Framework for Systematic Training and Assessment of Technical Skills

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The purpose of training programs for all medical specialities is to produce competent individuals who are able to meet the health-care needs of society. Recent editorials have commented on the crisis in medical education and the requirement for defined competencies to assess performance before new physicians begin independent medical practice.[1,2] Effective since July 2002, the Accreditation Council for Graduate Medical Education (ACGME) listed 6 categories of competence, defined as the ACGME Outcomes Project (Table 1).[3]

This article does not address the specific need for demonstration of proficiency in technical skills. This is not an issue for the surgical specialities only but also for physicians training in cardiology, anaesthesiology, gastrointestinal medicine, chest medicine, and interventional radiology, together with allied health specialists. The introduction of new techniques and instruments to these specialities requires training of not just residents, but also of independent practitioners. This was clearly evident with the increased rate of complications associated with the introduction of laparoscopic cholecystectomy and has led to the development of training programs at many centers around the globe.[4,5]

Although there is a transfer of skills to the trainee, current training programs have not been designed from a background of scientific research to ensure the curriculum is valid, efficient, and competency based. The aim of a surgical residency program is to produce competent professionals, displaying the cognitive, technical, and personal skills required to meet the needs of society. Within the context of surgical procedures, patients can expect satisfactory outcomes in terms of cure, complication rates, and return to daily activities. Technical proficiency is paramount to the delivery of such outcomes, and substandard performance must be recognized, enabling review and possible modification of the training program.

To become technically proficient in any procedure, it is necessary to develop a strategy that can enable identification and mastery of the skills associated with that procedure. A hierarchic, task-based approach can be used to break the procedure into its constituent parts and develop a systematic strategy for learning the required skills.[6] It is also possible, within such a framework, to identify key tasks that are integral to the procedure and form the basis of an assessment process.[7,8] The model can provide a standardized program of training, commencing in a skills laboratory and progressing into the operating room, underpinned by the notion of a systematic approach to training and assessment.[9]

METHODS

A literature search was performed on PubMed and Medline from their inception to the present for all English-language articles using the following Medical Subject Headings (MeSH): education; professional; curriculum; clinical competence; teaching; and keywords *skills, assessment,* and *simulation*. The following educational and nursing databases were also searched for relevant articles: the Education Resources Information Centre (www.eric.ed.gov) database, the Cumulative Index to Nursing and Allied Health Literature (CINAHL), and the British Nursing Database (BNI), using the same MeSH headings as for the initial search.

Additional articles were obtained from references within papers identified by the initial search, in addition to articles from the authors' experience and by discussion with other experts in the field of medical education.

Knowledge-based learning

A systematic approach to learning begins with the acquisition of procedure-specific knowledge. These have been broadly (and arbitrarily) defined into the categories of preprocedure assessment, and preparation, anatomic

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Table 1. Core Competencies for the Accreditation Council for Graduate Medical Education Outcomes Project[3]

Competency
Patient care
Medical knowledge
Practice-based learning
Interpersonal and communication skills
Professionalism
Systems-based practice

knowledge, safety and limitations of specific instruments, ergonomics, and postprocedure management. Within this mode of learning, it is crucial to teach likely errors that can occur during an operative procedure, enabling trainees to anticipate and avoid errors, or to identify when errors have been committed, along with strategies to manage them.[10] The knowledge requirements for each of these categories can be defined by a consensus group of experienced surgeons. These must be studied by the trainee before technical skills training and should be followed by satisfactory performance on a paper-based test of knowledge, such as those required for membership in any of the Royal Colleges in the United Kingdom.

But the reality of how one learns is far removed from the simplistic notion of acquiring procedure-specific knowledge. Learning and educational theories have been proposed in an attempt to make students learn more effectively.[11] For example, Ausubel and colleagues[12] stated that the "most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly." There are few who would argue with this concept, and, indeed, a structured, hierarchical approach to learning that builds on past knowledge is the basis of the apprenticeship model of training, popularized by Halstead at the end of the 19th century.[13]

Kolb[14] defined the experiential learning cycle, enabling a learner to reflect on his own experience and develop a theoretic understanding of it that can be applied to new situations, providing additional opportunities for experience and reflection. This model appreciates the intuitive nature of medical practice and the importance of defining otherwise hidden theories of action. But it is well known in medicine, especially during technical tasks, that the underlying mechanisms of performing a skilled procedure are a mystery even to the experienced operator.[15] For an experienced surgeon, tying a surgical knot is "easier done than said." To teach an inexperienced trainee to perform a procedure necessitates a rigorous mechanism for elucidation of the steps of the procedure, which are then taught in a structured manner.

In just this manner, Fitts and Posner[16] described a three-stage theory of motor skill acquisition. During the first stage (cognition), the trainee gains an understanding of the task through instructor explanation and demonstration and performs steps in a distinct manner. In the second stage (association), the user practices the task to eliminate error, with the instructor providing feedback to identify errors and suggest corrective actions. The final phase (automation) occurs when the learner performs the tasks in a relatively automated fashion, with little or no cognitive input. Within a surgical training program, basic skills should be trained to an automated (or proficient) level within the skills laboratory, enabling the trainee to focus on more complex issues within the operating room. When the student has acquired the basic ingredients of a technical specialty, experiential learning should enable application of this knowledge to new situations.

Training to the automated phase with associative experiential learning leads to competence but rarely to expertise. Ericsson[17] described the notion of deliberate practice as a critical process for development and maintenance of mastery or expertise. The focus is on selection of a defined task to improve overall performance through repeated practice and supportive feedback. Time devoted to deliberate practice has been shown to relate to attained levels of expertise in other high-performance domains, ie, expert chess playing, music, and athletics. Within a surgical context, operative procedures are complex, and it is much more manageable to focus on a specific part of a procedure for further training. In addition, Ericsson emphasized the role of life-long learning to ensure maintenance of expertise.

One of the key principles of effective learning for professional education is to ensure contextualization of the task in hand. For basic skills training, an important, though declining, issue is poor motivation to learn on bench-top models.[18] A recent survey of general surgery program directors reported that 88% consider skills laboratories an effective way to improve operating room performance.[19] Nonetheless, during laparoscopic skills training, it may be difficult for the learner to grasp the clinical relevance of transferring chick peas from one pot to another. It may be necessary to begin in a concrete

Table 2. Operational Definitions of Surgical Steps in Nissen Fundoplication[22]

Surgical steps	Beginning	End
1. Prepare patient	Moment the insufflation needle contacts abdomen	Liver in place and liver elevator is stable
2. Divide peritoneum	Moment the tool moves toward the peritoneum to be cut	Last cut of peritoneum
3. Expose crura and gastroesophageal junction	Last cut of peritoneum	Last cut of tissue and when scissors are removed
4. Repair crura	Moment the endostitch contacts abdomen	Completion of cut suture and removal of endostitch
5. Divide short gastrics	Moment scalpel contacts abdomen	Last cut and scalpel removed
6. Wrap fundus	Moment esophageal elevator contacts abdomen	Completion of last suture—endostitch is removed
7. Close	When endostitch is removed	Completion of last open suture

manner by providing trainees with relevant first-hand experiences of surgical practice, before presenting conceptual tasks.[20]

Task deconstruction of a procedure

To develop a systematic approach to technical skills training, it is necessary to fragment a procedure into its constituent parts. The ideal manner in which to do this is through observation of a complete procedure. But different strategies are regularly used by different operators, so it is necessary to observe procedures performed by a number of experienced clinicians. This can be achieved through video-based recording of the procedure, and then by dividing the procedure into steps and substeps. Task decomposition of laparoscopic cholecystectomy and Nissen fundoplication have been published, and work is ongoing in our department to develop similar breakdowns of other common surgical procedures such as hernia repair, saphenofemoral junction dissection, and appendectomy.[21,22]

Ideally, the procedure is fragmented into 6 to 10 tasks, as shown in Table 2 for the surgical steps of Nissen fundoplication.[22] Each task should have a clear and unambiguous start point and end point. For example, step 6, "wrap fundus," begins with "moment esophageal elevator contacts abdomen" and ends at "completion of last suture—endostitch is removed." Further hierarchical task decomposition may be performed, as detailed in the article, down to the level of "position jaws," "bite tissue," "pull needle through," and so on.

In the realms of developing a simplified curriculum for procedure-based training, task decomposition should be focused on division into the first two levels of steps and substeps. By recording videos of inexperienced operators performing the same procedure, and comparing performance at each stage with that of expert surgeons, it is possible to define the most challenging parts of the procedure. Payandeh and associates[8] adopted a task-based approach to assess performance of intracorporeal suturing techniques by expert and novice laparoscopic surgeons on a bench-top model. The task was divided into seven steps, and the time taken for each subject to complete the step was recorded. Compared with expert surgeons, novices took longer, on average, to complete all subtasks. A statistical analysis was not presented, although the chart of the timelines revealed much greater differences between novices and experts in two of the seven tasks, namely, positioning and repositioning of the needle (Fig. 1). It may be inferred from this result that these are the two most challenging steps to master, and acquisition of technical skill to expert levels in these two steps would enable a trainee to perform the entire task in a time similar to that of the expert surgeon.

Using the methodology of this study, it is possible to define the most challenging tasks of any procedure. But time alone should not be the basis for definition of procedural competence, and objective assessment using dexterity measures and rating scales should be used to provide more information about the differential performance of experienced and novice operators.[23] Expertise in key tasks can then be compared with overall procedural performance, and correlations calculated using the same assessment measures for both task and procedural performance.

In a recent article by Beard and coworkers,[24] 33 general surgical trainees undertook 5 simple skill simulations on synthetic models (knotting, skin incision and

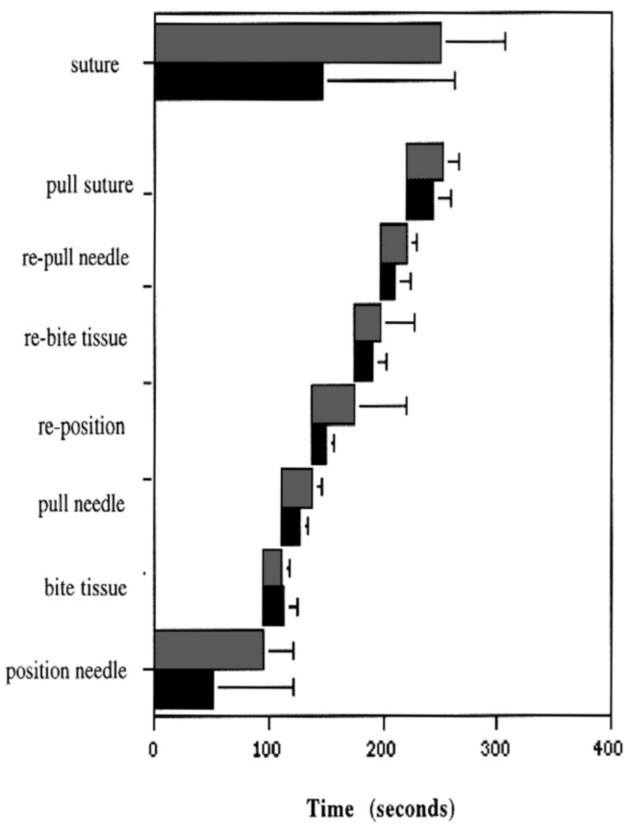

Figure 1. Timeline for suturing task and the subtask components. Gray bar, novice; black bar, expert. (From: Payandeh S, Lomax AJ, Dill J, et al. On defining metrics for assessing laparoscopic surgical skills in a virtual training environment. Stud Health Technol Inform 2002;85:334–340, with permission.)

suturing, tissue dissection, vessel ligation, and small bowel anastomosis) and then had an operative competence assessment during real saphenofemoral disconnection procedures. Two of the skills, dissection and ligation, and number of previous procedures performed, were reported to be the best predictors of operative competence. This study highlights the importance of predictive validity when training on a simulated model and suggests that task deconstruction of operations is a suitable method for both training and assessment of trainee doctors.

Acquisition of basic skills, such as suturing and knot tying, is fundamental before progressing on to more complex tasks. In the surgical skills laboratory, these tasks are taught in a context-free manner, though in real situations, procedure-specific knowledge (and practice) may be necessary to enable the trainee to modify the task accordingly. This underlines both the experiential model of learning and the notion of deliberate practice, as previously described.[14,17] The aim is not to try to produce expert surgeons solely through simulation-based training, but rather to arm trainees with a basic semblance of surgical skill before they enter the operating theater, subsequently shortening the time taken to achieve satisfactory outcomes within the clinical environment.

Training in a laboratory environment

Once the key tasks of a real procedure have been identified, it is necessary to develop a suitable model for training. The ideal platform for training may be said to be the patient, although this can be problematic for learning new skills. Training on patients occurs through chance encounters, rather than along a structured and stepwise mode of progression. It is often difficult to predict the intraoperative complexity of a procedure, leading to “take over” by the senior surgeon and the loss of a hands-on training opportunity. Patient safety is, of course, the most important factor when acquiring or honing skills in the operating room; the skills laboratory enables primacy of the trainees’ goals, regardless of complication or error. In addition, specific tasks can be repeated over and over again, with time available during the session to stop for discussion, feedback, or evaluation, until proficiency is achieved. Although training within the operating room is a necessary part of surgical education, the aim is to reduce the length of the learning curve so that surgical novices are not subjected to the acquisition of new skills through practice on patients. The development of technical skills laboratories and advancements in simulation technology can allow trainees to learn the skills required in a safe environment on standardized models, which can then transfer to improved performance in the real environment.[25-29]

Models for laboratory-based training

The models to be used may be synthetic, cadaveric, live animal tissue, or computer based. The choice of model type is defined by the design of the curriculum, which, in turn, is driven by the objectives of training; the best fit for the curriculum secondarily depends on what is available and affordable. For example, abstract tasks such as chick pea transfer or peeling a grape are adequate to teach basic hand-eye coordination for laparoscopic surgery, but procedure-specific tasks may benefit from the use of more realistic animal or human cadaveric models.

Synthetic models are relatively cheap, easy to use and store, and can teach the skills required for mastery of a wide variety of technical skills such as suturing, central venous catheter placement, and episiotomy repair. Synthetic models also exist for training of simple surgical procedures such as hernia repair, appendectomy, cholecystectomy, and Nissen fundoplication.[30] But they have been criticized for a lack of tissue realism and problems with contextualization of the full procedure.[9]

Animal tissue can provide a greater sense of realism for training in technical skills, but it needs specialized storage and handling.[31] Cadaveric animal tissue has greater fidelity than synthetic models and can allow trainees to learn the skills required in a classroom environment. Anesthetized animals can also be used to teach the skills required to perform a complete procedure, although this form of training is illegal in the United Kingdom.[32] Simulation can also cause problems because of differences in anatomic configurations of the animal; an example is the lack of a mesenteric attachment of the sigmoid colon in a porcine model.

Training by using virtual reality simulation is currently expanding, and encompasses systems to teach laparoscopic, endoscopic, and percutaneous interventional techniques.[33] The models are standardized and, after the initial outlay cost, are relatively cheap to maintain. An additional advantage of virtual reality simulation is the built-in and automated feature of objective assessment, providing data on parameters such as number of errors, instrument path length, and quality of the procedure performed. During a simulated coronary catheterization, it is possible to provide data on the extent of the lesion traversed with the stent, or, for colonoscopy, the percentage of red-out time, ie, the time that the endoscope tip is pressed against the wall of the colon, so is not performing a useful function.

Decisions about which simulation modality to use depend on the intended outcomes of the training curriculum, as previously described. The fidelity of synthetic, animal, and virtual reality models is also variable, and the general, though unvalidated, consensus has been to use the highest fidelity possible. But a recent article by Grober and coworkers[18] has called into question the need to train on the highest fidelity models available, with equivalence of learning on synthetic and anesthetized rat models for spermatic cord microanastomoses.

Validation of simulated models

It is both time consuming and expensive to simulate an entire procedure, and, indeed, for acquisition of technical skills, it may not be necessary to do this to achieve the desired goals. But the notion of developing key tasks for a procedure must have a scientific base. It is necessary to demonstrate the construct validity of such models, ie, that one is measuring the trait that one purports to measure, and this can be inferred by comparison of novice, intermediate, and expert performances on the key tasks, assessed by time taken and other measures such as dexterity and error scores.[21,34,35] The metrics from the model must display significant statistical differences in performance between the three subject groups to be able to confirm a measurable learning process when used for training.

Validation of the simulated models involves not only the physical model used but also the assessment parameters used to differentiate between the three groups of practitioners. Assessment of technical skill must be objective, reliable, and easy to perform. Current systems for this type of assessment can be divided into dexterity-based and video-analysis systems.[36] Dexterity-based systems record parameters such as time taken, path length, number of movements, and trajectories of the hand or instrument tip. Video analysis provides a qualitative method of assessment, but quantification of performance through definition of correct steps and errors, although labor intensive, is a powerful mode of both formative and summative assessment.[21]

Dexterity analysis is generic, but video-based analysis can be used in a procedure-specific manner to ensure the key steps are completed to a satisfactory level with minimal occurrence of error. This entails development of a procedure-specific scale, which is an amalgamation of the steps, substeps, tasks, and subtasks of the procedure.[37] The level of technical skills assessment depends on whether it is the procedure or key task that is being assessed.

A framework of key task definitions can also enable institutions and commercial companies involved in developing models for surgical skills training to direct efforts toward simulation of particular tasks, rather than procedure-based simulation models, which inevitably take longer to develop and tend to be more expensive. Additional research may be able to define common key tasks between different procedures, and enable the trainee to learn the skills required to perform more than one procedure.

Transfer of skills to the real environment

It is essential to confirm that skills improve when training on a particular task, but it is also necessary to ensure that achievement of expert performance on the one or two key tasks will lead to proficiency at performing the entire procedure on a real patient. In this case, the learning curve for achieving procedural proficiency on a patient should be primarily a function of the knowledge required to integrate the technical skills learned from training in the laboratory environment.

Transfer of skills from the laboratory environment to real scenarios has been demonstrated for laparoscopic cholecystectomy and gastrointestinal endoscopy, although one of the main obstacles has been which tools to use for assessment of real procedures.[25,27-29] The same measures developed for assessment in the laboratory environment could be used, and could be further validated by comparison with performance in the operating room, also known as concurrent validity. Outcomes parameters can be defined clinically by error analysis, failed procedure rates, and record of complication rates.[38] In this case, it is also necessary to ensure there is built-in stratification to grade the difficulty of the real procedure to ensure the assessment is of technical skill rather than patient or disease variability.[39]

Impact of a competency-based training curriculum

Current training programs in technical skills are primarily run on an ad hoc basis, with the majority organized as 2- to 5-day courses. These are intensive and teach a number of skills to trainees of varying capabilities. A number of the course participants will return to their hospitals without additional exposure to many of the skills taught in these courses.

A structured training program using a curriculum approach can provide graded teaching sessions. These sessions are targeted toward a specific group of doctors and, with preset expert-based benchmark criteria to be achieved at every stage of the curriculum, can ensure that everyone in the group benefits from the program. This benefit increases the motivation of both trainees and faculty involved, providing a more personal approach to technical skills acquisition. The curriculum should provide formative feedback to trainees, and can also provide a clear indication of those who are falling behind and require further attention from their trainer.

A systematic training and assessment program is built on the notion of task-based learning within the skills laboratory, which, when transferred to the operative environment, also enables deconstruction of a complex procedure into its constituent parts. This provides a structured approach to learning the operative procedure, managing errors, and identifying tasks for deliberate practice. The framework also maintains continuity of objective assessment in the real environment, using similar modes as in the skills laboratory. Competency at the real procedure still entails a learning curve, although this should be shorter than if the apprenticeship model of training had been followed. Additional studies to compare the two methods of training in terms of total time taken, cost, and complication rates can confirm this assumption. Through use of the assessment tools in the real environment, participants in such a program can then be granted certification for independent practice of a technical procedure.

A more philosophical question is how we define attainment of competence. The *Concise Oxford English Dictionary* definition is of one "having the necessary skill or knowledge to do something successfully."[40] In medicine, success would be in accordance with the principles of safe practice, to achieve a satisfactory result for each individual patient. Studies of technical skill have generally defined individuals to be competent in a particular procedure when they have performed a defined procedure more than 100 times, for example, laparoscopic cholecystectomy. But this is a poor assumption based on experience rather than expertise. It is believed that the learning curve has reached a plateau, though to quote Vince Lombardi (a well-known American football coach), "It is not practice that makes perfect, but *perfect* practice that makes perfect."

Current assessment of competence is not performed in an objective, valid, and rigorous manner.[23] This concept is being challenged, and achieving a certificate for independent practice is just one point on a spectrum of ability. The ultimate validation of any objective measure of technical skill shall be to correlate it with clinical outcomes.[18] Once these measures are chosen as the benchmark, the definition of competence can direct the delivery of high-quality outcomes. Attainment of this benchmark level of proficiency is a process of summative assessment. But assessment strategies can be further tailored to diagnose and rectify strengths and weaknesses in the process of formative assessment.

This training and assessment continuum can form the educational basis for validation and revalidation of technical excellence, analogous to phase IV of a clinical trial.[41] This can augment the process of life-long learning, currently performed through a system of continuing medical education credits.[42] The publication of national databases may be used to provide information about outcomes and provide remedial action as necessary.

Those physicians who fail to make the grade should repeat constituent parts of the curriculum, but there is a possibility that some shall continue to lack the skills to become, or remain, competent. The medical profession must deal with this issue head-on by ensuring that the scientific base developed from a competency-based training curriculum is openly available so judgments of this nature can be made. This is possible only by configuring training programs in a systematic manner, as described in this article, leading to delivery of high-quality care to all patients.

Application to nonmedically qualified personnel

The framework detailed in this article is directed toward the training of technical skills and may be applied to any technical skill within medicine. Similarly, the framework may also be applied to nonmedically trained personnel, such as nurses, physiotherapists, and paramedics. Intravenous cannulation, application of plaster, and endotracheal intubation are technical skills that also necessitate a high level of skill to ensure favorable outcomes.[43] These skills are commonly learned in short courses, although, again, without a scientific base for training and assessment.

The task-based approach to training, commensurate with the educational principles of learning, such as concretization of the task and practice on simulated models in a skills laboratory, is applicable here too. A similar process of assessment, both formative and summative in nature, can reassure both the patient and practitioner.

Use of the same model for training medical and allied health personnel can also encourage the concept of interprofessional learning.[44] It is not necessary to uphold the hegemonic nature of training in medical tasks, and this framework enables trainee doctors to be supported by experienced nurses when performing skills such as cannulation early in their training.[45] In addition, within the current climate of new professional roles in surgery, a framework of training that is identical for doctors and allied health professionals, with the same levels of competence to achieve, can reassure the public and health-

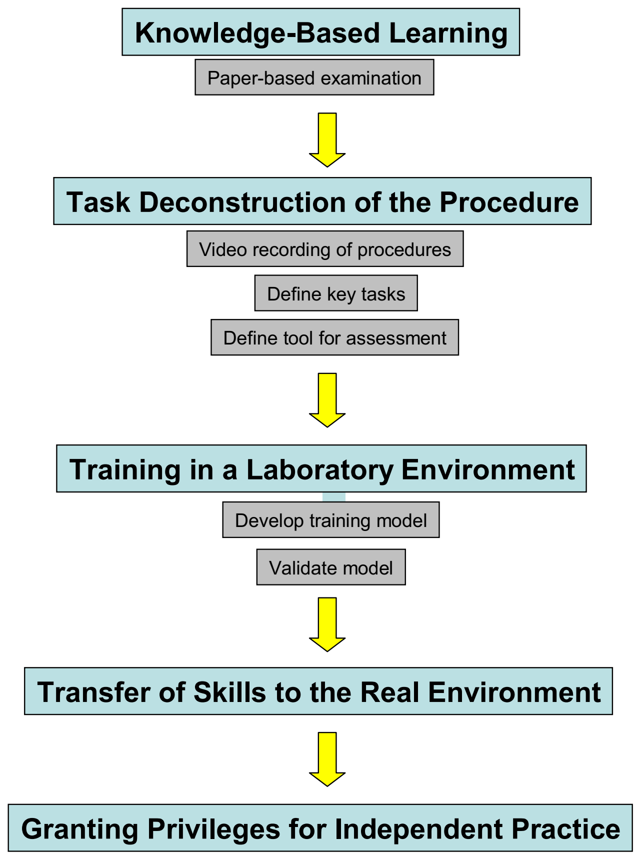

Figure 2. Framework for systematic training and assessment of technical skills (STATS).

care community of the continued maintenance of standards of excellence.[46,47]

In conclusion, there is currently a lack of definition of methods required for training future health-care professionals. Curricula exist, though they are based on experiential notions and are not standardized between regions or centers.[48-50] This leads to a variation in the quality of training and, more importantly, a variation in the definitions of competence for independent practice.

The model charted in this article is simplistic, feasible, and generic to any branch of medicine that involves acquisition of technical skill (Fig. 2). The model also provides an opportunity to develop valid, objective, and reliable methods to assess technical skill both in laboratory-based and real environments. It is imperative that such an approach be pursued, especially in the context of growing public and political pressure for competency-based practice. It will then be possible not only to define levels of skill, but also to audit training programs and provide academic institutions with an objective argument to obtain more resources to fund these programs. Finally, it is also possible that this model of training can reduce the number of unnecessary complications caused by having to learn technical skills on real patients.

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