Simulation and Learning in Disaster Preparedness: A Research and Theory Review

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Because of perceived advantages, simulations are increasingly being used for performance-based training. This is a review of computer simulation as a learning tool, and its application within the context of disaster preparedness. Concepts from established learning theory are examined and research verifiable by empirical data is referenced. To summarize, this review found, despite a lack of empirical evidence, there exists wide support for computer simulation as a preferred tool in disaster preparedness.

Key words: Simulation, Learning, Disaster Preparedness

After the terrorist attack on the World Trade Center on September 11, 2001, questions were raised as to the adequacy of the overall preparedness that exists in this country to serious, unanticipated mass emergency events. Subsequent assessments of Federal, State, and Local emergency first response agencies revealed some serious deficiencies in preparedness. Of all jurisdictions responsible for disaster response, a thorough literature review (DeGraffenreid, 1999) revealed local preparedness to be among the weakest links in the emergency response chain. Now, four years post 9/11, Hurricane Katrina has again raised serious concern regarding the adequacy of this country's Federal, State and Local mass emergency response protocols. In this regard, one concept is clearly evident; a fully coordinated state of emergency response preparedness that links the national, state and local levels will ultimately depend on demonstrated competency of 1st responders at the local level. This necessitates relevant training, opportunity for practice of learned skills, coordinated mock drills/exercises for experience and a comprehensive evaluation of local responder competencies. These are aspects of Human Resource Development that link directly to and are within the purview of current HRD professionals. With this in mind, and because of certain perceived advantages, computer simulations are increasingly being used for performance-based training. This paper describes a current review of computer simulation instruction as to its effectiveness for performance-based learning specifically in disaster preparedness training.

Problem Statement and Research Proposition

There is evidence that authenticity in realism (termed *fidelity*) to the mass emergency experience may be integral to the instruction necessary to produce competency in emergency response personnel (Lebow, 1994). However, sole reliance on first-hand application of competent response within actual emergency events by classroom-trained responders is impractical; there is no guarantee of proficient performance in the field. Further, it could be deemed an irresponsible, if not unethical, expectation. To approximate the type of fidelity necessary to practice a contrived mass emergency event through a full-scale role-play or drill is also impractical; the costs are prohibitive in terms of time, money, and personnel. To employ a "*next best*" instructional alternative whereby costs are maintained at a feasible limit without compromise to competency in *readiness*, computerized simulations are currently being used and are being widely advocated for future training (Doyle, 2005).

There is ample literature describing the use of simulations in instruction and learning in several different settings (Smith, 1986; Tennyson, 1987; West, 1991). However, evidence attesting to an increased learning effectiveness with computer simulated instruction vs. conventional classroom strategies is sparse. Remarkably, with the exception of several "no significant difference" (NSD) findings, research on computer simulations has been absent significant empirical evidence of an improved learning outcome over conventional, classroom methods. This seems to be in stark contrast to what may be anticipated. Computer simulations offer the opportunity for "risk-free" exercise experience without the undue consequence of property damage or personal harm. Further, it could be anticipated that the opportunity for practice with simulations is greater, allowing learned skills to be reinforced. The reported NSD results with simulated instruction, therefore, pose a conundrum when considering the generally held belief in the importance of skills *practice* as an essential component in instructional systems design (Seels & Richey, 1994). The need to gain insight into this unexpected dilemma, as well as the increase in demand for its use, has warranted this review. With this in mind, the following proposition has been formulated.

It is proposed that, in lieu of experience gained in actual disaster incidents, simulations offer an equivocal option for effective skills practice in a mass emergency/disaster context within realistically represented learning situations at a significantly low risk of personal injury/property damage, and at manageable cost.

To test the proposition, this review considered two research questions:

1. Does computer simulation provide an effective *instructional tool* for disaster preparedness in terms of measured improvement in learning?
2. As a *learning strategy* for disaster preparedness, does computer simulation provide for the desired outcome of improved performance in the field?

Methodology & Scope

This literature review focused on the effectiveness of learning outcomes that can be achieved through training or instruction within computer-based environments. Recognized learning theory (in particular, *constructivist learning theory*), has been assessed where its application appears to support expected learning outcomes. Where possible, however, emphasis was placed on research that yields outcomes that are verifiable by empirical data. In this computer-based search, there were multiple key words used. It is notable that the most productive key phrase was found to be "computer simulation," followed by a wide selection of specific fields dealing with learning and/or performance, (e.g., "computer simulation & experiential learning", "computer simulation & performance outcomes", etc.). With the exception of early studies considered to be seminal to the subject of learning theory (Bruner, 1966; Jonassen, 1977; Vygotsky, 1978), the review cites findings from recently published and/or currently recognized scholarly research, and takes into account the most recent applications of computer technology. In the course of this study, there has been an underlying salient question that may never be adequately answered, but none-the-less, needs to be raised. If there is an acceptable degree of preparedness, *what is it and how is it best measured*? While this study can provide direction towards a possible resolution to that question, it is not the intent nor objective of the study to provide a definitive answer. That scope is broader than this investigation can address.

Theoretical Framework

Simulation as an Instructional Strategy

The instructional value of computer simulations by virtue of their richness of content, authenticity, and multi-sensorial affect, is seemingly unquestionable. A significant amount of the research reviewed seems to assume an inherent effectiveness of simulations as though intuitively obvious. The results suggest that simulations are at least as effective in learning outcomes as those achieved in actual laboratory exercises or case studies (Agrait, 2004; Gredler, 2004; Lee, 1999; Morgan, 2000; Smith, 1986; Tennyson, 1987; West, 1991; Yildiz, 1992). When one considers time and resource savings after development, and ever-increasing improvements in computer and instructional technologies, the use of simulations could become the primary instructional tool of choice for performance-based training. At the very least, their use could become standard as preferred instructional supplements for certain training situations. The considerable use of computer-based simulation in aviation pilot training is a familiar historical example (Franchi, 1995; Ericksson, 1999). It is worth noting that the physical infrastructure of training tools in that industry exceeds that which would likely be feasible for local emergency preparedness training. But the similarity in concept applies.

In an interactive instructional computer simulation, participant(s) take on a particular role in actively addressing a given situation and experience the effects of their decisions, including the social and physical aspects of their role and their defined responsibilities and constraints. A simulation provides to participants an *ill-structured* problem (not strictly defined) of *low transparency* (without an immediately obvious solution) but with potentially several parameters (reinforcements or constraints) and possible pathways of action (options) that may appropriately address the problem (Jonassen, 1997).

Despite claims of significant effectiveness, it has been difficult to locate sufficient empirical evidence to assess the actual positive learning and performance outcomes that are realized through simulation instruction. Without such data, there remains an inability to predict with certainty the degree of knowledge that will be transferred from simulated exercises to real, ongoing mass emergency/disaster events.

Simulation Application in Disaster Preparedness

When a disaster incident occurs, the Fire, Police, Emergency Medical (EMS) and Public Health[1] agencies individually respond to employ the specific aid that each agency has been professionally trained to provide. However, what are not always prepared for are the unique and unanticipated inter-agency interactions (variables) that may be encountered which may require unplanned coordination but are none-the-less necessary to effectively mitigate the emergency and the extent of damage (outcome).

External and internal factors within each agency can influence the effectiveness of that agency's response and, in turn, the effectiveness of the total, four-agency emergency response. Any inconsistency or conflict in coordination and/or collaboration amongst responding agencies will produce a performance gap between the optimal and actual actions taken. Minimization of any performance gap(s) is the ultimate objective of disaster preparedness. Figure 1 shows an example of an assessment model as it would apply to one of the response agencies, Public Health.

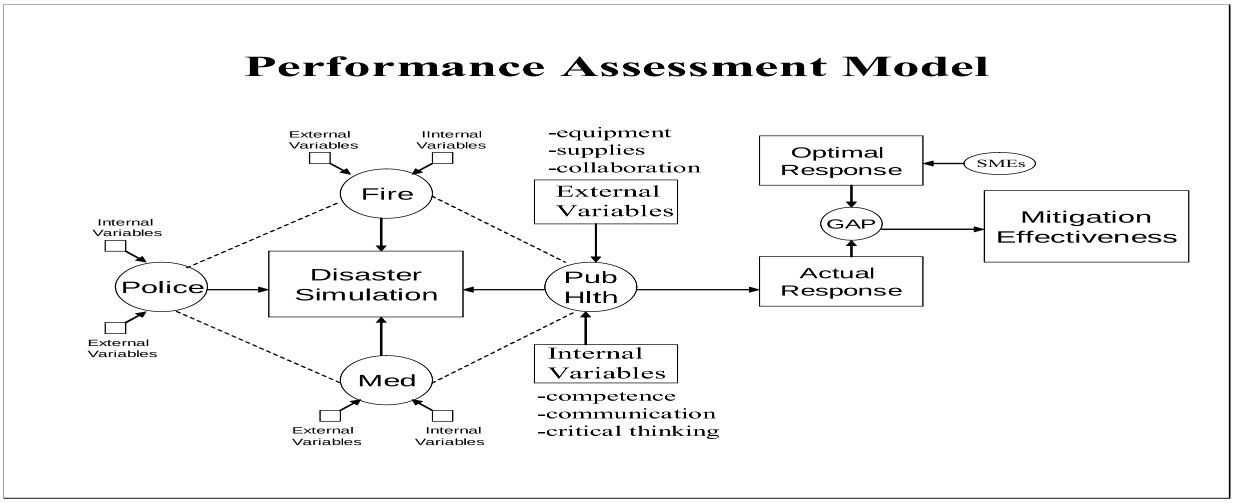

Figure 1. *Assessment Model for Public Health*

Like Public Health, the Fire, Police and Medical (EMS) agencies are also impacted by various external and internal factors that will influence effectiveness of overall performance (mitigation). As depicted in the model, optimal response in a simulated exercise is that performance defined as optimal by subject matter experts (SMEs) who are experienced in disaster response and who have been familiarized with the pertinent factors included in the simulated instructional exercise. All agencies need to interact collaboratively, and the actual agency(s) performance would be evaluated according to SME-defined criteria.

Results and Findings

Theories of Learning Associated with Computer Simulation

No single learning theory accounts for the use and effectiveness of simulation in learning. Rather, several theories lend validity to its application. The fundamental similarities in these theories are that learning is an active process, best experienced within a realistic context, to allow for application and use (transfer) of knowledge to realistically the same, or similar, situations. All of these theories are, or are related to, the *constructivist* learning theory. *Constructivism* has been described (Kauchak & Eggen, 1998, p. 184). as a "view of learning in which learners use their own experiences to construct understandings that make sense to them, rather than having understanding delivered to them in already organized form. Learning activities based on constructivism put learners in the context of what they already know, and apply their understanding to authentic situations." Table 1 provides a summary of several learning approaches that have incorporated simulation as an instructional strategy. As a

[1] We realize that the first responder community can be broader than these four agencies to include State, Federal, and other local agencies and even broader to the private sector. However, these four are the primary local organizations designated as first responders, so we will concentrate our efforts initially on them.

detailed examination of these theories is not practical nor within the scope of this article, the interested reader is directed to the references cited to pursue additional elaboration.

Variables Affecting Computer-Simulated Instruction Outcomes

Degree of Simulation Fidelity & Richness. As this review earlier proposed, to be most effective as a learning tool, computer simulations need to provide learning experiences that are as representative of the actual experience as possible (Standen, 1996). This is the simulation *fidelity* and is characterized by both a *realistic experience* and a *realistic learning environment*. Simulations low in fidelity may be low in realism and presumably lower in learning effectiveness. The Simulation Interoperability Standards Organization (SISO) adopted a formal definition of *simulation fidelity* as "the degree to which a model or simulation reproduces the state and behavior of a real world object, or the perception of a real world object, feature, condition, or chosen standard in a measurable or perceivable manner."

Table 1. *Learning Theories and Simulation Strategies*

Theories	*Principles*	*Goals*	*Strategies*
Experiential Learning (Kolb, 1984)	Learning is a cycle involving experiencing, reflecting, thinking, and acting.	Usable knowledge created through transformation of experience	Simulated exercise for experience. Role Plays. Coaching. Learning through Doing.
Situated Learning (Lave, 1990)	Learning is a function of the activity, context, & culture in which it occurs.	Application of learned knowledge in similar (not necessarily same) context	Knowledge must be presented in an authentic context. It requires social interaction and collaboration.
Problem-Based Learning (Vygotsky, 1978)	Focus is on problem to be solved vs. content to be mastered	Develop reasoning skills, self-directed strategies	Present learners with "ill-structured" simulated problem situation to be mitigated.
Discovery Learning (Bruner, 1966)	Learners explore problem and discover/retain solution concepts aided by prior knowledge	To independently solve problems through informed decisions	Use virtual simulated exercises, role plays, concept mapping.
Computer-Supported Collaborative Learning (Koschmann, 1996)	Learning occurs through knowledge-sharing and collaboration among multiple participants.	Facilitate & optimize collaborative understanding through computer-assisted learning.	Computer simulations, games providing authentic learning scenarios for multiple participants.

There is also indication that the amount of *detail* in a simulation has an impact. This degree of detail in a simulation is defined as its *richness*. Because any simulation is only a representation of some reality, most of the value is in its ability to simplify the complexity of the real world into a form that is comprehendible and usable. Frequently, simulation designers include all the fidelity and richness they can afford, without consideration of the overload burden that is created and the reduced benefit that results. A highly detailed and "over-engineered" training simulation may in its complexity obscure the real issues for which training is required. That would undermine one of the real values of simulations, i.e., the abstracting away of irrelevant details. Each component to be learned from a particular computer-simulated instruction can have its own learning objective (e.g., factual comprehension, procedural accuracy, etc.). Accordingly, the degree of *fidelity and richness* may be relevant to a specific learning context, and their significance will likely vary with the needs of that particular context.

Qualitative vs. Quantitative Fidelity. A *quantitative* measure of simulation fidelity as described in the SISO definition is "objective" and not easily obtained. *Qualitative* measures may be "subjective" but, in general terms, they can be understood (e.g. "spicy" food, "chilly" evening, etc). Without resorting to various quantitative methods that may prove ambiguous, it could be possible to compare one simulation to other simulations designed to meet the same objectives in order to gauge its effectiveness for that purpose (Quarantelli, 2000). In doing so, it is conceivable that the *validity* of the simulation in meeting intended objectives may be determined. It may be that the validity of a simulation is more critical than its fidelity. Here, simulation validity refers to that quality of being inferred, deduced, or calculated correctly enough to specifically apply to a particular problem situation.

Novice vs. Experienced Simulation Learners. Choice of simulation representations will depend not only on the application context, but on the level of participants' experience with learning from simulations. Novices learn best with lower level fidelity, while experienced learners do better with high fidelity (Chen, 2004). The difference appears to be due to the richness of the simulated presentation. For novices, high fidelity may provide too much information to process rapidly, resulting in response delays. For learners experienced with simulation instruction, too simplistic a presentation may not engage the learner and concentration can drift or be lost. Where novices may also be lacking in prior emergency response experience, this will further impact computer simulated instruction and delay. Acceptable *individual* competence may need to be gained before group (team) competence in response can be accomplished.

Lessons from Computer-based Instruction. A recent meta-analysis (Lowe and Holton, 2005) of computer-based instruction sheds some light on the various interactions of instructional design, learner characteristics and learning outcomes that have relevance to this investigation. They investigate a number of relationships that are too numerous to review here, but there are important conclusions that should lend themselves to generalization for computer-based simulation instructional environments. Among those of importance include the following:

- Learning to perform in complex problem-solving environments requires more elaborate feedback mechanisms and considerably more practice opportunity. These are especially effective with learners having high meta-cognitive skills. Where there is a high internal locus of control, high meta-cognitive skills, and high motivation, there is less need of support required to achieve effective learning.
- Instructional strategy selection should precede visual design for learning to be most effective. Over-engineering graphic interfaces, including screen display, the amount of information available and the feedback process is likely to result in a mismatch between learning goals and instructional strategy.
- Instructional strategy design is also influenced by certain learner characteristics such as self-directedness and motivation, prior computer experience, amount of external/environmental support (appropriate computer equipment, technical support, time released to participate, support from peers, supervisors, management) and clearly specified personal learning objectives.
- Simulations would appear to be better suited for environments where higher-order learning outcomes are desired. In fact, Lowe and Holton found evidence that simple learning tasks requiring the use of simple resources led to learning outcomes that were insignificantly impacted by computer-based delivery. It appears the use of simulation for low level learning outcomes would be a waste of resources. In contrast, emphasis on higher-order outcomes would require learners to generate solutions to problems and demonstrate the application of rules learned.

Why the Ambiguity in Performance Measurements?

In reviewing the literature, and in discussions with key simulation researchers, there are at least two causes proposed which may explain the NSD effectiveness found between conventional classroom and computer simulation instruction. The first appears to be the ambiguity inherent in the measurement methods that have been used. Much of the evaluation has involved surveys or anecdotal recall and not quantitative measurement. A basic means of determining if transfer of learning has occurred is by direct observation of the learned tasks/procedures being applied (Kirkpatrick, 1998). In an emergency scenario, there may be several ways to address a single problem or procedure, complicating the observation of a "correct" learned application. Events occur simultaneously, by chance, and not necessarily in sequence, further hindering evaluation. It seems comprehensive evaluation would require an army of evaluators, each measuring a specific response that can be directly correlated back to a specific instructional aspect of the simulation, and that clearly is impractical.

The second explanation relates to the ambiguity that exists in the computer-simulation learning process itself. The process still has not yet been satisfactorily defined to be clearly understood. It is here where side-by-side comparisons become somewhat futile, like comparing the proverbial apples to oranges. Simulation is multi-sensory in its instructional impact unlike any other instructional strategy. As such, a comparison assessment of simulation with another instructional method (e.g. conventional classroom) is inappropriate because the measurable outcomes are not likely to be the same. Two simulations, however, may be compared against each other (Quarantelli, 1989), and the inherent pros/cons of the simulation instruction technique itself should reasonably be identifiable, and measurable. A comparison of two *like* simulations would seemly provide the most meaningful measurable results.

A Design Framework for Disaster Preparedness Instruction

Disaster preparedness involves a "readiness to respond and suggests purposive, or anticipatory action. It implies the knowledge of appropriate behavior, conveys the need for training and practice, and subsequent capability to achieve purposes." (Gillespie, 1993). This review has focused on that aspect of "readiness to respond" that computer simulated instruction may provide. There are nine (9) attributes that have been identified which can guide the development of exercises / drills / participatory events, etc., to produce an effective degree of disaster preparedness.

Experiential Learning

The design of the exercise should, as a minimum, take into account primary principles of experiential learning, including situated and adult learning (Fenwick, 2000; Henning, 1996). The experiential learning cycle of *Experience*→ *Reflection*→ *Generalization*→*Application* (recycling back to)→ *Experience* is advocated. Experiential learning principles hold that an individual acquires useful knowledge or learning for future behavior and application to necessary tasks through the experiences of participation, as opposed to pure cognitive learning that may be acquired through structured classroom situations. Thus, a more participative, interactive, and reflective environment for learning should be designed to incorporate this approach to learning. It should be noted that such environments (while seeming to mirror a *preferred* approach advocated by many first responders) may not result in a *single most effective* learning outcome (for an individual or a group).

Multi-Learner/Collaborative Activities

The potential use of exercises for learning events which assumes a multi-learner environment is important. More specifically, groups of learners should be placed together to achieve the exercise objectives. This is one of the fundamental components of the Activity Learning Theory, whereby higher order/critical thinking learning is enhanced in individuals interacting within a group experience (Hannafin & Land, 1997). Careful attention is required regarding not only how the groups are formed (in order to best accomplish the objectives) but also designing activities that utilize sound participatory and collaborative principles. While such activities may not involve 'teams' per se, team-like activities that benefit individual learners is an important consideration**.**

Definition of Objectives

One of the issues emphasized in the literature, and personally observed in numerous exercises over a two-year period (2003-2005), is the specification of measurable objectives that are aligned with the exercise environment. Whether it be the lack of particular objectives, the over-specification of objectives, or the imprecise wording of objectives, more attention to the development of clear, attainable objectives is essential. Furthermore, the objectives should be stated with language that specifies performance (what participants are supposed to do in action terms), conditions (the situation, describing available resources), and criteria (how well the learner must perform, or what is considered acceptable).

Realism (Fidelity)

The situation posed by the exercise should have two components of realism (ThoughtLink, Inc., 2004). One is that the scenario should reflect as much as possible the general type of conditions present in a disaster or emergency, possibly based on past real occurrences. Second the exercise should be realistic on a more personal side, reflecting the regional environment with local landmarks, use of local resources and organizational culture considerations (i.e. with specificity). The degree of fidelity must take into account prior simulation learning-experience, with the complexity being low to moderate with less experienced individuals and increasing in detail with more experienced learners.

Repetition (Frequency)

It is impractical to assume that a single exercise focused on a given knowledge/skill set is sufficient to assure competency. Repeated experiences are needed to strengthen and instill the correct behaviors associated with necessary performance, increase the fluency in decision-making skills, and increase problem-solving capacity.

Safety

Exercises should reinforce the use of recognized safe protocol as a requirement for disaster/emergency response and/or performance under adverse conditions (ThoughtLink, Inc., 2004). Thus, exercises should expose participants to simulated (only) hazardous conditions for problem-solving and simulated (only) dangerous events which are also necessarily linked to the use of safe procedures and actions to be reinforced. *Critical Thinking & Problem-Solving.*

When considering the use of *advanced* exercises (i.e., those that go beyond simple awareness and application of basic skills and knowledge), activities should be constructed with unusual or unanticipated consequences. The objective is to provide experience in modeling the control of the unexpected. Such activities would introduce high-stress response situations, but in the "risk-free" simulated format. The degree of accuracy, efficiency, and timeliness should be specifically defined in measurable terms.

Use of Existing Protocols

Exercises should be designed for participants to use practiced, standardized procedures in order to test both the adequacy/effectiveness of the procedures as well as the ability of participants to correctly and appropriately apply them. This can assist in potential refinement in the efficiency, effectiveness and clarity of the procedure documentation. In addition, sophistication in the exercise design could be modulated to generate data to be subsequently examined/analyzed by protocol designers for the purpose of performance improvement. As an extension, this activity would also have implications for organizational performance.

Measurement of Performance

A critical component of learning exercises is that they be designed to facilitate the collection, measurement, and analysis of learner performance. Actions such as response time, decision steps, resource expenditures, communication, information sharing, use of expert advice, casualty counts, etc., can be recorded by observers during the course of the exercise. Results of such measurement could potentially be linked to certification procedures.

Conclusion and Recommendation

Few studies have been successful in generating quantitative empirical data which demonstrates specific improvements in measurable learning effectiveness of simulations or improved performance as a result of computer simulated preparedness instruction. Much of the research data is based on interview and observational data that lacks substantiation, or on determination of efficiencies in costs or time reduction. Yet, the use of computer simulations for instruction in a multitude of disciplines is increasing almost exponentially as technology advances are achieved and used. Quite literally, the use of computer simulation instruction appears to be out-pacing the research on its learning effectiveness. The experience in the use of computer simulation and simulators in such key instructional contexts as pilot/astronaut flight training and nuclear power plant operation provide a historical record in support of simulation effectiveness with regard to high stress situations. With this historical experience, and based on the body of literature reviewed, there has been a significantly favorable experience with the use if computer simulations in instruction in general, and now specifically, with instructional exercises for disaster preparedness. Based on the currently limited quantitative evidence, but more considerable qualitative support, the body of evidence from this literature review is supportive of simulation as an effective instructional strategy. Given the appropriateness of their fidelity and richness, simulations can provide realistic learning situations at the lowest possible risk of personal injury/property loss. With a reduced reliance on significant resources, simulations can provide an equivocal learning experience at manageable cost.

In the emergency preparedness field of application, there is currently a significant interest in a “blended instruction” approach to first responder preparedness training (e.g. Department of Homeland Security. 2004). *Blended Instruction* (a.k.a. *hybrid instruction*) involves the use of a *mix* of conventional and online instructional strategies. Computer simulation is supported to contribute to a blended format for mass emergency/disaster preparedness training, particularly where performance vs. factual knowledge is the instructional criterion and objective for learning. The design strategy framework for simulated disaster preparedness should be subject to continuous improvement modification as technology progresses, experience is gained from its use, and its effectiveness is validated via ongoing evaluation. In linking this review to HRD, this article constitutes an examination and synopsis of the current research regarding computer simulation effectiveness as a learning tool, in this case, specifically to disaster preparedness. The information can arguably apply to any team-oriented training context where collaboration is critical to group effectiveness. From a Human Resource Development perspective, the knowledge gained from a practical and theoretical standpoint supports and furthers the *group-think* concept to achieving both individual and team competencies. In the case of disaster preparedness competency, this is critical where experience through physical, real-world practice is constrained yet competence in on-site performance is crucial. This responsibility to develop competency in personnel more often than not is a direct responsibility of the Human Resource Development professional. This review can assist the HRD professional in that effort and also supply valuable empirical data, which is currently lacking, but which would support continuing research on computer simulation effectiveness in general.

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