VMAS – A Proposed Educational Framework

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Introduction

This white paper describes an educational framework for training combat medics, physicians and others to increase the readiness of medical personnel in the military. The central premise of this framework is the use of simulation to form an effective bridge between textbook and patient, while reducing errors associated with acquisition of patient care skills. Procedural skill acquisition requires both development of technical skills and cognitive or decision making components (i.e. when, where, and how) of implementation. The complex tasks performed by medics and surgeons require the performance of a large set of different skills, of which some are simultaneously performed and others in a temporal order. This proposed educational framework is designed to foster coordination and integration of those skills through employment of realistic problem situations and the use of simulation to permit learners to practice and demonstrate skills. The educational framework employs a key set of principals of learning science that have been demonstrated to enhance learning.

1 Proposed Educational Framework

Advances in cognitive science research have provided great insight into how people learn and recommendations for improving learning outcomes. As a result, there has been a proliferation of instructional design theories and models for education and training. While there are numerous theories and models – many of which use different terms – there are fundamental underlying principals which many have in common. With this education framework, we have attempted to identify a key set of underlying principals that are relevant to training of medics and surgeons. The framework is compromised of 12 components that incorporate these key principals. The components are described briefly below. Section II provides a more detailed discussion of each component.

Educational Framework Components:

1) **Simulations.** Current research provides strong evidence that use of simulation and immersive environments enhance learning because of their ability make complex principals more concrete, illustrate and highlight aspects of performance and facilitate learning by doing.

2) **Modification of existing curriculum to incorporate simulation-based training**. A wealth of data from aviation, military and anesthesiology training shows that insertion of simulators into traditional curricula is less effective than modification of the existing curricula to specifically address the requirements of these novel training tools.

3) **Problem-centered learning.** Current research suggests that the most effective learning environments are those that are problem-centered. Problem-centered design is an instructional strategy in which tasks or problems relevant to the instructional provide the context for learning. Problem-centered designs range from relatively simple approaches in which problems or cases serve to define learning issues, to very complex guided discovery simulation-based multimedia lessons. The more complex designs derive problems and problem solutions from cognitive task analysis and often use simulation, incorporate coaching, and provide ways for learners to review 'maps' of their problem solving steps to compare with expert maps.

4) **Critical skills focus.** Specific skills and curriculum required will vary depending on the target learners and procedures to be learning. Areas of expert-novice difference of the important skills underlying the task need to be identified. Skills should be decomposed in a hierarchy of constituent skills and problems. Training should highlight the key steps to help the learner understand that the steps are relevant to the transfer task. Simulations should incorporate the skills and problems hierarchy both for skills demonstration, practice and assessment. Cuschieri and others have identified general skills important in surgical trainees, including handling of tissues, intraoperative decision-making, identification of tissue planes, surgical exposure and reaction to adverse operating situations. For medics, the Army 91W combat medic is used as the model for training requirements because these individuals and their counterparts in the other services represent the largest component of the military responsible for medical readiness. The 91W training model is built on three equally important components that include medical skills, soldier skills and clinical experience and reinforcement. (Higgins 2003).

5) **Varied and contrasting examples.** Examples that look different on the surface but that illustrate the same guidelines maximize learning transfer. Contrasting examples help the learner understand which features are relevant or irrelevant to a particular concept. The emphasis

should be on a sequence of problems, so that demonstration and application are integrated as a whole rather than as distinct parts.

6) **Demonstrations**. Learning is promoted when the instruction demonstrates what is to be learned, rather than just telling about what is to be learned. Demonstrations should be consistent with the learning goal, and should include varied examples concepts; demonstration for procedures; visualizations/simulations for procedures; and modeling for behavior.

7) **Practice opportunities**. The learning environment should include many opportunities for practicing performance. Learners should practice simple to complex versions of a whole task, with instructional methods that promote just-in-time information presentation to support the recurrent aspects of the whole task while at the same time, instructional methods that promote elaboration should be used to support the non-recurrent aspects of the task.

8) **Reflection**. Research shows that training learners to self-explain examples consistently improves learning outcomes. Learners' thinking should be made visible through discussions, text or tests, and feedback must be provided.

9) **Feedback.** Feedback is most valuable when students have the opportunity to use it to revise their thinking as they are working on a task. Feedback should occur continuously, but not intrusively, as a part of instruction.

10) **Assessment.** Expert-novice differences in the subject domains should be the targets of assessment. Assessment should measure each stage in development of expertise. Task analysis techniques are vital to this stage of the evaluation process. A task analysis should be conducted to define (1) the key steps involved in the performance of the medical procedures under investigation, and (2) the underlying skills that enable trainees to perform those procedures. This information is critical in the formulation of appropriate test scenarios and related performance measures, and assures that the evaluation provides a fair assessment of the simulator's ability to provide effective training. Test scenarios should provide complete coverage in terms of testing the critical skills and abilities of interest in the training situation and do this in a naturalistic, operationally valid context. Assessments should also provide feedback to the learning systems to enable designers to modify the learning environment as needed to improve learning outcomes.

11) **Skills refreshment.** Professional organizations such as the American College of Cardiology and American Heart Association have recommended that physicians practice a minimum number of percutaneous transluminal coronary angioplasty procedures per year as the primary operator

in order to maintain competence in the procedure. The educational framework should include skills refreshment and the assessment should provide information to determine frequency of refreshment.

12) **Reusable education training materials**. The development of the simulations, content, instructional strategies, and curriculum will require contributions by many disciplines. Considerable effort and cost can be saved if they are reusable. A repository of instructional objects will permit building on materials prepared by others and use for multiple purposes. Reusability also enables fast updates, so that content can be kept accurate and current.

2 Discussion of the Educational Framework Components

2.1 Simulations

Current research demonstrates the effectiveness of simulation and virtual reality to train to a high level of skill. Simulations provide learners with opportunities for practice and experimentation. Typically, the results are immediately reported by the system. At any point the learner can revisit his or her problem-solving steps and compare them to the steps an expert would take. Learning occurs as learners take action, see the results, reflect on their approach, and retry when needed. When considering the acquisition of some high specific knowledge or skill, certain laws of skill acquisition always apply. The first of these is the “power law of practice” - acquiring skill takes time, often requiring hundreds of thousands of instances of practice in retrieving a piece of information or executing a procedure. This law operates across a broad range of tasks, from typing on a keyboard to solving geometry problems (Rosenbloom & Newell, 1987). According to the power law of practice, the speed and accuracy of performance in a simple or complex cognitive operation increases in a systematic nonlinear fashion over successive attempts. This pattern is characterized by an initial rapid improvement in performance, followed by subsequent and continuous improvements that accrue at a slower and slower rate. Virtual reality training has been shown to significantly improve OR performance of residents during laparoscopic cholecystectomy (Seymour, et al 2003).

2.2 Modification of existing curriculum to incorporate simulation-based training

New technology brings new educational opportunities, and these require changing existing curriculum. Simulation technology in the military has been shown to be much more effective if the educational framework is tailored to the attributes conveyed by addition of new technology

(Higgins et al, 1997). The new and *different* educational content should benefit from the *difference* in the technology, such that the curriculum has added value beyond the same material presented with previous technology. For example, compared to books and anatomical prosections, simulators bring the promise of individualized learning on patient models, so the content using simulation should emphasize this form of active interaction, rather than simply as an addendum to series of slides shown to a passive audience. Simulator technology brings real time interactivity and "infinite perspective", which invites learning through discovery. Therefore, added educational value can be attained by creating highly interactive 3D models that provide an "infinite number of perspectives" (i.e. the anatomical structures can be seen from a limitless number of angles, from outside or inside, etc) and invite the student to learn by exploring and interacting with the anatomy. In contrast, there is a danger that instructors will overemphasize the use of simulators because of their novelty and ease-of-use compared to training actual procedures in real world settings. When used excessively, simulators may negatively influence morale and retention – e.g., “I joined to practice medicine on humans, not on manikins!” (Moroney and Moroney, 1998).

2.3 Problem-centered Learning

One way to help students learn about conditions of applicability is to design problems that help students learn when, where, and why to use the knowledge they are learning. Proponents of using problems as a vehicle to contextualize learning suggest that transfer of learning will be better than instruction that presents content out of context. Using problems to anchor learning bridges the gap between general and specific knowledge since the general knowledge is learned in the context of specific applications. Active engagement with new knowledge and skills is an essential prerequisite to learning. By starting a lesson with a problem the engagement process begins right from the start. Starting with a problem makes learning a much more inductive experience, especially when the learner has multiple options to build the knowledge base needed to solve the problem. Sterling (1996) emphasizes the importance of case studies for simulation-based training.

Learning is promoted if the instruction provides a structure that the learner can use to build the required organizational schema for the new knowledge. Merrill (2002) recommends starting with easier problems and moving to more difficult ones and providing more support in the form of hints and demonstrations available in the beginning and removing support as learning proceeds. Andre (1997) discusses the role of advance organizers in providing structure for later learning. Mayer (1975) indicates that providing learners with a conceptual model can facilitate the acquisition of problem-solving. Clark and Blake (1997) recommend presenting dynamic schema and analog models to promote far transfer.

The challenge in instruction is to provide learning environments that manage the limited processing capability in working memory so that new information gets encoded into long-term memory in a way that it can be effectively retrieved or transferred later. Experts in a subject domain typically organize factual and procedural knowledge into schemas that support pattern recognition and the rapid retrieval and application of knowledge. (Chase and Simon, 1973; Chi et al., 1981). Experts' abilities to solve problems depend strongly on a rich body of knowledge about subject matter that support thinking about alternatives that are not readily available if one only memorizes facts. (Bransford and Stein,1993). Experts have not only acquired knowledge, they are also good at retrieving the knowledge that is relevant to a particular – conditionalized knowledge is knowledge that includes a specification of the contexts in which it is useful (Glaser, 1992).

2.4 Critical Skills Focus

It is critical to understand expert-novice differences and ensure the curriculum addresses those tasks that make substantial impact to critical job performance and that require demonstrations and practice to learn. Experts can rarely articulate the mental models that are the source of their expertise. They have so much tacit knowledge stored in long-term memory that it is difficult for them to explain it verbally. For example, detailed analysis estimated that chess masters have about 50,000 play patterns stored in their long-term memories, patterns routinely used as the basis for game strategies (Simon & Gilmartin, 1973). The military developed Cognitive Task Analysis (CTA) to facilitate rapid and effective acquisition of expertise by enlisted personnel in complex cognitive-technical skills (i.e. fighter pilot training, complex electronics trouble-shooting). CTA uses a structured interview and analysis process in which experts are asked to solve authentic job problems and at the same time to verbalize their problem-solving thoughts (Jonassen, Tessmer, & Hannum,1999).

CTA studies can reveal performance differences between experts, intermediate-level learners and novices. Past studies have revealed differences in content and structure related declarative knowledge, knowledge schemes, pattern recognition, etc., corresponding to differences predicted from study of cognitive psychology and expertise. Expert-novice differences were frequently in categories of assumed pre-requisite knowledge or learned solely through procedural knowledge.

2.5 Varied and Contrasting Examples

Merrill, Tennyson and Posey (1992) indicate that a necessary condition for effective concept instruction is was a range of divergent examples. The use of well-chosen contrasting cases can help learners learn the conditions under which new knowledge is applicable. When teaching problem-solving or decision-making tasks, present several examples that look different on the surface but that illustrate the same guidelines to maximize transfer. The goal of instructional methods is to build mental models in long-term memory that will transfer effectively to working memory after training. Training can build specific mental models that apply only to limited situations or more flexible mental models that transfer to various situations. When training tasks that involve decision-making and problem-solving, a more flexible mental model gives better performance since it transfers to various diverse situations. Build flexible mental models by using several examples that vary surface features but keep the illustrated principles consistent.

A number of studies by Sweller, van Merrienboer, and Paas (1998) have shown that training time can be reduced and learning improved when worked examples are substituted for some practice problems. Thus in training requiring problem-solving, rather than showing one or two examples and then assigning ten practice exercises, it is better to show two worked examples, followed by a practice problem, and then two more worked examples, followed by another practice problem, and so forth. By using worked examples to build new mental models rather than spending working memory resources to solve problems, learning load is reduced and learning is made more efficient. Van Merrienboer's 4C/ID approach incorporates both near and far transfer tasks. During the analysis phase, a top-down job and task analysis defines far transfer tasks (called nonrecurrent tasks) and near transfer tasks (called recurrent tasks) as well as the supporting knowledge for both including concepts, facts, mental models, and problem-solving approaches (called systematic approaches to problem solving). Once job functions (called job classes in his model) are identified, they are sequenced from simpler versions of whole authentic tasks to more complex versions. The nonrecurrent (far transfer) tasks are the source for the core problems that drive the training. Learners complete a series of far-transfer problems using the supporting knowledge provided. The problems presented are diverse in surface structure to help build more transferrable mental models

Clark and Blake (1997) show that far transfer is promoted when the structural features are carefully identified and explicitly mapped for the learner; such guidance focuses the learner's attention on relevant information in the task. As the instruction progresses this information focusing should be faded and learners expected to attend to and focus their own attention on the relevant aspects of the information (Andre, 1997).

2.6 Demonstration

Effective instruction must provide an opportunity for learners to demonstrate their newly acquired skills. (Gardner, 1999); Perkins & Unger, 1999) and (Schwartz, et al, 1999). Instruction is far more effective when the information is demonstrated via specific situations or cases. Jonassen

(1999) recommends demonstration of each of the activities involved in a performance by a skilled (but not expert) performer. He identifies two types of modeling: behavioral modeling which describes how to perform the activities identified and cognitive modeling which articulates the reasoning that learners should use while engaged in the activity.

2.7 Practice opportunities

Merrill (1994) cites research that shows that presenting examples in addition to practice promotes better learning than practice alone. Learning is most effective when people engage in deliberate practice that includes active monitoring of one's learning experiences (Ericsson et al, 1999). Research shows that adding practice to information and examples increases learning. Gardner (1999) and Perkins & Unger (1999) both emphasize the necessity of many opportunities for performance.

2.8 Reflection

Research shows that training learners to self-explain examples consistently improves learning outcomes. When faced with a worked example, learners can do one of several things. They may choose to ignore it; or they may choose to process it at a surface level. But learning is maximized when learners actively study and encode the example. In this way the new mental models are actively constructed. The Vanderbilt Cognition and Technology Group (Schwartz, et al, 1999) states that reflection is key to integration of new knowledge and skills. The ability to recognize the limits of one's current knowledge, then take steps to remedy the situation is critical. The process of reflecting on and directing one's own thinking is one of the hallmarks of expertise. Experts use metacognition strategies to monitor understanding during problem solving and for performing self-correction.

Learners' thinking should be made visible through discussions, text or tests and feedback must be provided. The learning environment should incorporate techniques that require learners to self-explain examples to promote deep processing and maximum learning from examples.

2.9 Feedback

Feedback is most valuable when students have the opportunity to use it to revise their thinking as they are working on a task (Barron et al, 1998; Vye et al, 1998). Learners acquire a skill much more rapidly if they receive feedback about the correctness of what they have done. If incorrect they need to know the nature of the mistake. Timely feedback is critical so that the learner's practice of a skill and its subsequent acquisition will be effective and efficient. Feedback should occur continuously, but not intrusively, as a part of instruction. Technology is providing new learning tools that can be used to monitor actions, intervene with hints and feedback, ask questions to elicit learner understanding, and direct learners to summon instructors when the learners need additional help (Genscope, Hickey, Kindfield and Horwitz, 1999).

2.10 Assessment

Assessments function within a large system of curriculum, instruction, and assessment. Changing one of these elements and not the others runs the risk of producing an incoherent system. All of the elements and how they interrelate must be considered together. Every educational assessment should be based on a set of foundations: 1) every assessment is grounded in a theory about how people learn, what they know, and how knowledge and understanding progress over time; 2) each assessment embodies certain assumptions about which kinds of observations, or tasks, are most likely to elicit demonstrations of important knowledge and skills from students; and 3) every assessment is premised on certain assumptions about how best to interpret the evidence from the observations to draw meaningful inferences about what students know and can do.

Most assessments are “static”; they provide snapshots of achievement at particular points in time, but they do not capture the progression of students’ conceptual understanding over time, which is at the heart of learning. This limitation exists largely because most current modes of assessment lack an underlying theoretical framework of how student understanding in a content domain develops over the course of instruction, and predominant measurement methods are not designed to capture such growth. Assessments should include learners’ organization of knowledge, problem representations, use of strategies, self-motivating skills, and individual contributions to group problem solving.

A general paradigm for conducting experimental evaluations of simulator training effectiveness for medical applications is based on the work of Pugh, Hettinger, Higgins and others (Pugh et al, 2001a,b; Hettinger et al, 1995; Higgins et al, 1997; Lathan et al, 2001). It uses the Transfer-of-Training paradigm that has been successfully applied to simulator training evaluations in aviation and other domains (Moroney and Moroney, 1998; Orlansky et al, 1994; Champion and Higgins, 2000). This work is being coordinated with the VMAS (Validation, Metrics, Assessment for Simulation) Steering Committee.

2.11 Skills Refreshment

There are “learning curves” for the performance of medical procedures, but these may vary between individuals. In a laparoscopic procedure such as cholesytectomy, the steepest part of the learning curve has been empirically demonstrated to be the first 10 cases the surgeon performs, but can continue up until the first 50 cases have been completed (The Southern Surgeons’ Club 1995); for GI endoscopy, the learning curve has been estimated to be as many as 300 procedures (Cass 1999). The urology learning curve for procedures such as cystoscopy has been estimated to be 25-100 procedures (Shah and Darzi, 2002). There has been considerable debate about the need for increased procedural volume to reduce error in the performance of procedures such as percutaneous transluminal coronary angioplasty (PTCA) (Hannan et al, 1997; Ritchie et al, 1993; Ryan et al, 1996: Shook et al, 1996). Initial studies showing that adverse outcomes were significantly higher in low-volume centers (Ritchie et al, 1993; Jollis et al, 1994), raised public concern (Squires, 1996), but did not adequately explore the issue of whether low-volume centers may have more complications because they treat high-risk patients (Ryan, 1995). Two important findings of the work of Kimmel et al (1995), as emphasized by Ryan (1995), are that laboratory volume was linearly and inversely associated with major complications, and the odds reduction from major complications becomes statistically significant when laboratory volume is more than 400 cases per year. Professional organizations such as the American College of Cardiology and American Heart Association have recommended that physicians practice a minimum number of PTCA procedures per year as the primary operator in order to maintain competence in the procedure (Douglas et al, 1993; Ryan et al, 1990). In Maryland, civilian EMT medics are required to perform at least 6 needle sticks a year to maintain certification. For many practitioners, it may be difficult to meet the professional guidelines for maintenance of competence established because they do not treat enough patients, thus training on a simulator may take the place of performance on patients to help prevent skills decay. However, trainers or professional organizations that require trainees to ‘train’ on simulators without much systematic thought about what they are trying to achieve may not recognize individual variability. The underlying assumption seems to be that individuals who have performed the required number of procedures will be safe practitioners, but this ignores variability in individual learning rates. Setting a fixed number of procedures or number of training hours is a less than optimal approach to learning**.**

2.12 Reusable education and training materials

The development of education and training materials is time consuming. It involves contributions by many disciplines: domain experts, information technologists, computer scientists, cognitive scientists and education and training specialists. Some parts of the tools and content are common among different courses, some are unique. Considerable effort and cost can be saved if the tools and content are reusable. If designed with re-use in mind, the components and objects developed can be used by different instructors, teachers and learners for different purposes. Re-usable simulations, instructional content and learning tools can be combined to create new learning systems, can facilitate maintenance of learning systems by making it easier to keep material up-to-date, and allow customization of learning systems for specific learners' needs. In addition, resources can be used in ways not previously considered, permitting creation of totally new teaching resources.

Simulations and content should be structured in such a way that they can be adapted and reused. Content material should include metadata to permit search and retrieval from digital repositories. Simulations should be designed to be interoperable so that larger systems can be built from component simulations. Current work in learning objects, interoperable simulations, software development communities and digital libraries should be used and expanded. Examples include the Department of Defense's Advanced Distributed Learning (ADL) Initiative www.adlnet.org, which is designed to accelerate large-scale development of dynamic and cost-effective learning software and systems to meet the education and training needs of the Military Services through the development of a common technical framework for computer and net-based learning for the creation of reusable learning content as "instructional objects." The Federation of American Scientist's Digital Human project www.fas.org is focused on building a community of researchers working in biomedical simulations to develop a framework to support interoperable software components and biological simulations.

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Appendix A

Validation Metrics and Assessment of Simulation (VMAS)

Steering Committee

Name	Affiliation
Col (USAF) Mark Bowyer, MD **Co-Chair**	USUHS National Capital Area Medical Simulation Center (NCAMSC)
Howard Champion, MD **Co-Chair**	Tech Med Inc.
Steve Dawson, MD	Center for Integration of Medicine and Innovative Technology (CIMIT) Simulation Group
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Leroy Heinrichs, MD	Stanford University
Larry Hettinger, PhD	Northrup-Grumman
Gerald Higgins, PhD	SimQuest Inc.
Kay Howell, PhD	Federation of American Scientists
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