Scientific Principles to Support Rapid Scenario Development

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ABSTRACT

Rapid development of training scenarios grounded in the principles of learning science has been an on-going challenge for the military. Typically, little, if any, attempt is made to utilize these principles in scenario development for several reasons. First, the literature in this area is highly varied in content, commonly focused upon K-12 education, and dispersed throughout education, psychology, and cognitive science journals. As a result, the ability of scenario developers to apply readily available scientific principles is significantly hindered. Second, due to the evolving battlespace, the immediate need for new or modified training products often outweighs the longer term advantage of a scientifically sound methodology for scenario creation. In response, this paper translates existing research from training science into actionable principles for scenario development. The recommendations are organized by trainee expertise level. Categories of recommendations include complexity level, length of scenario, feedback type and timing, knowledge acquisition goals, number of practice segments, and instructor type. Taken together, these principles will help developers tailor the format and content of training scenarios to address different types of learning, maximize knowledge acquisition, and adapt to levels of learning, while simultaneously decreasing the resources required to develop effective scenarios.

ABOUT THE AUTHORS

Jennifer Vogel-Walcutt is a Senior Scientist at the Cognitive Performance Group with over 15 years experience in research development for training and education. Dr. Vogel-Walcutt's recent interests focus primarily on developing instructional techniques to improve the effectiveness and efficiency of training military personnel. Projects in development currently focus on the application of these techniques to develop specific skills such as to enhance resilience, improve the development of metacognitive skills, and to increase the appropriate use of intuition during decision making. Dr. Vogel-Walcutt has acted as PI or co-PI on several large (exceeding $1M), federally funded, education and military grants.

Jennifer Phillips is a Senior Scientist at the Cognitive Performance Group with over 16 years of experience conducting research and developing applications in the area of human cognition and naturalistic decision making. Her research interests include skill acquisition, cognitive performance improvement, and the nature of expertise. She has extensive experience conducting cognitive task analysis to model expertise, and generate training requirements and learning objectives. She has also studied the role of instructors as facilitators of the learning process, and has developed instructor guides and train-the-trainer workshops to ensure a focus on the cognitive elements of decision making.

Karol Ross is the Chief Scientist at the Cognitive Performance Group. She has conducted research and development for the US Army, the USMC, the US Air Force, and the Office of Naval Research. She conducts applied research in qualitative methods for the assessment of expertise and the development of training interventions for tactical thinking and performance in military environments. Currently, Dr. Ross is supporting TECOM's SUDM (Training and Education Command's Small Unit Decision Making) Initiative by overseeing the design and planning of the continuum study, serving as PI in the initial literature review to identify instruments for measuring the competencies and CARS (Cognitive and Relational Skills) relevant to small unit decision making, and conducting cognitive task analysis interviews to capture the progression of skill development from novice to master maneuver squad leader.

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INTRODUCTION

Rapid development of training scenarios grounded in the principles of learning science has been an on-going challenge for the military. Typically, little, if any, attempt is made to utilize these principles in scenario development for several reasons (Vogel-Walcutt, Fiorella, & Malone, 2011). First, the literature in this area is highly varied in content, commonly focused upon K-12 education, and dispersed throughout education, psychology, and cognitive science journals (Vogel-Walcutt, Bowers, Marino-Carper, & Nicholson, 2010). As a result, the ability of scenario developers to apply readily available scientific principles is significantly hindered. Second, due to the evolving battlespace, the immediate need for new or modified training products often outweighs the longer term advantage of a scientifically sound methodology for scenario creation. In response, this paper translates existing research from training science into actionable principles for scenario development.

EDUCATIONAL SCIENCE

Two major theories drive the majority of the educational literature: Cognitive Load Theory (CLT; van Merriënboer & Sweller, 2005) and Constructivism (Vygotsky 1978; Taber 2006; Loyens & Gijbels 2008). CLT assumes the brain has a limited working memory (WM) capacity and because of this limitation, certain teaching methodologies should be employed in order to optimize the use of that theoretical space. Further, because novices are the most hindered by this limitation, the majority of their recommendations are focused upon early learners and explicit, low-level knowledge. Constructivism, on the other hand, is more typically focused on the understanding of complex material. Under this theoretical umbrella, the organization of information in long term memory, or the 'construction' of schema, is the primary goal of the teaching principles. Consequently, some argue that information can either be learned efficiently or deeply but that the literature does not provide quality guidance on how to achieve both (Vogel-Walcutt, Gebrim, Bowers, Carper, & Nicholson, 2010).

In response, reviews have been conducted attempting to marry these two theoretical positions and develop a framework for guiding strategy selection (Vogel-Walcutt, et al., 2010; Belton & Prihadharshini, 2007; Hmelo-Silver, Duncan, & Chinn, 2007). Generally, however, these reviews discuss strategies in general, rather than specifically, and they rarely provide a generalized set of training principles that can drive the rapid development of scenarios. One partial exception is Mayer's (2009) work which helps define principles of multi-media design to facilitate efficient learning within these types of programs. For example, Mayer notes that there are 12 principles of design including, but not limited to coherence (exclude extraneous pictures or words), modality (split material across verbal and pictorial modes to reduce the drain on working memory), and personalization (provide learning material in a conversational tone). However, these principles do not address *instructional* strategies used to support knowledge acquisition, rather, they focus on design principles. Unfortunately, it remains difficult to find training strategies that are translated into practical solutions and ready for use by military populations. Thus, this paper aims to compile those 'lessons learned' from the training literature and translate them into practical, clear, easily implementable recommendations for rapid scenario development.

SCENARIO BASED TRAINING

Scenario-based Training (SBT) is an experiential learning technique that involves providing learners with contextual information in the form of a narrative. SBT is commonly used to orient learners' knowledge to real-world applications, teach problem-solving skills, and illustrate the secondary effects and future impact of various decisions (Cannon-Bowers & Salas, 1998; Ross, Phillips, Klein, & Cohn, 2005). Oftentimes, especially in the military, storytelling is used to illustrate problematic events, challenge novice personnel's thought processes, or model how to translate classroom learning to the real-world. It is also commonly used in simulators due to their ability to provide clear presentations of the outcomes of trainees' decisions. In other words, within a simulator, a full scenario can be experienced without the safety, cost, or time issues present in the execution of a field exercise.

Unfortunately, while simulators typically provide rich contextual cues and storylines for trainees, they rarely provide the instructional support necessary for learning to occur (Vogel-Walcutt, 2010). Consequently, the majority of simulators or more broadly, computer-based training systems, provide *practice* platforms, as opposed to *training* programs. The difference is that one simply provides a context in which learning *can* occur, but without a skilled instructor, often does not (Fletcher, 1990; Smith-Jentsch, Johnston & Payne, 1998; Kulik, 1994), while the other provides guidance throughout the experience to encourage learning. In response, this paper translates the principles of cognition to provide a set of practical instructional guidelines for scenario development that can be easily implemented into simulation-based training environments. Ultimately, it is expected that a framework of recommendations, such as is provided in this paper, will not only increase the effectiveness of computer-based training programs, but it will also increase the efficiency, or rapidity, with which they are developed.

KEY ELEMENTS FOR SCEARNIO DEVELOPMENT

The recommendations herein are first organized by trainee expertise level (see Table 1). Categories of recommendations include complexity, length of scenario, feedback type and timing, knowledge acquisition goals, number of practice segments, and instructor type. Second, they are organized by task focus (see Table 2). In this table, the type of knowledge being taught is addressed and appropriate training techniques are provided. Taken together, these principles can help developers tailor the format and content of training scenarios to address different types of learning, maximize knowledge acquisition, and adapt to levels of learning, while simultaneously decreasing the resources required to create effective scenarios.

Table 1. Ideal Training Timeline

Expertise	Complexity	Length	Feedback	Goal types	Practice	Instructor
Novice	Low	Short	Immediate, Focused	Identify	Massed	Instructor
Intermediate	Medium	Medium	Short Delay, Focused w/ explanation	Assess	Massed + Segregated	Instructor, Peer-to-peer
Expert	High	Long	Delayed, Explained	Judge	Segregated	Peer-to-peer, Independent

Table 2. Ideal Training Elements/Scaffolding

Knowledge	Task	Question	Intervention Timing	Techniques
Declarative	Identify	What is it?	Pre/During	Drill & practice Highlighting
Conceptual	Assess, Evaluate, Analyze	What does it mean? Does it matter?	During	Part-task training Advance Organizer Metacognition Exercises Worked Examples
Integrated	Determine, Judge	What do I do?	During/Post	Intuitive vs. Recognition-Primed Decision Making exercises Vicarious Learning After Action Review (AAR) Display downstream outcomes (Simulations)

Complexity

Complexity refers to the number of competing stimuli provided within a scenario. It can be varied by increasing or decreasing the number of distracters or number of tasks required to be completed, adjusting the clarity of the mission goal, or by making distracting stimuli more or less intrusive within the scenario. Other elements can also be adjusted in a similar fashion to these options. Underlying the purpose of these variations can be explained using CLT. Specifically, as individuals increase in expertise, they are more efficient at identifying relevant material, ignoring distractions, and filing information into long term memory (LTM). Consequently, trainees can better navigate and acquire knowledge within increasingly complex scenarios. However, if the expertise level is mismatched with the level of complexity, the trainee may become cognitively overloaded, and task shedding will result. Stated another way, the individual will be unable to distinguish important from unimportant information and as a result, the information that does become filed in LTM is likely to be disjointed, disorganized, and more difficult to retrieve. Application of that information is consequently hindered.

Length

The lower the expertise level, the shorter the simulated mission needs to be in order to avoid task shedding. Individuals at the lowest levels of expertise will more easily overload working memory because they are not yet efficient in moving incoming information to LTM. Thus, novices require shorter duration simulated missions to allow for the opportunity to receive input, feedback, or guidance that will guide their LTM organization. Without those pauses, information will be lost. Further, it is not possible to determine which information will be lost. Consequently, the most important points may not be filed.

Feedback

At the lowest levels of expertise, individuals lack the appropriate schema in LTM to be able to effectively benefit from explanatory feedback and they are unable to hold enough information in WM to process delayed feedback (Dieterle & Murray, 2009; Wulfeck, 2009). Therefore, it is recommended that at the lowest levels of expertise, explicit, direct feedback is provided just-in-time. In other words, the simulator should cue trainees to mistakes or provide guidance during the simulated mission to ensure a successful outcome. This will allow individuals to most efficiently create appropriate schema in LTM and to optimally file associated information. As the trainee progresses in expertise, it is recommended that individuals are allowed a longer time to process the mission's lessons before feedback is provided. Also, it is recommended that the feedback is accompanied by an explanation about why one should perform differently or think differently because individuals at the highest level of expertise already possess sophisticated LTM schema that allow them to use the incoming feedback to refine that organization effectively. Conversely, a novice would be overwhelmed by the additional information and would most likely fail to retain the necessary knowledge.

Goals

For these types of exercises, the goal of the lesson can be determined by the instructor or the trainee. Further, it can be more or less complex, contain many or few sub-goals, and the fulfillment of these goals can be self-guided and assessed or guided and assessed by the instructor. The differences in the goals and their facilitation should be decided based upon the expertise level of the trainee. Specifically, at the highest level of expertise, the goals should be more complex yet less clear, in order to allow the individual to utilize previous experience (stored in LTM) and existing schema to guide their decisions, processes, and actions. However, at the lower levels, goals should be clear, concise, and manageable. This allows trainees to reduce the impact on WM by addressing one goal at a time. They are not yet able to integrate all of the possible ways to address a problem because they lack the experience, knowledge, and organization of schema to self-determine the actions needed to solve a problem.

Practice

Practice, in this paper, refers to the number of times an individual completes the same or similar mission or mission type and how frequently those repetitions are made. The number of repetitions is generally dictated by the level of mastery achieved by the individual and is typically determined by completing an assessment or by some sort of scoring plan embedded within the simulator. However, the rate of repetition is better determined based on the expertise of the individual. Specifically, the lower the level of expertise, the more massed the initial practice should be to allow for effective organization of information in LTM (Kim, Ritter, & Koubeck, 2009). Initially, individuals lack schema in LTM to effectively file incoming information at an effective rate to handle distributed practice, or practice that is more spread out over time. Rather, massed practice, or repetitions completed in one sitting or over a short period of time, allows those points that are missed during each mission to be provided again in the next one and ultimately allow the trainee to create a more adequate, and clearer, schema organization. Once individuals begin to proceduralize the information, the time between practice missions can be elongated.

Instructor

As individuals gain expertise, they are more metacognitive about their learning experience and consequently, they are better able to self-guide and support peers in gaining knowledge. Thus, the choice of instructor should be varied based on the level of expertise of the learner. Specifically, novices require the use of a skilled instructor to help guide them in the development and organization of schema in LTM. On their own, novices will be unable to determine which information should be retained, will not know how to develop an appropriate organization of the schema, and will struggle to determine where to file incoming information.

Alternatively, intermediate learners have already developed a rudimentary set of schema and therefore need less guidance in establishing schema and more input on how to refine what he or she already possesses. In this case, peer-to-peer group work can help individuals solve problems together more quickly than alone by capitalizing on the experience and knowledge of other group members. It can also help refine schema organization quicker by providing the trainee with a diverse set of experiences. At this level, instructors are helpful when organizing complementary groups, assigning appropriate problems, and assessing progress.

Advanced trainees already possess a sophisticated set of schema. However, what they still need are an abundance of experiences to help solidify and further refine their schema patterns. Consequently, these trainees benefit greatly from self-guided learning and peer-to-peer learning. Because they already possess a strong schema organization, they also are aware of the holes in their repertoire. Thus, they are better equipped than those at the lower levels to identify and find the information and experiences they require.

Knowledge Types

Table 2 provides an outline of suggested techniques for creating an optimal scenario, dependent upon the type of knowledge being taught. While it is generally the case that a novice would learn declarative knowledge, the intermediate, conceptual, and the advanced individual would learn to integrate their knowledge, it is not always the case that instructors teach within this organizational structure. Thus, it becomes necessary to design scenarios that account for knowledge type as well as expertise level. Three knowledge types are noted here (Krathwohl, 2002) to represent the major categories and general hierarchy of knowledge.

Declarative knowledge refers to basic, commonly memorized, information (Cohen, Eichenbaum, Deacedo, & Corkin, 2006; Bechara, Tranel, Damasio, Adolphs, Rockland, & Damasio, 1995). It can be descriptive but typically does not involve an analysis of the information; it simply reflects awareness of the cue or information. Conceptual knowledge refers to information that is understood at a deeper level (van Boxter, van der Linden, & Kanselaar, 2000; Eisenhart, Borko, Underhill, Brown, Jones, Agard, 1993). To comprehend something at a conceptual level, one must not only be able to identify the cue or information but also be able to determine in which schema to file the information and to what additional schema it is connected. In doing so, a trainee is able to better understand the importance and impact of a particular cue or piece of information. Integrated knowledge refers to the application of information stored in LTM (Vogel-Walcutt, Marino-Carper, Bowers, & Nicholson, 2012). Thus, incoming information is not only recognized and filed, it is also used to extract previously stored information and meaningfully combine it to make decisions in the field or take action as previously determined. Accordingly, each type of information should be taught differently since each type interacts with LTM differently.

Tasks and Associated Questions

At the lowest level of knowledge, the trainee should first begin by being able to simply identify items or cues within the scenario that differ from baseline. Trainees should be able to describe what they see. Once an individual can adequately distinguish between appropriate and problematic cues, their lessons should begin to focus upon assessing, evaluating, and analyzing the importance and anticipated impact of those cues. Questions at this level focus on awareness of the cues' potential impact or meaning and its importance to the mission. Novices will generally be overloaded with the task of identification because they lack the sophisticated network of schema that can help focus their attention on the critical points, rather than the most salient ones. However, at the intermediate level, trainees will more easily and efficiently be able to identify concerning cues. They will need practice, however, to determine which cues are most important to note, what the cues indicate might occur, and to whom, the cues should be noted. Finally, at the highest level, advanced trainees will judge the quality and importance of the intelligence and then determine what, if any, actions should be taken. Scenarios should focus on these types of goals, as determined by the trainee's expertise level.

Intervention Timing

The next major consideration involves the timing of possible instructional support techniques. There are many instructional activities that can be provided to trainees to aid them in their development and refinement of schema in LTM. However, when to apply these techniques can also impact the effects of their use. Within the military, and oftentimes used in other training scenarios, lessons are designed around a pre, during, and post training phase structure. This allows instructors to provide feedback or input at more clearly defined time periods within the training cycle. It also supports a more organized framework for developing training events. Accordingly, we use this framework to help define when to apply various strategies.

Specifically, because the goal of a novice is to create schema that, at least theoretically, do not yet exist, the optimal time for providing assistance is prior to and during a training event. This will allow trainees to have guidance about the initial organization of their schema and then also benefit from assistance in populating those nodes. At the intermediate level, individuals will already possess an organized structure making interventions during the training cycle most impactful. This will benefit this stage of learners by helping them to refine their existing frameworks. Finally, at the advanced level, some support can be provided during training, but the majority of the techniques will focus upon post-training interventions. This is because individuals at this stage require the full training cycle to fully comprehend the lesson and determine which elements are most important to file in which schema and how to incorporate them with other pieces of information. Accordingly, if the advanced trainee is interrupted too often during the cycle, it may actually impede their ability to integrate information meaningfully and negative learning can occur.

Techniques

Based on a previous, and extensive, meta-review of the literature that spanned psychology, education, and cognitive science, several particular instructional techniques were noted as being highly impactful for learners at different stages, learning different types of information (Vogel-Walcutt, Fiorella, & Malone, 2012). At the declarative and novice level, the drill and practice and highlighting techniques are noted. Drill and practice involves using flash cards or other memory devices to encourage trainees to memorize specific pieces of information (Olesen, Westerberg & Klingberg, 2004) while highlighting simply involves highlighting material verbally, on paper, or on the computer screen (Leutner, Leopold, & Elzen-Rump, 2007). The purpose of these techniques is to first draw attention to the more important information and second to help individuals move it to LTM. Because novices need help in these two areas, these techniques are best suited to helping reduce the drain on working memory (by helping them focus upon the most important information as opposed to the easiest to identify or the most salient) and by allowing them the repetitions required to solidify the information in LTM.

For the intermediate learner learning conceptual information, advance organizers, worked examples, part-task training, and metacognition exercises are recommended. At this stage of learning, the individual requires help organizing their schema in LTM and filing additional incoming information. Therefore, an advance organizer can help ensure that intermediate learners' organizational scheme matches the instructor's.

Advance organizers can be simply an outline of the material to be learned or it can be more complicated at this level of knowledge by involving the use of a pre-scenario on the computer to provide context for the learning (Ausubel, 1960; Lin, Dwyer, & Swain, 2006; Vogel-Walcutt, Del Guidice, Bowers, & Nicholson, 2012). Worked examples involve providing explicit examples of how to complete a task or scenario (Darabi & Nelson, 2004). By showing exactly how to complete a problem, rather than allowing the learner to figure it out for him/herself, knowledge about how to complete the task is more efficiently trained. Further, providing explanations about why each step is taken can improve the trainee's conceptual knowledge.

Part-task training involves breaking problems or tasks into smaller segments for training purposes (Hussain, et al., 2010). The use of this method during this stage is to manage working memory capacity so that the individual can begin to comprehend portions of knowledge but without experiencing overload. Finally, metacognition exercises involve prompting individuals to consider, explicitly, the choices they are making before taking action in the simulator and helping trainees to identify how and when to utilize individual learning techniques to enhance their personal learning experience (Mathan & Koedinger, 2005; Schraw & Dennison (1994). Research has shown that although it can elongate the initial training process some, prompting trainees to consider their decisions prior to action can improve understanding and future performance (Lacerenza & Vogel-Walcutt, 2012).

Finally, for the advanced learner, the goal of instructional interventions is to promote efficient acquisition of experiential knowledge and integrate it into LTM to refine and extend existing schema. Therefore, intuitive decision making exercises, vicarious learning, after action reviews (AARs), and simulation games are recommended. Individuals at the advanced level become automatic in their decisions. They no longer require explicit review of each step in decision making and they are typically no longer able to articulate each step, as they have been truncated into efficient groups of sub-decisions. Accordingly, creating simulation exercises that encourage efficient, or intuitive, decision making can help increase the speed in which the individual can complete the task.

Vicarious learning involves allowing trainees to learn from the experiences of others (Chi, Roy, & Hausmann, 2010). This type of exercise is particularly beneficial at the advanced level because it allows trainees to file others' personal experiences into their own LTM. In other words, they can more efficiently build their repertoire of experience and refine their schema without having to actually experience each event personally. AARs are used across all levels of learners and knowledge types. However, at this stage of learning and with the goal of learning focused upon integration and application of knowledge, the AAR should be the primary time during which individuals receive feedback and that feedback should be focused on the process of decision making rather than the outcome. Because advanced learners are trying to integrate incoming information into a highly complex framework of schema, they require feedback to be delayed until they can fully comprehend the material being presented and how it relates to their existing knowledge. Otherwise, feedback provided during the exercise will likely act to interrupt their thinking rather than enhance their schema refinement. Further, process-oriented feedback helps individuals focus on how they make decisions rather than the specific decisions being made.

At the advanced level, individuals can vary greatly in their decisions without differing in success. However, the process by which experts make decisions is more static and therefore these individuals can be well supported by refining their personal process for assessing anomalies, comparing them to their previous experience and knowledge, and then determining a course of action in an efficient manner. Finally, simulations are particularly beneficial to individuals at this level for two reasons (Gelbart Brill, & Yarden, 2009). First, because they are learning to apply their knowledge in real-world settings, a simulation allows them to practice their knowledge application without the financial, time, or safety costs. Second, simulations provide an opportunity to individuals to observe the outcomes of their decisions and actions without having to wait the actual length of time it would require to demonstrate such outcomes. By creating more temporal contiguity, individuals can better determine causal relationships between their decisions and the results.

SUMMARY

The goal of this paper was to identify a set of practical instructional variations and techniques that can enhance learning within simulation based training systems. It is additionally hoped that the provided explanations of how these interventions affect learners' cognitive processes differently depending upon their level of expertise, will allow for additional interventions to be developed based on a better understanding of the theory. Generally speaking, the goal of each intervention is to optimize the use of working memory in order to maximize the amount of information that segues to LTM and to optimize the organization of schema within LTM to improve knowledge application. It is noted throughout this paper that in order to accomplish that goal, training systems must vary the way information is provided and how simulated missions are organized based upon the trainee's current level of expertise and the type of knowledge being taught.

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