher levels of engineering or psychological fidelity. A larger number and variety of pediatric-specific simulators are also expected to come onto the market. These improvements in fidelity and variety of pediatric simulators may allow for more direct translation of simulation-based learning to the clinical realm. An increase in the use of SPs during pediatric training is expected because of the demand for more direct observation of professional and communication skill competencies in trainees. With the exponential growth in computer technology, the utilization of pediatric VR simulation is expected to greatly increase. The use of handheld and mobile devices could provide a framework for delivering educationally beneficial SBME experiences to learners anytime, anywhere. With SBME, the acquisition of knowledge, skills, and behaviors of future pediatric trainees and practitioners will shift from the chance encounter and learning through random opportunity to deliberate practice with mastery-level learning. This will allow essential practice in low-volume, high-risk tasks such as key procedural skills, delivery room emergencies, pediatric cardiopulmonary arrest, and difficult conversations with patients and families. Teamwork and leadership skills could also be trained and honed to improve the functionality of pediatric care teams. Ultimately, this augmentation in training will result in better-trained pediatric providers and improved clinical outcomes for pediatric patients.

Future research in the field of pediatric SBME should focus both on educational as well as the translational outcomes, with translational defined as simulation training that directly effects patient care.[2] The learning curve in acquiring a new skill and its concomitant decay should also be investigated in order to enlighten training needs.[54] Additionally, the value of instructor training to learning outcomes and comparative studies that identify optimal instructional methods are required.[2,54] Organizations such as the International Network for Simulation-Based Pediatric Innovation, Research, and Education (INSPIRE)[55] and the International Pediatric Simulation Society (IPSS)[56] offer a global collaborative community to investigate and research these questions. Through these organizations, it is hoped that in the future, large multicenter international research on pediatric SBME intervention and outcomes will become the norm.

Conclusions

We have provided a brief overview of some important aspects of SBME in pediatrics. We reviewed the types of simulators used in SBME and discussed their use in pediatrics. We explored several principles of effective learning in SBME that should be incorporated into pediatric SBME. We hope that this article informs educators currently involved in pediatric SBME about best practices in the education of pediatric residents and other health care professionals, and entices other pediatric educators to learn more about the benefits of SBME. The variety of simulators and simulation technology available to pediatric educators is expected to increase, and continued research will better define the optimal educational strategies in pediatric SBME. As a community, pediatric simulation educators and researchers have been a leading force in the advancement of simulation in medicine. As the use of simulation in pediatrics expands, we hope this perspective will serve as a guide for all those interested in improving the state of pediatric SBME.

REFERENCES

1. Al-Elq AH. Simulation-based medical teaching and learning. *J Family Community Med*. 2010;17:35–40.
2. Cheng A, Lang TR, Starr SR, et al. Technology-enhanced simulation and pediatric education: a meta-analysis. *Pediatrics*. 2014;133:5.e1313–5.e1323.
3. Rudolph JW, Simon R, Dufresne RL, et al. There's no such thing as "nonjudgmental" debriefing: a theory and method for debriefing with good judgment. *Simul Healthc*. 2006;1:49–55.
4. Ziv A, Small S, Wolpe PR. Patient safety and simulation-based medical education. *Med Teach*. 2000;22:489–495.
5. Ziv A, Ben-David S, Ziv M. Simulation based medical education: an opportunity to learn from errors. *Med Teach*. 2005;27:193–199.
6. Hamstra SJ, Brydges R, Hatala R, et al. Reconsidering fidelity in simulation-based training. *Acad Med*. 2014;89:387–392.
7. Norman G, Dore K, Grierson L. The minimal relationship between simulation fidelity and transfer of learning. *Med Educ*. 2012;46:636–647.
8. Scerbo MW, Dawson S. High fidelity, high performance? *Simul Healthc*. 2007;2:224–230.
9. Maran NJ, Glavin RJ. Low-to high-fidelity simulation—a continuum of medical education? *Med Educ*. 2003;37(suppl 1):22–28.
10. Lopreiato JO, Halamek LP, Calaman S, et al. Pediatric Simulation in Textbook of Simulation, Skills and Techniques. Tsuda ST, editor. Woodbury, CT: Cine-Med Publishing, Inc., 2012.
11. Donoghue AJ, Durbin DR, Nadel FM, et al. Effect of high-fidelity simulation on pediatric advanced life support training in pediatric house staff: a randomized trial. *Pediatr Emerg Care*. 2009;25:139–144.
12. Stone K, Reid J, Caglar D, et al. Increasing pediatric resident simulated resuscitation performance: a standardized simulation-based curriculum. *Resuscitation*. 2014;85:1099–1105.
13. Barsuk JH, McGaghie WC, Cohen ER, et al. Simulation-based mastery learning reduces complications during central venous catheter insertion in a medical intensive care unit. *Crit Care Med*. 2009;37:2697–2701.
14. Barsuk JH, McGaghie WC, Cohen ER, et al. Use of simulation-based mastery learning to improve the quality of central venous catheter placement in a medical intensive care unit. *J Hosp Med*. 2009;4:397–403.
15. Barsuk JH, Ahya SN, Cohen ER, et al. Mastery learning of temporary hemodialysis catheter insertion by nephrology fellows using simulation technology and deliberate practice. *Am J Kidney Dis*. 2009;54:70–76.
16. Barsuk JH, Cohen ER, Vozenilek JA, et al. Simulation-based education with mastery learning improves paracentesis skills. *J Grad Med Educ*. 2012;4:23–27.
17. Barsuk JH, Cohen ER, Caprio T. Simulation-based education with mastery learning improves residents' lumbar puncture skills. *Neurology*. 2012;79:132–137.
18. Kessler DO, Auerbach M, Pusic M, et al. A randomized trial of simulation-based deliberate practice for infant lumbar puncture skills. *Simul Healthc*. 2011;6:197–203.
19. Harden RM, Gleeson FA. Assessment of clinical competence using an objective structured clinical examination (OSCE). *Med Educ*. 1979;13:41–54.
20. Newble D. Techniques for measuring clinical competence: objective structured clinical examinations. *Med Educ*. 2004;38:199–203.
21. Joorabchi B, Devries JM. Evaluation of clinical competence: the gap between expectation and performance. *Pediatrics*. 1996;97:179–184.
22. Serwint JR, Simpson DE. The use of standardized patients in pediatric residency training in palliative care: anatomy of a standardized patient case scenario. *J Palliat Med*. 2002;5:145–153.
23. Stillman PL, Swanson DB, Smee S, et al. Assessing clinical skills of residents with standardized patients. *Ann Intern Med*. 1986;105:762–771.
24. Lane JL, Ziv A, Boulet JR. A pediatric clinical skills assessment using children as standardized patients. *Arch Pediatr Adolesc Med*. 1999;153:637–644.
25. Biese KJ, Moro-Sutherland D, Furberg RD, et al. Using screen-based simulation to improve performance during pediatric resuscitation. *Acad Emerg Med*. 2009;16(suppl 2):S71–S75.
26. Curran VR, Aziz K, O'Young S, et al. Evaluation of the effect of a computerized training simulator (ANAKIN) on the retention of neonatal resuscitation skills. *Teach Learn Med*. 2004;16:157–164.
27. Hubal RC, Deterding RR, Frank GA, et al. Lessons learned in modeling virtual pediatric patients. In: Westwood JD, ed. *Medicine Meets Virtual Reality 11—NextMed: Health Horizon*. IOS Press; 2003.
28. Ventre KM, Collingridge DS, DeCarlo D, et al. Performance of a consensus scoring algorithm for assessing pediatric advanced life support competency using a computer screen-based simulator. *Pediatr Crit Care Med*. 2009;10:623–635.
29. Kahn K. *Simulation in Healthcare Education: Building a Simulation Program—A Practical Guide*. Dundee, Scotland: Association for Medical Education in Europe; 2011.
30. Motola I, Devine LA, Chun HS, et al. Simulation in healthcare education: a best evidence practical guide. AMEE Guide No. 82. *Med Teach*. 2013;35:e1511–e1530.
31. Issenberg SB, McGaghie WC, Petrusa ER, et al. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. *Med Teach*. 2005;27:10–28.
32. McGaghie WC, Issenberg SB, Petrusa ER, et al. A critical review of simulation-based medical education research, 2003–2009. *Med Educ*. 2010;44:50–63.
33. Kolb DA. *Experiential Learning: Experience as the Source of Learning and Development*. Englewood Cliffs, NJ: Prentice-Hall; 1984.
34. Sawyer TL, Deering S. Adaptation of the US Army's after-action review for simulation debriefing in healthcare. *Simul Healthc*. 2013;8:388–397.
35. Byrne AJ, Sellen AJ, Jones JG, et al. Effect of videotape feedback on anaesthetists' performance while managing simulated anaesthetic crises: a multicentre study. *Anaesthesia*. 2002;57:176–179.
36. Savoldelli GL, Naik VN, Park J, et al. Value of debriefing during simulated crisis management: oral versus video-assisted oral feedback. *Anesthesiology*. 2006;105:279–285.
37. Sawyer T, Sierocka-Casteneda A, Chan D, et al. The effectiveness of video-assisted debriefing versus oral debriefing alone at improving neonatal resuscitation performance: a randomized trial. *Simul Healthc*. 2012;7:213–221.
38. Brett-Fleegler M, Rudolph J, Eppich W, et al. Debriefing assessment for simulation in healthcare: development and psychometric properties. *Simul Healthc*. 2012;7:288–294.
39. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med*. 2004;79(10 suppl):S70–S81.
40. Ericsson K, Charness N, Feltovich P, et al. *The Cambridge Handbook of Expertise and Expert Performance*. New York, NY: Cambridge University Press; 2006.
41. McGaghie WC, Issenberg SB, Cohen ER, et al. Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. *Acad Med*. 2011;86:706–711.
42. McGaghie WC, Issenberg SB, Cohen ER, et al. Medical education featuring mastery learning with deliberate practice can lead to better health for individuals and populations. *Acad Med*. 2011;86:e8–e9.
43. Wayne DB, Butter J, Siddall VJ, et al. Mastery learning of advanced cardiac life support skills by internal medicine residents using simulation technology and deliberate practice. *J Gen Intern Med*. 2006;21:251–256.
44. Barsuk J, Cohen E, McGaghie W, et al. Long-term retention of central venous catheter insertion skills after simulation-based mastery learning. *Acad Med*. 2010;85:S9–S12.

45. Kessler DO, Arteaga G, Ching K, et al. Interns' success with clinical procedures in infants after simulation training. *Pediatrics*. 2013;131:e811.
46. Barsuk JH, Cohen ER, Potts S, et al. Dissemination of a simulation based mastery learning intervention reduces central line associated bloodstream infections. *BMJ Qual Saf*. 2014;23:749–756.
47. McGaghie W, Issenberg S, Barsuk J, et al. A critical review of simulation-based mastery learning with translational outcomes. *Med Educ*. 2014;48:375–385.
48. Gordon MS, Issenberg SB. *The Cardiopulmonry Patient Simulator—Learner Manual* Leonard M. Miller School of Medicine. Miami, Fla: University of Miami Press; 2007.
49. Thomas F, Carpenter J, Rhoades C, et al. The usefulness of design of experimentation in defining the effect difficult airway factors and training have on simulator oral–tracheal intubation success rates in novice intubators. *Acad Emerg Med*. 2010;17:460–463.
50. Aggarwal R, Grantcharov T, Moorthy K, et al. A competency-based virtual reality training curriculum for the acquisition of laparoscopic psychomotor skill. *Am J Surg*. 2006;191:128–133.
51. Sawyer T, Sierocka-Casteneda A, Chan D, et al. Deliberate practice using simulation improves neonatal resuscitation performance. *Simul Healthc*. 2011;6:327–336.
52. Eich C, Timmermann A, Russo S, et al. Simulator-based training in paediatric anaesthesia and emergency medicine—thrills, skills and attitudes. *Br J Anaesth*. 2007;98:417–419.
53. Steadman RH, Huang YM. Simulation for quality assurance in training, credentialing and maintenance of certification. *Best Pract Res Clin Anaesthesiol*. 2012;26:3–15.
54. Cheng A, Auerbach M, Hunt EA, et al. Designing and conducting simulation-based research. *Pediatrics*. 2014;133:1091–1101.
55. International Network for Simulation-based Pediatric Innovation, Research and Education (INSPIRE). Available at: http://www.inspiresim.com/. Accessed July 31, 2014.
56. International Pediatric Simulation Society (IPSS). Available at: http://ipssglobal.org/. Accessed July 31, 2014.