Although multiple simulators have been validated as effective training tools, curriculum development is lagging, and considerable work is needed to determine the best methods for training. This article identifies the factors that influence the successful incorporation of simulator training into the resident curriculum, reviews the evidence regarding laparoscopic curriculum development in the surgical literature, and provides a formula for effective curriculum design. A successful laparoscopic skills curriculum depends on many factors including participant motivation, available resources and personnel, and trainee and faculty commitment. It should encompass goal-oriented training, sensitive and objective performance metrics, appropriate methods of instruction and feedback, deliberate, distributed, and variable practice, an amount of overtraining, maintenance training, and a cognitive component. A curriculum that follows these principles is likely to spark trainee interest, ensure their satisfaction and participation in training sessions, and lead to an effective and efficient way of acquiring new skills using simulators. A skills curriculum is a dynamic process that should be tailored to individual needs and be continuously optimized based on accumulated evidence and experience.

Arch Surg. 2009;144(1):77-82

Evidence of the educational value of simulators for surgical training is accumulating rapidly\(^1\)-\(^5\); however, most surgical training programs struggle to incorporate them into their residency curricula.\(^6\),\(^7\) Although multiple simulators have been validated as effective training tools,\(^1\),\(^2\) curriculum development is lagging, and considerable work is needed to determine the best methods for training. Realizing the importance of a structured curriculum for simulator training, the Association of Program Directors in Surgery, in collaboration with the American College of Surgeons and the American Board of Surgery, recently released a national curriculum for the teaching and mastery of surgical skills for use by residency programs.\(^8\)

In addition to a structured skills curriculum, many other factors influence the successful incorporation of simulator training into the residency curriculum.\(^9\) It is not surprising that after the acquisition of surgical simulators for resident training, many surgery programs encounter difficulties incorporating them into their curriculum.

See Invited Critique at end of article

This article aims to identify the factors that influence the successful incorporation of simulator training into the resident curriculum, explore the evidence regarding laparoscopic curriculum development in the surgical literature, and provide a formula for effective curriculum design.

WHAT IS NEEDED FOR SIMULATOR TRAINING TO WORK

Many factors affect the successful incorporation of simulator training into the surgical curriculum. One of the most important...
is trainee motivation. Trainee motivation is essential for learning because it fuels participation in training sessions and ensures deliberate practice and persistent efforts to improve performance.\textsuperscript{10,11} Without motivated learners, any educational intervention will have limited success and skills laboratories will be attended infrequently.

Motivation can be either internal or external.\textsuperscript{10} Internal motivation is a prerequisite for learning, but is unique to each individual and may be impossible to modify. External motivation, which refers to interventions aimed at modifying behavior and characterizes all aspects of our daily lives, may effectively produce the desired outcome of a training intervention. However, external factors can also affect trainee motivation negatively, and should therefore be carefully evaluated before skills training implementation. In the case of surgical residents, fatigue, long working hours, limited free time, interference with clinical responsibilities, and operating room experience can all negatively affect a trainee's motivation to participate in a skills curriculum. Moreover, accumulating operative experience may render training for similar tasks or procedures on inanimate models less stimulating for senior residents. These factors make voluntary participation, which relies mainly on the internal motivation of trainees, unlikely to succeed.\textsuperscript{12-14} In a study by Chang et al,\textsuperscript{12} resident participation in a skills curriculum in a busy residency program was only 14%, and the authors concluded that participation should be mandatory. In our institution, attendance rates jumped from 6% to 71% when time was dedicated specifically to skills training and supervising personnel were hired.\textsuperscript{14} These studies highlight the importance of external motivation. Residents can be motivated to attend training sessions by mandating participation or by introducing punitive measures when attendance is low. Scheduling mandatory training sessions at consistent, predetermined hours that are known to both trainees and faculty, much like the scheduling of morbidity and mortality conferences or grand rounds, is an effective strategy.\textsuperscript{2} Moreover, setting performance requirements on simulators before operating room participation is allowed and encouraging healthy competition among residents by introducing awards for good attendance and performance can also be helpful.

Another important factor for a successful simulator curriculum is the availability of dedicated personnel and appropriate resources. Simulation centers must have the financial resources to ensure their long-term continuation.\textsuperscript{2} It is paramount that skills curricula be built on appropriately validated simulators and that skills laboratories be well equipped and offer training variability to maintain participant interest and maximize trainee benefit.

The availability of ample space is important because it allows more residents to train concurrently and makes the scheduling of sessions more flexible. It can also facilitate the organization of large departmental skills courses and the training of outside participants.

Even more important than space and resources, however, is dedicated personnel who can schedule sessions, provide instruction and performance feedback during training, monitor progress, carry out research studies, troubleshoot equipment, order supplies, and, in essence, ensure the smooth operation of the center. Without dedicated personnel, a skills laboratory is unlikely to be successful. It is not surprising that the certification criteria for Educational Institutes set by the American College of Surgeons have specific requirements for space and dedicated personnel.\textsuperscript{15} Nevertheless, recent studies have demonstrated that equipment and training practices vary broadly in skills laboratories in US residency programs. A recent study demonstrated that only 55% of 162 US surgery training programs surveyed had skills laboratories, with widely ranging setup costs ($300-$1 000 000), and only 73% of those offered supervised training to their residents.\textsuperscript{5} Faculty commitment and support should not be overlooked. The attending surgeons must believe in the importance of the skills curriculum and support resident participation by allowing residents to leave the clinic or be absent from the operating room during scheduled training sessions. The skills curriculum director and the program director or chairman should encourage other faculty to teach with simulation equipment and to help create a comprehensive and challenging curriculum.

**CURRICULUM**

In addition to the factors that contribute to the success of skills centers, the most important contributor to resident learning is the simulator curriculum. A number of publications have demonstrated the importance of structured skills curricula for the acquisition of a variety of laparoscopic techniques.\textsuperscript{5,16-19}

A simulator skills curriculum should incorporate a cognitive component as the first critical step for surgical skill acquisition.\textsuperscript{20} Didactic sessions should accompany manual skills training on simulators to provide learners with the required knowledge and to improve their understanding of the task or procedure they are learning. Moreover, the direct application of knowledge into practice may significantly improve the retention of this information compared with didactics alone. Realizing the importance of an accompanying cognitive component to manual skills training, the Society of American Gastrointestinal and Endoscopic Surgeons–American College of Surgeons–endorsed Fundamentals of Laparoscopic Surgery education module includes CD-ROM–based material on the physiology and fundamental knowledge of basic laparoscopy in addition to the 5 basic laparoscopic manual tasks.\textsuperscript{21} Furthermore, the 20 new modules of the American College of Surgeons/Association of Program Directors in Surgery national skills curriculum also include a cognitive component.\textsuperscript{8} Thus, a laparoscopic skills curriculum should incorporate procedural video tutorials and reading material that will put the manual skill acquisition into context, improve the knowledge of trainees, and motivate them to work harder on their skills. On a practical note, laparoscopic textbooks and well-chosen journal articles, along with the Fundamentals of Laparoscopic Surgery CD-ROM and procedural videos that may be available at a local level or can be obtained from national organizations, can be used for resident teaching.

A specific component of the cognitive elements of a simulator curriculum is the instruction and demonstra-
tion of the motor skills to be acquired. It is well documented that effective instruction facilitates skill acquisition and leads to superior learning of trainees, whereas inappropriate instruction and demonstration may have a negative effect on performance. Video-based education has proved effective for the acquisition and retention of simulator-acquired skill. Rosser et al demonstrated that a CD-ROM tutorial on laparoscopic suturing performed this task significantly better than those who did not watch it. Recently, Xeroulis et al demonstrated that computer-based video instruction was as effective as expert feedback for the retention of simulator-acquired suturing and knot-tying skill. In our experience, frequent video tutorial viewings during simulator training showed a trend toward faster achievement of proficiency. Thus, task demonstration should be one of the first steps of simulator training and video tutorials should be used liberally to provide effective instruction to trainees, which will minimize the need and expense of expert instructor involvement. The new national skills curriculum incorporates a number of instructional videos that can be used by residency programs, but additional videos can also be easily created at a local level.

In the literature, feedback refers to the return of performance-related information to the performer and consists of intrinsic and extrinsic or augmented feedback. Intrinsic feedback is directly available to the sensory system of the performer, ie, the visual, auditory, or haptic perceptions during the performance of tasks. Extrinsic or augmented feedback is provided by an external source and aims to augment intrinsic feedback. Augmented feedback facilitates achievement of the action goal and motivates learners to continue to strive for the achievement of that goal. In medical education, feedback has been defined as an informed nonevaluative appraisal of performance by the teacher and aims to reinforce strengths and foster improvements in the learner by highlighting the differences between the intended and the actual results of the actions. Indeed, improved performance owing to augmented feedback has been demonstrated during simulator training, but inappropriate feedback may also have deleterious effects on skill acquisition. In a recent study, intense continuous external feedback during simulator training impaired acquisition of laparoscopic suturing skills compared with limited intermittent feedback provided after task completion. Furthermore, summary expert feedback after training sessions has resulted in better skill retention compared with concurrent feedback, but expert verbal feedback has been shown to be more effective than motion efficiency feedback. Performance feedback is thus essential for skill acquisition and retention during simulator training, and laboratory coordinators and faculty should devote time to observation of trainees during practice to provide them with feedback at the end of the training session on how to improve their performance.

For improved motor skill acquisition, a successful skills curriculum should set training goals that motivate learners by providing a performance target. Proficiency-based simulator curricula set training goals based on expert-derived performance, tailor the training to individual needs, and have been demonstrated to produce uniform skill and improve operating room performance. Several authors have highlighted the advantages of proficiency-based training and the limitations of traditional time-based training (Figure 1). While one study failed to demonstrate significant performance differences in the animal operating room between a goal-directed simulator-trained group and a self-directed group, additional study of better quality is needed to establish the advantages of proficiency-based training. Nevertheless, such training is limited by our incomplete understanding of surgical expertise. Who is the appropriate expert from whom to derive performance goals? How many experts are needed to create reliable goals? How many times should trainees perform the task at the expert level to have truly reached proficiency? Should we even use expert performance as a training goal or are there other more suitable methods? Are the available metrics the most appropriate for performance assessment and sensitive enough to distinguish subtle performance differences? If we do not understand who is truly an expert in a task, and if our metrics cannot capture subtle but important performance differences, the goals set for novices may be flawed and thus their learning may be incomplete. The traditional metrics of speed and accuracy used by most proficiency-based curricula may not be ideal for the measurement of superior performance, as they provide little or no information about what effort the performer invested or how much learning has occurred. Even motion-tracking metrics, which have proved valid for performance assessment on simulators and in the operating room, have similar limitations. While 2 individuals may perform similarly based on speed, accuracy, and motion metrics, they may experience substantial differences in workload and attentional demands, which reflect differences in experience, true skill level, and learning. Importantly, incomplete metrics may impair the ability of simulators to confer the maximal skill to trainees. In a prior study, a visual-spatial secondary task that measured the spare attentional capacity of the performer proved more sensitive in de-

![Figure 1](https://archsurg.jamanetwork.com/)

**Figure 1.** The typical learning characteristics of different individuals during simulation training. Each trainee (solid line) achieves the expert-derived performance goal at different training durations. When the training duration is chosen arbitrarily (dashed line, arrow), some trainees will not have achieved the desired performance level and others will have trained for too long. Given the variability of individual skill acquisition rates, time-based curricula prevent some trainees from reaching the desired skill level, while others train longer than needed.
tecting superior performance differences than the traditional metrics of speed and accuracy. Thus, incorporating these new metrics of automaticity into simulator training may help to better define and assess performance; this may have a considerable positive effect on trainee skill acquisition and learning. Such metrics may also help us determine the appropriate simulator training duration. Currently, most proficiency-based curricula require that trainees reach the proficiency level 2 consecutive times, an arbitrary amount of overtraining. Overtraining refers to the amount of additional training after initial proficiency is achieved that can positively affect trainee skill and learning. \(^{10}\) Because excessive training can lead to skill degradation, \(^{10}\) secondary task metrics may help quantify the amount of overtraining required to maximize learning by identifying the point of training where learning is complete. In a recent study, \(^{49}\) the application of automaticity metrics led to longer training duration of novices compared with the traditional metrics of speed and accuracy. On a practical note, expert-derived performance goals on the chosen tasks of the available simulators should be established and provided to residents as training goals. Such goals that are usually based on speed and accuracy/errors (+motion metrics) can be found in the literature for most laparoscopic simulators, but could also be established using local experts and previously described methods. \(^{14,50,51}\) In addition, trainees should be required to achieve these goals on consecutive attempts (2 are used by most authors) \(^{32,37}\) and perform a number of additional repetitions (5-10) for reinforcement. As mentioned, these requirements need further study, and additional metrics may be needed for optimal performance assessment.

Deliberate, repetitive practice is essential for performance improvement \(^{11}\) and should be an integral component of a skills curriculum. Another important factor is practice distribution. Distributed practice (multiple training sessions) has been demonstrated to lead to better skill acquisition compared with massed practice (all training occurs in one training session). \(^{11}\) Moulton et al \(^{52}\) demonstrated in a randomized controlled trial that residents retain and transfer simulator-acquired skills better if taught in a distributed rather than massed manner. Little is known about the optimal duration of and the interval between training sessions. Expert opinion suggests that 1-hour training sessions may be best, \(^{12}\) but no high-quality evidence exists. From a practical standpoint, weekly 1-hour sessions may be best suited for resident training. Such a schedule provides ample opportunity for training and rest time between sessions, is easy to organize, and is unlikely to interfere with the busy schedule of the house officer.

An important and frequently overlooked aspect of simulator training is the retention of acquired skill. Evidence suggests that simulator-acquired skill deteriorates over time without ongoing practice. \(^{37,39}\) A recent study showed that novices who trained at regular intervals after achieving initial proficiency maintained more of their skill 6 months later than those who had no ongoing training. \(^{37}\) Maintenance training should thus be part of all simulator curricula and can be accomplished by scheduling testing/training sessions every 1 to 3 months after initial proficiency is achieved. Evidence of significant skill deterioration between retention sessions should lead to the reinstatement of weekly training.

Because proficiency-based simulator curricula have variable lengths depending on individual performance differences, the ability to predict training duration enables educators to better plan training sessions so that every trainee can achieve proficiency within the confines of the academic year. A number of baseline tests have been shown to correlate with the training duration of a proficiency-based simulator curriculum. \(^{53,54}\) Using this information may help identify slow learners early in the training process so they can undergo more intense training and complete the curriculum in the required time. \(^{51}\) Testing at baseline and at the end of the curriculum combined with performance monitoring during training can help boost trainees’ motivation by enabling them to track improvements in their performance. \(^{38}\) It also helps instructors document participant progress, adjust the curriculum, and obtain useful information for future curriculum improvement and research. Thus, training should be tailored to individual needs based on baseline performance.

Practice variability and increasing levels of training difficulty have also been shown to improve the retention and transfer of simulator-acquired skill \(^{55,56}\) by challenging trainees, increasing the contextual interference of training, and promoting the development of different learning strategies. \(^{57}\) A recent systematic review of the effect of high-fidelity medical simulations on learning reported that learning was enhanced when trainees practiced with progressively increasing levels of difficulty. \(^{55}\) Similar findings were reported by Ali et al \(^{48}\) and Aggarwal et al \(^{19}\) for laparoscopic simulator training. We have previously demonstrated that training in laparoscopic suturing under more difficult simulator conditions led to improved performance on the simulator but not in the animal operating room. \(^{33}\) Skills curriculum should thus include many tasks, variability of practice, and training of increasing difficulty. Furthermore, the curriculum should be adjusted to the level of training by fostering basic skills for the junior residents and should become more challenging for the seniors. Along these lines, junior resi-

![Figure 2](https://archsurg.jamanetwork.com/)
...dents should start with basic laparoscopic skill training and advance to complex laparoscopic procedural training over the ensuing years.

Mental imagery, the mental rehearsal of a skill before it is practiced, appears to be effective as a practice strategy to facilitate the learning and relearning of motor skills and can be used as a preparation strategy for well-learned skills.10 Its application to simulator training may prove valuable.59

In summary, a successful laparoscopic skills curriculum depends on many factors including participant motivation, available resources and personnel, and trainee and faculty commitment. It should encompass goal-oriented training, sensitive performance metrics, appropriate methods of instruction and feedback, deliberate, distributed, and variable practice, an amount of overtraining, maintenance training, and a cognitive component (Figure 2). A curriculum that follows these principles is likely to spark trainee interest, ensure participation and satisfaction, and lead to an effective and efficient way of acquiring new skills using simulators. While a best formula for a simulator curriculum may not exist, a skills curriculum is a dynamic process that should be in constant evolution based on accumulated experiences. Furthermore, a skills curriculum should have plasticity and should be tailored to the individual training needs rather than be inflexible and insensitive to individual learning differences. Our experience with the practical application of these principles to the resident curriculum has recently been published elsewhere.14

Accepted for Publication: December 11, 2007.

Correspondence: Dimitrios Stefanidis, MD, PhD, Department of General Surgery, Carolinas Medical Center, 1000 Blythe Blvd, MEB 601, Charlotte, NC 28203 (dimitrios.stefanidis@carolinashs healthcare.org).

Author Contributions: Study concept and design: Stefanidis and Heniford. Drafting of the manuscript: Stefanidis. Critical revision of the manuscript for important intellectual content: Heniford. Study supervision: Heniford.

Financial Disclosure: None reported.

REFERENCES


S

tefanidis and Heniford have provided a wonderful formula for educational leaders to design a comprehensive skills laboratory curriculum that is fully integrated into the residency training program. They emphasize the importance of trainee motivation and mandatory attendance, available resources and personnel, faculty commitment and participation, appropriate performance metrics, well-designed instruction with a cognitive component, and practice that is deliberate, distributed, and variable.

Trainee and faculty commitment are perhaps the most important ingredients to ensure that this formula transitions skills laboratory training into a routine part of the educational culture. There is little chance of this cultural change without support from departmental leadership and broad faculty participation, and an academic incentive program can further encourage and reward faculty participation in this teaching activity. The American College of Surgeons/Association of Program Directors in Surgery Skills Curriculum includes a series of Verification of Proficiency modules developed to accomplish the task of verification of proficiency prior to performance in the operating room using faculty review of videotaped performances.

My only concern with this excellent review is its focus on a laparoscopic skills curriculum and simulator training. While laparoscopic surgery may have been an early stimulant to the skills laboratory movement, it is now critical that programs incorporate training in basic surgical skills as well as advanced open procedures. There are a wide range of alternatives to simulators or virtual reality devices that are effective in this training such as cadavers, porcine organs, and less expensive plastic models.

In time, incorporation of these key principles into a skills laboratory program will transition into a rich educational culture where trainees cannot imagine acquiring surgical skills in the absence of a skills laboratory.

Gary Dunnington, MD

Correspondence: Dr Dunnington, Southern Illinois University, Department of Surgery, PO Box 19638, Springfield, IL 62794 (gdunnington@siuimed.edu).

Financial Disclosure: None reported.