Learn, See, Practice, Prove, Do, Maintain: An Evidence-Based Pedagogical Framework for Procedural Skill Training in Medicine

Taylor Sawyer, DO, MEd, Marjorie White, MD, MPPM, MEd, Pavan Zaveri, MD, MEd,
Todd Chang, MD, Anne Ades, MD, Heather French, MD, JoDee Anderson, MD, MEd,
Marc Auerbach, MD, MSCI, Lindsay Johnston, MD, and David Kessler, MD, MSCI

Abstract

Acquisition of competency in procedural skills is a fundamental goal of medical training. In this Perspective, the authors propose an evidence-based pedagogical framework for procedural skill training. The framework was developed based on a review of the literature using a critical synthesis approach and builds on earlier models of procedural skill training in medicine. The authors begin by describing the fundamentals of procedural skill development. Then, a six-step pedagogical framework for procedural skills training is presented: *Learn*, *See*, *Practice*, *Prove*, *Do*, and *Maintain*. In this framework, procedural skill training begins with the learner acquiring requisite cognitive knowledge through didactic education (*Learn*) and observation of the procedure (*See*). The learner then progresses to the stage of psychomotor skill acquisition and is allowed to deliberately practice the procedure on a simulator (*Practice*). Simulation-based mastery learning is employed to allow the trainee to prove competency prior to performing the procedure on a patient (*Prove*). Once competency is demonstrated on a simulator, the trainee is allowed to perform the procedure on patients with direct supervision, until he or she can be entrusted to perform the procedure independently (*Do*). Maintenance of the skill is ensured through continued clinical practice, supplemented by simulation-based training as needed (*Maintain*). Evidence in support of each component of the framework is presented. Implementation of the proposed framework presents a paradigm shift in procedural skill training. However, the authors believe that adoption of the framework will improve procedural skill training and patient safety.

Procedures are fundamental to the medical profession. Acquiring competency in procedural skills is a fundamental goal of medical education, requiring specific education, training, and assessment. Once competency is acquired, maintenance of skills is essential to avoid natural skill decay. The well-known Halstedian mantra "see one, do one, teach one" is the traditional paradigm for teaching procedural skills in medicine. In this paradigm, procedural skill training is accomplished through direct patient care, with trainees practicing procedures on patients as part of a medical apprenticeship model. This training method has been brought under scrutiny within the past decade because of patient safety concerns,[1] and an end to the "see one, do one, teach one" era, through the use of simulation-based medical education, has been proposed.[2]

Simulation-based medical education is an instructional technique that enables trainees to safely gain competency in procedural skills without harm to patients. Its use has been associated with better patient care and improved patient safety.[3–9] The utility of simulation for psychomotor skills acquisition has been recently reviewed,[10] and the use of simulation is advocated by the Accreditation Council for Graduate Medical Education (ACGME).[11] Thus, a modern pedagogy for procedural skill education should incorporate instructional design strategies that effectively use simulation as a procedural skills training platform.

In this article we describe an evidence-based, pedagogical framework for teaching procedural skills in medicine. We developed our proposed framework—*learn*, *see*, *practice*, *prove*, *do*, and *maintain*—based on a review and critical synthesis of the literature. The proposed framework includes simulation as a key educational modality and incorporates proven instructional design features, such as deliberate practice and mastery learning, as critical components. The framework addresses the development, assessment, and maintenance of procedural skills. The foundation of the framework is rooted in adult learning theory.

We begin by describing the search methodology used to define the proposed framework. Next we describe the fundamentals of procedural skill development to provide context for the training framework. We then describe each step of the framework, including relevant examples and supportive data from the literature. To conclude, we summarize and discuss the implication of using the proposed framework.

Literature Review and Synthesis

To develop our proposed framework, we followed a nonsystematic, critical synthesis approach.[12,13] The process was completed in two phases over the course of two years. Phase I focused on collating evidence in support of a unified procedural skills training framework. Phase II involved a critical synthesis of the literature in relation to the proposed framework.

Please see the end of this article for information about the authors.

Correspondence should be addressed to Taylor Sawyer, Department of Pediatrics, Division of Neonatology, University of Washington School of Medicine, 1959 NE Pacific St., RR 539, HSB, Seattle, WA 98195; telephone: (206) 221-5716; e-mail: tlsawyer@uw.edu.

Acad Med. 2015;90:1025–1033.

doi: 10.1097/ACM.0000000000000734

During Phase I, five reviewers (T.S., M.W., P.Z., D.K., M.A.) performed a broad review of the literature pertaining to psychomotor skill training and procedural skill education in medicine. After individual reviews, the authors met in January 2013 to discuss the results and map a draft procedural skills training framework. During Phase II, after the draft framework was developed, the original five and five additional reviewers (T.C., J.A., H.F., A.A., L.J.) searched the medical literature for empiric evidence to support or refute the framework. The authors met again in January 2014 to review the evidence and formalize the final framework.

In keeping with a nonsystematic critical synthesis approach, articles reviewed in both phases comprised a broad range of materials, including descriptive/narrative reports; qualitative and quantitative studies using both experimental and quasi-experimental methods; literature reviews; systematic reviews; and meta-analyses. We also employed searches of gray literature and hand searches of bibliographies. Given the diversity of materials reviewed, we did not attempt to quantitate results, grade the level of evidence from each paper, or perform statistical analysis. Instead, we strove to consider the literature broadly to answer the focal question *What is the best framework for teaching procedural skills in medicine?*

Procedural Skill Development

We define *procedural skills* to include "the mental and motor activities required to execute a manual task."[14] Procedural skills can range from simple tasks, such as drainage of an abscess, to complex tasks, such as endotracheal intubation. However, we believe that learning any procedure follows the same fundamental process, thus allowing all procedural skills training to be based on a common framework.

The developmental stages of learning in medicine have been previously defined by Dreyfus and Dreyfus.[15] The "Dreyfus model" details the development of a medical provider's scope of vision and range of capabilities along a continuum of five stages: *novice*, *advanced beginner*, *competent*, *proficient*, and *expert*.[15] A five-stage developmental progression has also been defined specifically for psychomotor/procedural skills. Simpson's[16] and Harrow's[17] taxonomy of the psychomotor domain describes a progression of procedural skill development through a continuum of five stages:

1. *Guided response* indicates the earliest stage in learning a skill, and primarily includes imitation and trial and error.
2. *Mechanism* is an intermediate stage in skill learning and describes a state wherein learned responses have become habitual and the movements associated with the skill can be performed with some proficiency and confidence.
3. *Complex overt response* is a stage at which a procedure can be performed competently with quick, accurate, and highly coordinated performance. At this stage the learner would be considered "competent" with the procedure.
4. *Adaptation* indicates that skills are so well developed that the individual can modify movement patterns to fit difficult situations.
5. *Originating*, the final step in skill development, defines a phase in which the skill has been mastered to such an extent that new movement patterns can be created to fit a particular situation or unique problem.

Figure 1 shows the developmental progression in procedural skill mastery using Simpson and Harrow's taxonomy and correlates each of the five stages of psychomotor skill development with the Dreyfus and Dreyfus developmental stages lexicon. It is within this context of procedural skills development that our proposed pedagogical framework for procedural skill training is employed.

An Evidence-Based Pedagogical Framework

We identified numerous reports on how to conduct procedural skill training in medicine.[18–23] We also identified several practical guides on teaching medical procedures.[24–26] Of the available training methodologies, we felt the paradigm provided by Kovacs[18] provided one of the best approaches and possessed a high degree of validity based in its foundation in psychomotor learning theory. According to Kovacs, procedural skill training should encompass four steps:

1. *Learn:* A trainee should learn about the procedure and acquire the requisite cognitive knowledge.
2. *See:* The trainee should then see the procedure performed by an instructor or preceptor.
3. *Practice:* After learning the procedure and observing it being performed, the trainee should practice the procedure.
4. *Do:* Finally, the trainee should continue to practice the procedure by performing it on patients.

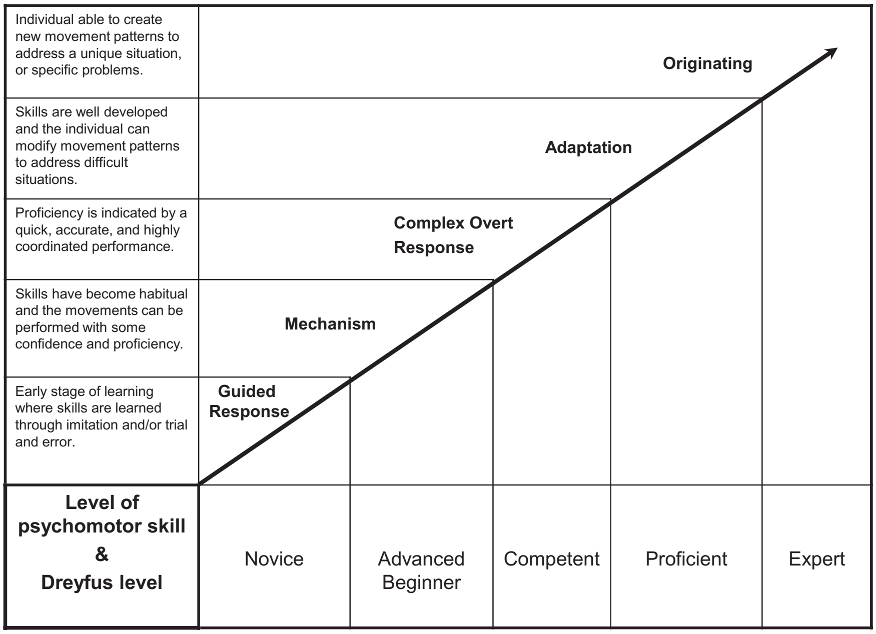

Figure 1 The progression of the development of expertise in procedural skills using Simpson's[16] and Harrow's[17] taxonomy of psychomotor skill development correlated with the Dreyfus and Dreyfus[15] lexicon of medical skill acquisition.

Kovacs briefly discussed the role of simulation in this paradigm, mentioning the use of "artificial settings" and "models," but his early report did not include modern evidence in support of simulation. Building on Kovacs's original framework, we identified two additional, vitally important, steps: *Prove* and *Maintain*. Our proposed framework is *Learn*, *See*, *Practice*, *Prove*, *Do*, *Maintain*. We believe this takes into account the best evidence currently available in procedural skills education and establishes a modern pedagogy for procedural skills education in medicine. An overview of the pedagogical framework is presented in Figure 2, and we discuss each of the components of the framework below.

Learn

Teaching and learning procedural skills can be divided into two phases: the *cognitive phase* and the *psychomotor phase*.[18] The relative importance of each phase, and the amount of time devoted to each, is dependent on both the procedure and the learner. The cognitive phase is the period devoted to learning about the procedure and developing an understanding of the indications, contraindications, and motor actions involved. Some complex procedures may require a significant cognitive component, whereas simple procedural skills may require minimal cognition. The cognitive phase comprised two subphases: *conceptualization* and *visualization*.[18]

In our proposed framework, the first phase of procedural skill training involves acquiring the required cognitive knowledge about the procedural skill. This *Learn* step focuses on *conceptualization*. Instructional techniques involved in this step could include learning strategies such as assigned reading, didactic sessions, and multimedia Web-based programs.[27] The benefits of providing a cognitive component prior to any hands-on training is supported by empiric investigation.[28,29] This step can be conducted individually, or in a group, through either asynchronous or synchronous modalities. Verification of cognitive knowledge can be done with a standardized test, such as a multiple-choice exam, which can be used to verify that requisite cognitive knowledge has been gained prior to the initiation of hands-on procedural skill training.

See

After the cognitive phase has been completed, the next phase of procedural skill training involves an instructor demonstrating and modeling the procedure for the learner. The *See* step focuses on *visualization*.[18] The demonstration of a skill is optimized by including both nonverbal and verbal instruction.[26,30] The nonverbal instruction includes a demonstration of the procedure from start to finish without commentary. The verbal instruction, referred to as "deconstruction" by Peyton,[30] includes a demonstration of each step in the procedure with accompanying verbal description. These demonstrations can be presented either through in-person training or in a video demonstration.[28,29] A third step may involve the learner explaining each step of the procedure with the teacher following the instructions.[30] Evidence supports the educational benefits of demonstrating procedural skills prior to hands-on training to enhance clinical skill acquisition.[28,29,31–33]

A requirement for the proper demonstration of a procedure is for educators and instructors to come to a consensus on the way the procedure is best performed and to identify the key steps of the procedure. This can be accomplished through the development of a validated procedural checklist via a Delphi method.[34–40]

Practice

The psychomotor phase of procedural skills training involves practicing the procedure with correction and reinforcement, as well as completing the procedure on a patient in the clinical arena.[18] In our proposed framework, practicing the procedure (*Practice*) and proving competency through simulation-based assessment (*Prove*) precede performing the procedure for the first time on a patient (*Do*). The *Practice* step is optimized by using *deliberate practice*.

As defined by Ericsson et al,[41–43] *deliberate practice* describes a regimen of effortful activity designed to optimize improvements in the acquisition of expert performance. The key features of deliberate practice are motivated learners, well-defined learning objectives, focused and repetitive practice, precise measurements of performance, and formative feedback. The goal of formative feedback during practice is to improve performance. The importance of formative feedback in procedural skills training is supported by Adams's[44,45] closed-loop theory (see Figure 3), wherein the feedback improves a learner's *knowledge of results* and facilitates the detection and correction of errors.

In the *Practice* step, the learner is allowed the opportunity for deliberate practice of the procedure in a safe learning

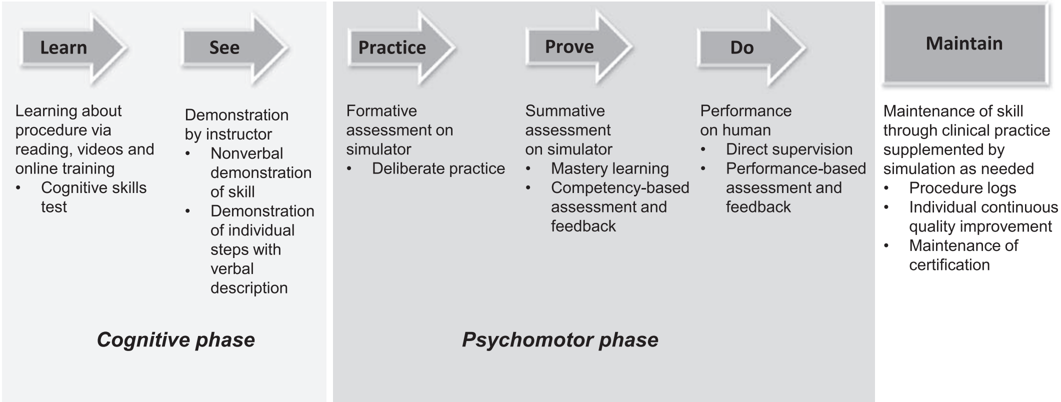

Figure 2 A proposed pedagogical framework for procedural skill training in medicine.

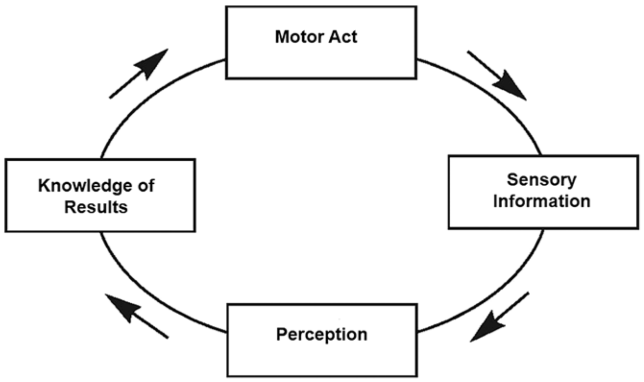

Figure 3 Adams's[44] "closed-looped theory" of motor learning (adapted from Kovacs[18]). Reprinted from the Journal of Emergency Medicine, Volume 15, Issue 3, Kovacs G, Procedural skills in medicine: Linking theory to practice, pages 387–391, copyright 1997, with permission from Elsevier.

environment (e.g., a simulation center or in situ simulation-based training) on a partial-task trainer, mannequin, or virtual reality trainer. Evaluation at this phase is formative in nature and directed at defining areas for improvement and modification to maximize performance. Numerous reports exist in the medical literature describing the benefits of deliberate practice at improving procedural performance.[46–49] Deliberate practice using simulation has been found to be superior to traditional clinical medical education in achieving specific clinical skill acquisition goals.[50] Other instructional design features shown to improve skills outcomes in simulation-based practice include a range of difficulty, distributed practice, longer practice time, using multiple learning strategies, introducing clinical variation, individualized learning, and mastery learning.[27]

Prove

In the *Prove* step of our proposed framework, the learner undergoes objective skills assessment on a simulator, to ensure that procedural competency has been achieved, prior to performing the procedure on a patient. The *Prove* step uses simulation-based mastery learning (SBML). The seven key characteristics of SBML include (1) clear learning objectives; (2) baseline skill assessment; (3) a valid assessment tool with a predetermined minimal passing standard (e.g., "mastery-level"); (4) practice that is focused on reaching mastery-level performance; (5) skill testing to assess achievement of mastery-level performance; (6) continued practice, as needed, until the mastery-level performance is achieved; and (7) progression to the next level of training only after achievement of the mastery standard.[4] Mastery learning augments deliberate practice through the addition of a clearly delineated level of performance that defines mastery, and the requirement for continuous practice until the learner achieves mastery-level performance.[51] This predefined mastery-level performance greatly informs the feedback provided to the learner and may assist with clarifying the *knowledge of results*, as defined by Adams.[44,45] Competency-based assessment using medical simulation, prior to the performance of the procedure on a patient, is one of the most important roles of simulation as a patient safety modality.[1,52] This type of "pre-patient training" is currently used in many medical training programs.[11,24,52] Multiple reports in the literature demonstrate the benefits of using an SBML model to teach procedural skills.[53–57] A recent meta-analysis showed simulation-based medical education incorporating mastery learning to be superior to nonmastery instruction.[58] The determination of mastery-level performance on the simulator can be performed prior to the start of clinical rotations,[24,32,52] or immediately prior to the performance of a procedure on a patient using a "just-in-time" model of performance assessment.[59]

The ability to evaluate mastery-level performance requires an assessment tool with a high level of validity and reliability. Assessment tools for procedural skills commonly take the form of either checklists or global rating scales.[20] Methods used to determine the validity and reliability of these assessment tools are described elsewhere.[60–62] The evidence supporting the psychometric properties of several assessment tools has been recently reviewed.[63,64]

Both checklists and global rating scales have benefits and drawbacks. Benefits of checklists include their specific and objective nature, typically involving a sequential series of steps in the procedure with a simple "done" or "not done" check box next to each step.[65] Drawbacks of checklists include the fact that sequential checklists may not convey a differentiation in status of critical versus less important steps, and that sometimes not all steps of a checklist are required to successfully complete a procedure.[20]

Global rating scales provide a more broad-based assessment of procedural competency. Global rating scales, typically involving a Likert-type scale, are used to provide a global rating of procedural skill (e.g., 1 = novice, 3 = competent, 5 = expert). Specific behavioral anchors can be used to provide explicit examples of the behaviors that are indicative of each skill level, yielding a type of global rating scale known as a *behaviorally anchored rating scale*. A benefit of a global rating scale is the comprehensive impression of competency it provides, without reliance on predefined steps to determine proficiency.[20] Limitations include the loss of granularity and inability to provide specific feedback based on incorrect steps.[20]

Given the benefits and drawbacks of each type of assessment method, we recommend a hybrid assessment tool that includes both a checklist and a global rating scale to mitigate the weaknesses of both methods and accentuate their respective strengths. An example template of such a hybrid procedural skills checklist is provided in Appendix 1.

Do

The teaching of procedural skills must eventually move from the simulation realm to the clinical realm. In Miller's[66] well-known hierarchy, assessment begins with "knows," then progresses to "knows how," "shows how," and culminates in "does." Assessment of procedural skills on a simulator aligns with "shows how," and assessment of procedural skills on a real patient aligns with "does" in Miller's pyramid.[66] In our proposed framework, after cognitive knowledge of the procedure has been attained (*Learn*), the procedure has been modeled (*See*), sufficient practice using simulation has been conducted (*Practice*), and verification of procedural skill to a predefined mastery level on a simulator has been achieved (*Prove*), the learner is finally allowed to perform the procedure on a patient (*Do*). Thus, only after a trainee is deemed competent on a simulator can he or she continue the process of procedural skill development on real patients in the workplace. This translation of the procedural skill from the realm of simulation to a real-world setting represents a key transition point.

Because of the inherent differences between simulation and real-life clinical practice, competency during simulation should never be considered adequate evidence of true clinical competency. Rethans et al[67] defined competency-based assessment as measures of what doctors do in testing situations (e.g., simulation), and "performance-based assessment as measures of what doctors do in practice."[67] Performance-based assessment is required to ensure that the learner can be trusted to perform the procedure independently and without direct supervision. The concept of entrusting a trainee to perform in the clinical environment without direct supervision is the core tenet of entrustable professional activities.[68] As proposed by ten Cate,[69] the levels of graduated supervision leading to entrustment progress from observation of the procedure only, to performing the procedure with direct supervision in the room, to having supervision available within minutes, to performing the procedure unsupervised (i.e., under clinical oversight), and eventually to providing supervision to more junior practitioners. In our proposed framework, graduated supervision occurs during the *Do* step, leading eventually to entrustment, and then to ongoing skill maintenance in the *Maintain* step.

For the *Do* step to be successful—and safe—the learner must initially be directly supervised during the performance of a procedure on a patient and receive real-time assessment and feedback on technique. This type of direct observation has been referred to as "workplace-based assessment," "assessment of performance," or a "supervised learning event."[70,71] These assessments are formative in nature and provide an opportunity for a preceptor to give direct feedback to a trainee to optimize procedural skills and patient outcomes while avoiding harm. Providing a structured environment within which a learner can reliably receive formative assessment of procedural skills can be accomplished through individualized one-on-one training during a clinical rotation, or by rotation on a dedicated medical procedure service.[72–74] Supervision in either context is best provided by an attending physician or other expert provider, as opposed to one of the trainee's peers.[74–76]

The determination of clinical competency with a procedural skill is challenging, but several methods may help determine clinical competency, including an individualized screening process, tracking the number of procedures performed by a trainee, and statistical analysis of procedural success and failure rates. Each of these methods has benefits and drawbacks. Ideally, some combination of these assessment methods could be used simultaneously to provide optimal evidence of clinical competency.

As described by Rethans et al,[67] assessment of procedural competency during clinical care should include a general screening component in which all trainees participate, followed by either a continuous quality improvement cycle for those who pass the screen, or a diagnostic investigation and follow-up for those who perform poorly on the screen. To facilitate the screening process and provide an accurate assessment of procedural competency, the same checklist or assessment tool used in the *Prove* step can be used in the *Do* step—this time to evaluate procedural skill on a patient, rather than a simulator. The benefits of this methodology include the one-on-one expert assessment provided to each individual learner. Drawbacks include difficulty facilitating the one-on-one supervision and feedback in a busy clinical environment and the need for faculty training in the use of the assessment tools.

In the United States, several ACGME resident review committees have outlined specific "key index procedures" for their specialty and have published guidelines on the minimum numbers of these procedures that a resident must perform prior to graduation.[77–80] The goal for this minimum number is to ensure that each trainee receives adequate exposure to these key index procedures and, as a result, achieves performance-based competency. Benefits of this method include the relative ease with which the assessment can be done using procedure logs, also referred to as case logs. A clear drawback is that performance of a set number of procedures does not provide definitive evidence of achievement of competency because there is a wide range of procedural experience required for individuals to achieve competency, and some trainees will achieve competency more slowly and require more procedures to do so than others.

Cumulative summative (CUSUM) analysis, a type of statistical control chart, has been explored as a method of obtaining objective information on both individual competency and the average number of procedures that are required to achieve competence amongst a given learner group. Using CUSUM analysis, individual learning curves can be created based on predefined acceptable and unacceptable failure rates and reasonable probabilities of type I and type II errors. Early evidence using CUSUM methodology to define the number of procedures needed to achieve competency is promising.[81–83] Benefits of CUSUM include the reliance on objective statistical analysis of procedural success. Drawbacks include the need for trainees to diligently record all procedural successes and failures and the inherent difficulties in defining "acceptable" success and failure rates for any given procedure.

Maintain

Once achieved, competency with a procedural skill will degrade with time if the procedure is not practiced regularly. The term "de-skilling" has been applied to the gradual loss of skills through infrequent practice.[84] In novice providers, this de-skilling will likely occur rapidly. In experienced providers, de-skilling may occur more slowly. However, degradation curves for procedural skills, based on learner groups and experience, have yet to be defined. Thus, the required frequency and intensity of practice needed to maintain procedural skill are unknown. The area of skill decay, and simulation-based interventions to avoid skill decay, is an active area of ongoing research.

For practitioners who do not perform a specific procedure on a regular basis in their clinical practice, or who have long gaps in clinical time, simulation provides

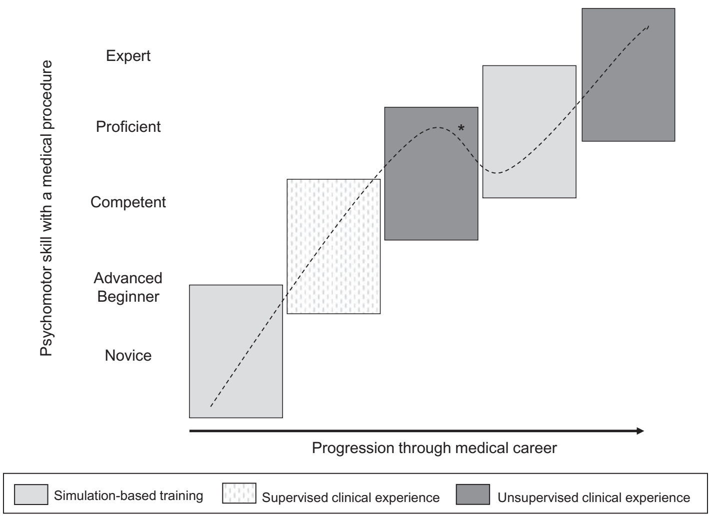

Figure 4 The theoretical interplay of simulation and clinical experience in procedural skill development and maintenance. The dashed line represents skill development and maintenance over time. The asterisk (*) indicates a clinical hiatus, or long break in clinical practice.

the only feasible method to allow needed practice with the procedure.[85] A theoretical representation of the synthesis between simulation and clinical practice on procedural skill development and maintenance is provided in Figure 4. As shown in Figure 4, skill maintenance could include both clinical practice and simulation, with simulation acting as supplemental training for infrequently performed procedures or as refresher training after breaks in clinical practice.[85] Tracking of procedures (e.g., with procedure logs) or CUSUM analysis could be included as part of individual continuous quality improvement to provide objective information on the potential need for simulation-based refresher training. Several methods have been used to provide simulation-based maintenance training: "dress rehearsals," "rolling refreshers," "just-in-time" training, and "booster" training.[9,86–89] Maintenance of competency in procedural skills in one's area of clinical practice is a critical component of lifelong learning, and key to the ACGME and American Board of Medical Specialties core competencies of *Patient Care and Procedural Skills* and *Practice-based Learning and Improvement*. The American Board of Anesthesiology currently uses a simulation-based practice performance assessment and improvement program to satisfy maintenance of certification (MOC) requirements.[90] Other medical specialties, including family medicine, are investigating the use of simulation-based training for MOC as well.[90]

Summary

In this article we have described a six-step, evidence-based pedagogical framework for procedural skill training in medicine: *Learn*, *See*, *Practice*, *Prove*, *Do*, *Maintain*. The framework was developed after a review and critical synthesis of the literature and is founded on adult learning theory. The evidence behind each of the key components of the framework is rooted in empiric investigation. We hope that the framework described here will provide a comprehensive conceptual guide to medical educators involved in teaching procedural skills. Implementation of our proposed framework will no doubt be challenging. The formal structure of the training paradigm, with a focus on competency-based assessments through simulation, performance-based assessments during clinical care, and skills maintenance augmented by simulation as needed, presents a paradigm shift in procedural skill training. However, we believe that adoption of the framework by medical educators will improve procedural skill training and will ultimately improve medical care and patient safety.

Funding/Support: None reported.

Other disclosures: None reported.

Ethical approval: Reported as not applicable.

Previous presentations: The framework proposed here has been previously taught as part of instructional workshops conducted by the authors at national and international conferences, including the Academic Pediatric Society Meeting, Washington, DC, May 2013; the International Pediatric Simulation Symposia and Workshops, Vienna, Austria, April 2014; and the International Meeting for Simulation in Healthcare, New Orleans, Louisiana, January 2015.

T. Sawyer is assistant professor, Department of Pediatrics, University of Washington School of Medicine, Seattle, Washington.

M. White is assistant professor, Department of Pediatrics, University of Alabama at Birmingham, Birmingham, Alabama.

P. Zaveri is assistant professor, Division of Emergency Medicine, Children's National Health System, Washington, DC.

T. Chang is assistant professor, Division of Emergency Medicine and Transport, Children's Hospital Los Angeles, Los Angeles, California.

A. Ades is associate professor, Department of Pediatrics, Children's Hospital of Philadelphia, Philadelphia, Pennsylvania.

H. French is assistant professor, Department of Pediatrics, Children's Hospital of Philadelphia, Philadelphia, Pennsylvania.

J. Anderson is associate professor, Department of Pediatrics, Oregon Health Sciences University, Portland, Oregon.

M. Auerbach is assistant professor, Department of Pediatrics, Yale School of Medicine, New Haven, Connecticut.

L. Johnston is assistant professor, Department of Pediatrics, Yale School of Medicine, New Haven, Connecticut.

D. Kessler is assistant professor, Department of Pediatrics, Columbia University College of Physicians and Surgeons, New York, New York.

References

1 Ziv A, Wolpe PR, Small SD, Glick S. Simulation-based medical education: An ethical imperative. Acad Med. 2003;78:783–788.
2 Lenchus JD. End of the "see one, do one, teach one" era: The next generation of invasive bedside procedural instruction. J Am Osteopath Assoc. 2010;110:340–346.
3 Cook DA, Hatala R, Brydges R, et al. Technology-enhanced simulation for health professions education: A systematic review and meta-analysis. JAMA. 2011;306:978–988.
4 McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. A critical review of simulation-based medical education research: 2003–2009. Med Educ. 2010;44:50–63.
5 Schaefer J, Venderbilt A, Cason C, et al. Instructional design and pedagogy science in healthcare simulation. Simul Healthc. 2011;6:S30–S41.
6 McGaghie WC, Draycott TJ, Dunn WF, Lopez CM, Stefanidis D. Evaluating the impact of simulation on translational patient outcomes. Simul Healthc. 2011;6(suppl):S42–S47.
7 Gunberg J. Simulation and psychomotor skill acquisition: A review of the literature. Clin Simul Nurs. 2012;8:e429–435.
8 Zendejas B, Brydges R, Wang AT, Cook DA. Patient outcomes in simulation-based

medical education: A systematic review. J Gen Intern Med. 2013;28:1078–1089.

9 Scholtz AK, Monachino AM, Nishisaki A, Nadkarni VM, Lengetti E. Central venous catheter dress rehearsals: Translating simulation training to patient care and outcomes. Simul Healthc. 2013;8:341–349.

10 Ross J. Simulation and psychomotor skill acquisition: A review of the literature. Clin Simul Nurs. 2012;8:e429–e435.

11 Philbert I, ed. Accreditation Council for Graduate Medical Education (ACGME) Bulletin. Published December 2005. https://tulane.edu/som/sim/faculty/upload/bulletin12_05.pdf. Accessed March 11, 2015.

12 Eva KW. On the limits of systematicity. Med Educ. 2008;42:852–853.

13 Cook D. Narrowing the focus and broadening horizons: Complementary roles for systematic and nonsystematic reviews. Adv Health Sci Educ. 2008;13:391–395.

14 Foley RP, Spilansy J. Teaching Techniques—A Handbook for Health Professionals. New York, NY: McGraw Hill; 1980:71–91.

15 Dreyfus S, Dreyfus H. A Five Stage Model of the Mental Activities Involved in Directed Skill Acquisition. Published February 1980. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA084551. Accessed March 11, 2015.

16 Simpson E. The Classification of Educational Objectives in the Psychomotor Domain. Washington, DC: Gryphon House; 1972.

17 Harrow A. A Taxonomy of the Psychomotor Domain. New York, NY: David McKay; 1972:14–31.

18 Kovacs G. Procedural skills in medicine: Linking theory with practice. J Emerg Med. 1997;15:387–391.

19 Norris TE, Cullison SW, Fihn SD. Teaching procedural skills. J Gen Intern Med. 1997;12(suppl 2):S64–S70.

20 Lammers RL, Davenport M, Korley F, et al. Teaching and assessing procedural skills using simulation: Metrics and methodology. Acad Emerg Med. 2008;15:1079–1087.

21 Kneebone R. Evaluating clinical simulations for learning procedural skills: A theory-based approach. Acad Med. 2005;80:549–553.

22 McLeod PJ, Steinert Y, Trudel J, Gottesman R. Seven principles for teaching procedural and technical skills. Acad Med. 2001;76:1080.

23 Wang E, Quinones J, Fitch M, et al. Developing technical expertise in emergency medicine—the role of simulation in procedural skill acquisition. Acad Emerg Med. 2008;15:1046–1057.

24 Grantcharov TP, Reznick RK. Teaching procedural skills. BMJ. 2008;336:1129–1131.

25 Brodsky D, Smith C. A structured approach to teaching medical procedures. NeoReviews. 2012;13:e635–e641.

26 Paulman P. A simple five-step method for teaching clinical skills. Fam Med. 2001;33:577–578.

27 Cook DA, Hamstra SJ, Brydges R, et al. Comparative effectiveness of instructional design features in simulation-based education: Systematic review and meta-analysis. Med Teach. 2013;35:e867–e898.

28 Srivastava G, Roddy M, Langsam D, Agrawal D. An educational video improves technique in performance of pediatric lumbar punctures. Pediatr Emerg Care. 2012;28:12–16.

29 Ventres WB, Senf JH. Introducing a procedure using videotape instruction: The case of the lateral birth position. Fam Med. 1994;26:434–436.

30 Peyton JWR. Teaching and Learning in Medical Practice. Rickmansworth, UK: Manticore Publishing House Europe Limited; 1998.

31 Bjerrum AS, Hilberg O, van Gog T, Charles P, Eika B. Effects of modelling examples in complex procedural skills training: A randomised study. Med Educ. 2013;47:888–898.

32 Kessler DO, Arteaga G, Ching K, et al. Interns' success with clinical procedures in infants after simulation training. Pediatrics. 2013;131:e811–e820.

33 Gaies MG, Morris SA, Hafler JP, et al. Reforming procedural skills training for pediatric residents: A randomized, interventional trial. Pediatrics. 2009;124:610–619.

34 Berg D, Berg K, Riesenberg LA, et al. The development of a validated checklist for thoracentesis: Preliminary results. Am J Med Qual. 2013;28:220–226.

35 Berg K, Riesenberg LA, Berg D, et al. The development of a validated checklist for radial arterial line placement: Preliminary results. Am J Med Qual. 2014;29:242–246.

36 Riesenberg LA, Berg K, Berg D, et al. The development of a validated checklist for femoral venous catheterization: Preliminary results. Am J Med Qual. 2014;29:445–450.

37 Riesenberg LA, Berg K, Berg D, et al. The development of a validated checklist for paracentesis: Preliminary results. Am J Med Qual. 2013;28:227–231.

38 Berg K, Riesenberg LA, Berg D, et al. The development of a validated checklist for adult lumbar puncture: Preliminary results. Am J Med Qual. 2013;28:330–334.

39 Riesenberg LA, Berg K, Berg D, et al. The development of a validated checklist for nasogastric tube insertion: Preliminary results. Am J Med Qual. 2013;28:429–433.

40 Huang GC, Newman LR, Schwartzstein RM, et al. Procedural competence in internal medicine residents: Validity of a central venous catheter insertion assessment instrument. Acad Med. 2009;84:1127–1134.

41 Ericsson KA, Krampe RT, Tesch-Romer C. The role of deliberate practice in the acquisition of expert performance. Psychol Rev. 1993;100:363–406.

42 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.

43 Ericsson KA. Deliberate practice and acquisition of expert performance: A general overview. Acad Emerg Med. 2008;15:988–994.

44 Adams JA. A closed-loop theory of motor learning. J Mot Behav. 1971;3:111–149.

45 Adams J. A historical review and appraisal of research on the learning, retention and transfer of human motor skills. Psychol Bull. 1987;101:41–47.

46 Kessler DO, Auerbach M, Pusic M, Tunik MG, Foltin JC. A randomized trial of simulation-based deliberate practice for infant lumbar puncture skills. Simul Healthc. 2011;6:197–203.

47 Sawyer T, Sierocka-Castaneda A, Chan D, Berg B, Lustik M, Thompson M. Deliberate practice using simulation improves neonatal resuscitation performance. Simul Healthc. 2011;6:327–336.

48 Clapper T, Kardong-Edgren S. Using deliberate practice and simulation to improve nursing skills. Clin Simul Nurs. 2012;8:e109–e113.

49 Issenberg SB, McGaghie WC, Gordon DL, et al. Effectiveness of a cardiology review course for internal medicine residents using simulation technology and deliberate practice. Teach Learn Med. 2002;14:223–228.

50 McGaghie WC, Issenberg SB, Cohen ER, Barsuk JH, Wayne DB. Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. Acad Med. 2011;86:706–711.

51 McGaghie WC, Issenberg SB, Cohen ER, Barsuk JH, Wayne DB. Medical education featuring mastery learning with deliberate practice can lead to better health for individuals and populations. Acad Med. 2011;86:e8–e9.

52 Cohen ER, Barsuk JH, Moazed F, et al. Making July safer: Simulation-based mastery learning during intern boot cAMP. Acad Med. 2013;88:233–239.

53 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.

54 Barsuk JH, McGaghie WC, Cohen ER, O'Leary KJ, Wayne DB. Simulation-based mastery learning reduces complications during central venous catheter insertion in a medical intensive care unit. Crit Care Med. 2009;37:2697–2701.

55 Barsuk JH, McGaghie WC, Cohen ER, Balachandran JS, Wayne DB. 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.

56 Barsuk JH, Ahya SN, Cohen ER, McGaghie WC, Wayne DB. Mastery learning of temporary hemodialysis catheter insertion by nephrology fellows using simulation technology and deliberate practice. Am J Kidney Dis. 2009;54:70–76.

57 Barsuk JH, Cohen ER, Caprio T, McGaghie WC, Simuni T, Wayne DB. Simulation-based education with mastery learning improves residents' lumbar puncture skills. Neurology. 2012;79:132–137.

58 Cook DA, Brydges R, Zendejas B, Hamstra SJ, Hatala R. Mastery learning for health professionals using technology-enhanced simulation: A systematic review and meta-analysis. Acad Med. 2013;88:1178–1186.

59 Kamdar G, Kessler DO, Tilt L, et al. Qualitative evaluation of just-in-time simulation-based learning: The learners' perspective. Simul Healthc. 2013;8:43–48.

60 Downing SM. Validity: On meaningful interpretation of assessment data. Med Educ. 2003;37:830–837.

61 Downing SM. Reliability: On the reproducibility of assessment data. Med Educ. 2004;38:1006–1012.

62 Cook D, Beckman T. Current concepts in validity and reliability for psychomotor instruments: Theory and application. Am J Med. 2006;119:e7–e16.

63 Jelovsek JE, Kow N, Diwadkar GB. Tools for the direct observation and assessment of psychomotor skills in medical trainees: A systematic review. Med Educ. 2013;47:650–673.

64 Ahmed K, Miskovic D, Darzi A, Athanasiou T, Hanna GB. Observational tools for assessment of procedural skills: A systematic review. Am J Surg. 2011;202:469–480.e6.

65 Hales B, Terblanche M, Fowler R, Sibbald W. Development of medical checklists for improved quality of patient care. Int J Qual Health Care. 2008;20:22–30.

66 Miller GE. The assessment of clinical skills/competence/performance. Acad Med. 1990;65(9 suppl):S63–S67.

67 Rethans JJ, Norcini JJ, Barón-Maldonado M, et al. The relationship between competence and performance: Implications for assessing practice performance. Med Educ. 2002;36:901–909.

68 ten Cate O. Trust, competence, and the supervisor's role in postgraduate training. BMJ. 2006;333:748–751.

69 Ten Cate O. Nuts and bolts of entrustable professional activities. J Grad Med Educ. 2013;5:157–158.

70 Beard J. Workplace-based assessment: The need for continued evaluation and refinement. Surgeon. 2011;9(suppl 1):S12–S13.

71 Ali JM. Getting lost in translation? Workplace based assessments in surgical training. Surgeon. 2013;11:286–289.

72 Smith CC, Gordon CE, Feller-Kopman D, et al. Creation of an innovative inpatient medical procedure service and a method to evaluate house staff competency. J Gen Intern Med. 2004;19(5 pt 2):510–513.

73 Lenhard A, Moallem M, Marrie RA, Becker J, Garland A. An intervention to improve procedure education for internal medicine residents. J Gen Intern Med. 2008;23:288–293.

74 Huang GC, Smith CC, York M, Weingart SN. Asking for help: Internal medicine residents' use of a medical procedure service. J Hosp Med. 2009;4:404–409.

75 Mourad M, Kohlwes J, Maselli J, Auerbach AD; MERN Group. Supervising the supervisors—procedural training and supervision in internal medicine residency. J Gen Intern Med. 2010;25:351–356.

76 Huang GC, Smith CC, Gordon CE, et al. Beyond the comfort zone: Residents assess their comfort performing inpatient medical procedures. Am J Med. 2006;119:71.e17–71.e24.

77 Review Committee for Otolaryngology, Accreditation Council for Graduate Medical Education. Required minimum number of key indicator procedures for graduating residents. Published March 6, 2013. http://www.acgme.org/acgmeweb/Portals/0/PFAssets/ProgramResources/280_Required_Minimum_Number_of_Key_Indicator_Procedures.pdf. Accessed February 27, 2015.

78 Review Committee for Thoracic Surgery, Accreditation Council for Graduate Medical Education. Case requirements for residents beginning residency. Published 2012. http://www.acgme.org/acgmeweb/Portals/0/PFAssets/ProgramResources/460_CaseRequirements_ResidentsBeginning_OnorAfter_July012012.pdf. Accessed March 11, 2015.

79 Review Committee for Emergency Medicine, Accreditation Council for Graduate Medical Education. Frequently asked questions: Emergency medical services. Published 2014. http://www.acgme.org/acgmeweb/Portals/0/PDFs/FAQ/112_emergency_medical_svcs_FAQs.pdf. Accessed February 27, 2015.

80 Program Directors of Pediatric Urology Programs, Accreditation Council for Graduate Medical Education. Review committee for urology. Minimum numbers memorandum. Published July 1, 2013. http://www.acgme.org/acgmeweb/Portals/0/PFAssets/ProgramResources/480_Memo_Ped_Uro_Operative_Minimum_Numbers.pdf. Accessed February 27, 2015.

81 Filho G. The construction of learning curves for basic skills in anesthetic procedures: An application for cumulative sum method. Anesth Analg. 2002;95:411–416.

82 Dalal P, Dalal G, Pott L, Bezinover D, Prozesky J, Murray WB. Learning curves of novice anesthesiology residents performing simulated fiberoptic upper airway endoscopy. Can J Anesth. 2011;58:802–809.

83 Ward ST, Mohammed MA, Walt R, Valori R, Ismail T, Dunckley P. An analysis of the learning curve to achieve competency at colonoscopy using the JETS database. Gut. 2014;63:1746–1754.

84 Levitt LK. Use it or lose it: Is de-skilling evidence-based? Rural Remote Health. 2001;1:81.

85 Kneebone RL, Scott W, Darzi A, Horrocks M. Simulation and clinical practice: Strengthening the relationship. Med Educ. 2004;38:1095–1102.

86 Kovacs G, Bullock G, Ackroyd-Stolarz S, Cain E, Petrie D. A randomized controlled trial on the effect of educational interventions in promoting airway management skill maintenance. Ann Emerg Med. 2000;36:301–309.

87 Niles D, Sutton RM, Donoghue A, et al. "Rolling Refreshers": A novel approach to maintain CPR psychomotor skill competence. Resuscitation. 2009;80:909–912.

88 Sam J, Pierse M, Al-Qahtani A, Cheng A. Implementation and evaluation of a simulation curriculum for paediatric residency programs including just-in-time in situ mock codes. Paediatr Child Health. 2012;17:e16–e20.

89 Bender J, Kennally K, Shields R, Overly F. Does simulation booster impact retention of resuscitation procedural skills and teamwork? J Perinatol. 2014;34:664–668.

90 Steadman RH, Huang YM. Simulation for quality assurance in training, credentialing and maintenance of certification. Best Pract Res Clin Anaesthesiol. 2012;26:3–15.

Appendix 1

Example Template for a Procedural Skills Assessment Checklist

Procedural Skill Checklist

[*Procedure name*]

Learner:____________________________ **Learner level:**________________ **Evaluator**:______________________

Context in which procedure performed: ☐ *Simulation* ☐ *Clinical* **Difficulty level:** ☐ *Normal* ☐ *Difficult*

Describe situation:____

	Done independently. Done correctly.	**Not done. Done incorrectly.**	
	Yes	**No**	**N/A**
Able to state *indications* for procedure?	☐	☐	☐
Able to state c*ontraindications* for procedure?	☐	☐	☐
***Plans* procedure (identifies anatomy)?**	☐	☐	☐
***Prepares* for procedure (obtains/verifies consent, gathers needed equipment, identifies patient, performs time-out)?**	☐	☐	☐
Procedural steps completed?			
1.	☐	☐	☐
2.	☐	☐	☐
3.	☐	☐	☐
4.	☐	☐	☐
5.	☐	☐	☐
6.	☐	☐	☐
7.	☐	☐	☐
8.	☐	☐	☐
9.	☐	☐	☐
Procedure successful?	☐	☐	☐
Able to troubleshoot during procedure?	☐	☐	☐
Complications? *If yes, please describe:* _________________________________	☐	☐	☐
Performs appropriate aftercare?	☐	☐	☐

Global Assessment of Procedural Skill: (circle one)

1	**2**	**3**	**4**	**5**
Novice *Early stage of learning where skills are learned through imitation and/or trial and error.*	**Advanced Beginner** *Skills have become habitual and the movements can be performed with some confidence and proficiency.*	**Competent** *Proficiency is indicated by a quick, accurate, and highly coordinated performance.*	**Proficient** *Skills are well developed and the individual can modify movement patterns to address difficult situations.*	**Expert** *Individual able to create new movement patterns to address a unique situation, or specific problem.*

Entrustment Assessment: (check one)

☐ Ready to *observe* the procedure only, not ready to perform procedure on patient, even with direct supervision*
☐ Ready to perform procedure *with direct supervision present* in the room
☐ Ready to perform procedure with *supervision available within minutes*
☐ Ready to perform procedure *without direct supervision* (i.e., under clinical oversight)
☐ Ready to provide *supervision* to juniors learning the procedure

* If learner/ trainee not competent to perform procedure please refer for remedial simulation training