Simulation-Based Mastery Learning Improves Medical Student Performance and Retention of Core Clinical Skills

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Introduction: Simulation-based mastery learning (SBML) improves procedural skills among medical trainees. We employed an SBML method that includes an asynchronous knowledge acquisition portion and a hands-on skill acquisition portion with simulation to assess senior medical student performance and retention of the following 6 core clinical skills: (a) ultrasound-guided peripheral intravenous placement, (b) basic skin laceration repair, (c) chest compressions, (d) bag-valve mask ventilation, (e) defibrillator management, and (f) code leadership.

Methods: Seven emergency medicine (EM) faculty members developed curricula, created checklists, and set minimum passing standards (MPSs) to test mastery of the 6 skills. One hundred thirty-five students on an EM clerkship were pretested on all 6 skills, viewed online videos asynchronously followed by a multiple choice computer-based skill-related quiz, received one-on-one hands-on skill training using deliberate practice with feedback, and were posttested until MPS was met. We compared pretest and posttest performance. We also retested, unannounced, a convenience sample (36%) of students from 1 to 9 months postintervention to assess skill retention.

Results: All students passed each quiz. The percentage of students who reached each MPS increased significantly (P < 0.001) from pretest to posttest for all 6 clinical skills. Ninety-eight percent of the students scored at or above the MPS when retested 1 to 9 months later. There was no significant decrease in mean score for any of the 6 skills between posttest and retention testing.

Conclusions: Simulation-based mastery learning using a substantial asynchronous component is an effective way for senior medical students to learn and retain EM clinical skills. This method can be adapted to other skill training necessary for residency readiness. (Sim Healthcare 11:173–180, 2016)

Key Words: Mastery learning, Simulation, Asynchronous learning, Clinical skills, Medical student learners are not always trained to a mastery standard, which may allow learners with substandard performance to advance. Simulation-based mastery learning (SBML) is an instructional approach that prevents substandard student progress. Simulation-based mastery learning includes, at minimum, the following 7 complementary features: (a) baseline or diagnostic testing of target skills; (b) clear learning objectives ordered by difficulty; (c) engagement in educational activities, for example, deliberate practice, to reach the objectives; (d) a set minimum passing standard (MPS) for each skill; (e) formative testing to gauge achievement of a MPS; (f) curriculum advancement when the MPS has been achieved; or (g) continued practice or study until the MPS is reached. A systematic review and meta-analysis of SBML demonstrated improved outcomes when simulation involved mastery learning (ML) versus no ML, although a slightly longer time may be needed for the educational interventions. When skill training involves SBML, it leads to improved performance by learners in the simulated setting and in the patient care environment with improved patient care outcomes and unanticipated collateral effects.

Educational protocols that balance student ML and adult learning principles are desirable. Asynchronous learning is a student-centered teaching method where the learner chooses the time, place, and frequency to use online teaching resources, thereby reducing the labor-intensive nature of a traditional,
instructor-centered format. We chose to employ asynchronous learning in this study as part of an SBML curriculum.

Six core EM skills for senior medical students were identified from the EM Clerkship Procedural Curriculum \(^8\) and the 2014 Core Entrustable Professional Activities for Entering Residency \(^9\): (a) ultrasound-guided peripheral intravenous (USPIV) placement; (b) basic skin laceration repair (BSLR); (c) chest compressions (CCs); (d) bag-valve mask ventilation (BVM); (e) defibrillator management (DM); and (f) code leader (CL). Our study’s primary objective was to assess whether fourth-year medical students could acquire the EM skill.

**METHODS**

**Design**

This was a pretest-posttest design of SBML intervention of 6 core EM clinical skills without a control group, where learners serve as their own controls. \(^11\) Fourth-year medical students received the intervention during their required EMC. Students undertook pretesting on the 6 core EM clinical skills using simulation, completed asynchronous and synchronous SBML educational interventions, and received a skills posttest. A convenience sample of 36% of the initial group also received retention testing. This study was reviewed by our institutional review board and was judged exempt.

**Setting and Population**

Synchronous training occurred within the simulation laboratory of a tertiary care academic teaching hospital. One hundred thirty-five fourth-year medical students on an EM clerkship were educated and evaluated to mastery standards on the 6 core skills. Medical student demographic data are presented in Table 1. Simulation-based mastery learning occurred from July 2013 to April 2014.

**Simulation-Based Mastery Learning Instruction**

The educational approach was consistent for all 6 skills (Table 2). On the first day of the EMC, students were pretested in a standardized simulation setting regarding their performance on the 6 skills. Student checklist performance was recorded electronically using Google docs on iPad minis. Within the following 2 weeks, students were required to asynchronously view video podcasts and take the related readiness assurance quizzes for each skill until it was passed (only allowed to miss 1 question). We were unable to track video podcast viewing details but were able to track quiz participation and performance. Upon passing the quiz, students participated in synchronous skills training that included a brief demonstration, followed by hands-on training with deliberate practice and one-on-one feedback from paramedic instructors. Once ready, students were posttested on each skill individually to assure that MPS was met. If MPS was not achieved, students received targeted practice with one-on-one feedback and assessment was repeated. This process was iterative until every student met the MPS for each skill as required for advancement in the EMC. Although we did not track times stringently, on the basis of instructor time and simulation laboratory time, the traditional face-to-face educational activities (eg, testing, hands-on practice, etc) took approximately 60 minutes, whereas the average total time spent in asynchronous learning (eg, viewing videos, taking quizzes, etc.) was 30 minutes on the basis of anecdotal reports, and thus, the total time per student per skill was approximately 90 minutes.

A convenience sample of the students (n = 49) participating in surgery, obstetrics and gynecology, and internal medicine boot camps 1 to 9 months after their EMC skills training were assessed for skills retention. The medical students received unannounced skill testing and their ability to meet the MPS again was measured. Students who did not reach the MPS received one-on-one focused feedback, and the assessment was repeated until they again met the MPS.

**Mastery Checklist**

A checklist for each of the 6 skills was developed by the investigators and finalized through expert consensus among 7 attending EM physicians and 1 surgeon for the BSLR checklist only. \(^16\) Sample checklists for CL: P/A (Fig. 2) and DM: VT/VF (Fig. 3) are provided. Two of the skills required 2 separate checklists because of minor management differences, that is, DM and CL required both asystole (A)/pulseless electrical activity (PEA) and ventricular tachycardia (VT)/ventricular fibrillation (VF) checklists. These checklists mirrored the steps in the asynchronous learning videos. An MPS for each checklist was set by a group of 7 attending emergency physicians using the Angoff and Hofstee standard-setting methods. \(^17\) The results from each method were averaged to determine the mean score, which served as the MPS. \(^19\)–\(^21\)

**Rater Training**

We trained a pool of 15 paramedics to assess student checklist performance, to provide one-on-one feedback, and skills training with each student. All paramedics were trained for approximately 1 hour per skill regarding the procedure, checklist, common questions, and errors that might occur. After training, paramedics watched 3 recorded videos for each skill and completed a checklist based on each video. Between each video, checklist data were discussed and all inconsistencies were clarified with an EM physician (T.R.) to standardize assessment. After the 3 videos, paramedics watched additional performance videos and scored the performance on the checklists with interval discussions until a k value of 0.75 was obtained as a benchmark. \(^22\) Paramedics were reminded of checklist items before each live scoring session in the simulation laboratory. During live scoring

**TABLE 1. Student Demographics**

<table>
<thead>
<tr>
<th></th>
<th>N = 135</th>
</tr>
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<tbody>
<tr>
<td>Male, n (%)</td>
<td>73 (54)</td>
</tr>
<tr>
<td>Age, mean (SE)</td>
<td>23.30 (0.17)</td>
</tr>
<tr>
<td>Undergraduate GPA, mean (SE)</td>
<td>3.63 (0.02)</td>
</tr>
<tr>
<td>MCAT, mean (SE)</td>
<td>31.79 (0.26)</td>
</tr>
<tr>
<td>Step 1 USMLE score, Mean (SE)</td>
<td>229.56 (1.83)</td>
</tr>
</tbody>
</table>

GPA, grade point average; MCAT, medical college admission test; USMLE, United States medical licensing examination.
<table>
<thead>
<tr>
<th>Skill</th>
<th>Materials</th>
<th>Asynchronous Preparation for Simulation</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>USPIV</td>
<td>Ultrasound (SonoSite M-Turbo Model Number LI0523 or SonoSite S-Fast Model Number LI0722-06)</td>
<td>• High-quality online educational video on placing an USPIV selected by the investigators&lt;sup&gt;13&lt;/sup&gt;</td>
<td>• Script asked students to perform the task of placing an USPIV</td>
</tr>
<tr>
<td></td>
<td>Deep vein simulator (Blue Phantom 4 Vessel Block Model Number BPBV110)</td>
<td>• Five-question quiz</td>
<td>• Issues addressed: patient ID and consent, ultrasound use, IV insertion and security, IV tubing</td>
</tr>
<tr>
<td></td>
<td>Skin prep, IV catheter, ultrasound gel, nonsterile gloves, a short piece of IV tubing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BSLR</td>
<td>Basic laceration repair kit, suture material, personal protective equipment, irrigation equipment, sharps disposal containers, sterile and nonsterile gloves</td>
<td>• High-quality online educational video on BSLR selected by the investigators&lt;sup&gt;14&lt;/sup&gt;</td>
<td>• Script described a patient with a linear skin laceration that was ready to be evaluated and closed</td>
</tr>
<tr>
<td></td>
<td>Laceration model: a foam rubber skin model with a precreated linear laceration (SimSkin Suture Pad Model Number FS1211)</td>
<td>• Nine-question quiz</td>
<td>• Issues addressed: patient ID and consent; protective equipment; wound assessment, preparation, and closure; procedure note</td>
</tr>
<tr>
<td>CCs</td>
<td>Patient simulator with a built-in program to assess CC adequacy (Laerdal SimMan Simulator with Software Model Number 212-01101) including depth, rate, location, recoil</td>
<td>• Internally created instructional lecture including clips from an American Heart Association advanced cardiovascular life support instructional video</td>
<td>• Script asked students to perform the task of CCs during a code</td>
</tr>
<tr>
<td></td>
<td>Hospital bed with an available backboard nearby on the crash cart as well as a detachable headboard, which could serve as a backboard</td>
<td>• Five-question quiz</td>
<td>• Issues addressed: positioning and quality</td>
</tr>
<tr>
<td>BVM</td>
<td>Bag-valve mask, an oral airway, nonsterile gloves</td>
<td>• High-quality online educational video on BVM selected by the investigators&lt;sup&gt;15&lt;/sup&gt;</td>
<td>• Script asked students to perform the task of airway management during a code</td>
</tr>
<tr>
<td></td>
<td>Patient simulator (Laerdal SimMan Simulator with Software Model Number 212-01101)</td>
<td>• Five-question quiz</td>
<td>• Issues addressed: use of an oral airway and bag-valve mask</td>
</tr>
<tr>
<td>DM</td>
<td>Defibrillator and a patient simulator (Laerdal SimMan Simulator with Software Model Number 212-01101).</td>
<td>• Internally created video and provided instruction in the use of a defibrillator during both ventricular arrhythmias and A/PEA arrests</td>
<td>• Script asked students to perform the task of defibrillator use during a code</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Four-question quiz</td>
<td>• Assessed using shockable and nonshockable rhythms</td>
</tr>
<tr>
<td>CL</td>
<td>Defibrillator and a patient simulator (Laerdal SimMan Simulator with Software Model Number 212-01101).</td>
<td>• Internally created instructional lecture including clips from an American Heart Association ACLS instructional video.</td>
<td>• Script asked students to perform the task of team leader during a code</td>
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<tr>
<td></td>
<td></td>
<td>• Five-question quiz</td>
<td>• Issues addressed: task assignment, appropriate drug and defibrillator use, assessing possible causes</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Assessed using shockable and nonshockable rhythms</td>
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**FIGURE 1.** Overview of the SBML process.
sessions, they were intermittently observed and evaluated for quality and accuracy.

Statistical Analysis

Fleiss $k$ was used to compare agreement among multiple raters of students' performance while controlling for inflated type 1 error. Improvement on each clinical skill was assessed from pretest to posttest using the dependent samples $t$ test. Rosenthal effect size ($r$) was calculated to standardize and describe improvement from pretest to posttest. In addition, for students with available retention test, data comparisons were made from posttest to follow-up to detect
achievement decay using a repeated measures F test controlling for the number of days between posttest and retention test. The McNemar $\chi^2$ test was used to compare the proportion of students passing the cut score from pretest to posttest for each construct. All analyses were conducted using SAS software version 9.4 (Cary, NC) and SPSS software version 22 (Armonk, NY).

RESULTS

One hundred thirty-five medical students participated in the program. All students were welcome to participate in all portions of the training, although analysis was only done on the subset of students for which we had a complete dataset for each skill (Fig. 4).

Pretest to posttest core clinical skills showed significant improvement ($P < 0.001$, Table 3, Figs. 5A–H). Forty nine (36%) of 135 students were tested for retention at periods ranging from 1 to 9 months after the posttest with a mean (SE) time in days ranging from 117.56 (75.38) days for CL: P/A to 129.46 (74.17) days for CC. Five of these students did not reach MPS on their first attempt on 3 skills (1 BSLR, 1 DM: VT/VF, 3 DM: P/A). Considering the varying number of cases analyzed across all checklists (Table 3), ninety-eight percent of these students met or surpassed the MPS on the first attempt during retention testing. Of the 5 students who...
were not successful, an average of 4 minutes was needed to review the material and reach MPS on a second attempt. After controlling for time, there was no significant decrease in mean score for any of the 6 skills (8 checklists) between posttest and retention testing (Table 3, Figs. 5A–H).

**DISCUSSION**

We demonstrated that an SBML curriculum with a substantial asynchronous component could produce both immediate and lasting improvements in student performance on 6 core EM clinical skills.

Training to established mastery standards has been described in resident education with paracentesis, central lines, thoracentesis, lumbar puncture, and advanced cardiac life support.\(^{23-27}\) Attempts to incorporate SBML\(^ {28}\) into a clinical clerkship to address time and faculty availability have also been described. Our method allowed us to teach students to mastery standards while including an asynchronous portion, which gave students freedom to decide
when and how often to review material in alignment with adult learning principles (internal motivation, self-direction, goal orientation, pragmatic approach, social respect).29

The traditional method of clinical skill education has relied on ad hoc teaching opportunities that pose many problems including reliance on chance opportunities to perform procedures, unreliable skill measurement, inability to assess skill retention, uneven time commitment among attending physicians, and patient refusal to submit to unsupervised medical student practice.3,30 Several encounters using ad hoc training (“see one, do one, teach one”) are unlikely to result in a student becoming competent to perform and demonstrate clinical skills from start to finish. Mastery learning is especially appropriate in this era of criterion-based training under the paradigms of entrustable professional activities and milestones. Medical education is beginning to standardize clinical learning expectations, performance metrics, passing standards, and attempts to attest that upon successful completion, learners have demonstrated an ability to perform the procedure in question in a simulation laboratory. Successful performance in procedural simulation has increasingly been shown to correlate with similar performance in actual patient procedures when SBML training is employed.7,8

Several scales have been developed that emphasize change in outcomes or behaviors over an increase in knowledge to improve the quality and generalizability of medical education research.31 The Kirkpatrick scale places behavioral change above acquisition of knowledge/skills and learning.32 We find this to be a compelling framework to understand and design medical education research. We believe that our EMC program has the following 4 novel parts: (a) a group of emergency procedural skills rather than a single skill; (b) involving a portion of asynchronous training with the SBML interventions; (c) the introduction and feasibility of an assessment of retention rather than a mere pretest/posttest model; and (d) support for the utility of substituting physician instructors with paramedic instructors to reduce the labor-intensive demands of a traditional, instructor-centered format on practicing physicians.

Retention is a critical part of skill training. Simulation has been shown to produce stable results in residents in skills such as central line placement, cricothyrotomy performance, difficult airway management, management of shoulder dystocia, advanced cardiac life support skills, and team resource management.33–38 There are also data that not all simulation-based procedural training produces lasting results.39 We found that our particular curriculum achieved lasting results by retention testing that was unannounced and unexpected. Although this is not at the level of translational patient outcomes, it does suggest that an enduring effect of this programmatic intervention extends beyond the original clerkship.

Our study has several limitations. This study was performed in a single center and we did not include a control group.11,12 Our posttesting immediately followed our deliberate practice skill training, and although we were able to later demonstrate skill retention, it was limited to a cohort of convenience from our original student group. Further work is needed to assess stability of these educational interventions. Because our educational intervention was set up as a package, it is difficult to say whether the asynchronous or synchronous interventions caused the results. A future study showing comparative effectiveness may be considered. In addition, it would be interesting to study the impact of these methods on skill transfer to a dynamic environment, particularly for the cardiac arrest–related skills.

**CONCLUSIONS**

Simulation-based mastery learning is an effective way for senior medical students to learn and retain EM clinical skills, even when one third of the SBML program is asynchronous. Incorporation of an asynchronous portion into SBML maintains the rigor of mastery training while allowing students freedom to decide when and how often to review the asynchronous material. These SBML methods seem adaptable to multiple skills needed for the development and demonstration of residency readiness by students.

**REFERENCES**


