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GAMES AND SIMULATIONS AND THEIR RELATIONSHIPS TO LEARNING

Margaret E. Gredler
University of South Carolina

21.1 INTRODUCTION

Educational games and simulations are experiential exercises that transport learners to another world. There they apply their knowledge, skills, and strategies in the execution of their assigned roles. For example, children may search for vocabulary cues to capture a wicked wizard (game), or engineers may diagnose the problems in a malfunctioning steam plant (simulation).

The use of games and simulations for educational purposes may be traced to the use of war games in the 1600s. The purpose was to improve the strategic planning of armies and navies. Since the 1800s, they have served as a component in the military planning of major world powers. In the 1950s, political–military simulations of crises, within the context of the Cold War, became a staple at the Pentagon. The first exercises involved a scenario of a local or regional event that represented a threat to international relations. Included were a Polish nationalist uprising similar to the 1956 Hungarian revolt, the emergence of a pro-Castro government in Venezuela, insurgency in India, and Chinese penetration into Burma (Allen, 1987). Each simulation began with a scenario, and the exercise unfolded as teams representing different governments acted and reacted to the situation.

Since the late 1950s, the use of simulations has become a staple of both business and medical education, and games and simulations are found in language and science education and corporate training. Further, designers have specified both the intellectual processes and the artifacts and dynamics that define games and simulations (see Gredler, 1992; Jones, 1982, 1987; McGuire, Solomon, & Bashook, 1975). Briefly, games are competitive exercises in which the objective is to win and players must apply subject matter or other relevant knowledge in an effort to advance in the exercise and win. An example is the computer game Mineshaft, in which students apply their knowledge of fractions in competing with other players to retrieve a miner's ax.

Simulations, in contrast, are open-ended evolving situations with many interacting variables. The goal for all participants is to each take a particular role, address the issues, threats, or problems that arise in the situation, and experience the effects of their decisions. The situation can take different directions, depending on the actions and reactions of the participants. That is, a simulation is an evolving case study of a particular social or physical reality in which the participants take on bona fide roles with well-defined responsibilities and constraints.

An example in zoology is Tidepools, in which students, taking the role of researcher, predict the responses of real tidepool animals to low oxygen in a low-tide period. Another is Turbinia, in which students diagnose the problems in an oil-fired marine plant. Other examples include diagnosing and treating a comatose patient and managing the short- and long-term economic fortunes of a business or financial institution for several business quarters.

Important characteristics of simulations are as follows: (a) an adequate model of the complex real-world situation with which the student interacts (referred to as fidelity or validity), (b) a defined role for each participant, with responsibilities and constraints, (c) a data-rich environment that permits students to execute a range of strategies, from targeted to "shotgun" decision making, and (d) feedback for participant actions in the form of changes in the problem or situation. Examples of high-fidelity simulations are pilot and astronaut trainers.

In the 1980s, the increasing capabilities of computer technology contributed to the development of a variety of problem-based exercises. Some of these exercises present the student with a nonevolving straightforward problem accompanied by one or more dynamic visuals or diagrams. Such exercises are sometimes referred to as simulations or simulation models, on the basis of the graphics or the equations that express a relationship among two or three variables. However, solving a well-defined problem is not a simulation for the student. In other words, like the real world, a simulation is an ill-defined problem with several parameters and possible courses of action. Discussed in this chapter are a conceptual framework for games and simulations, current examples, and unresolved issues in design and research.

21.2 CONCEPTUAL FRAMEWORK

Two concepts are important in the analysis of games and simulations: surface structure and deep structure. Briefly, *surface structure* refers to the paraphernalia and observable mechanics of an exercise (van Ments, 1984). Examples in games are drawing cards and clicking on an icon (computer game). An essential surface structure component in a simulation, in contrast, is a scenario or set of data to be addressed by the participant.

Deep structure, in contrast, refers to the psychological mechanisms operating in the exercise (Gredler, 1990, 1992). Deep structure is reflected in the nature of the interactions (a) between the learner and the major tasks in the exercise and (b) between the students in the exercise. Examples include the extent of student control in the exercise, the learner actions that earn rewards or positive feedback, and the complexity of the decision sequence (e.g., number of variables, relationships among decisions).

Shared features of games and simulations are that they transport the student to another setting, they require maximum student involvement in learning through active responding, and the student is in control of the action. However, in addition to having different purposes, they differ in deep structure characteristics. Included are the types of roles taken by individuals, nature of the decisions, and nature of feedback.

21.2.1 Games in Education and Training

Academic games are competitive exercises in which the objective is to win. Action is governed by rules of play (including penalties for illegal action) and paraphernalia to execute the play, such as tokens, cards, and computer keys (Gredler, 1992). Examples range from simple exercises, such as matching fractions to their decimal equivalents, to more complex contests, such as classroom tournaments involving several teams. The deep structure of games includes (a) competition among the players, (b) reinforcement in the form of advancement in the game for right answers, and (c) actions governed by rules that may be imaginative. For example, the rules may specify the point values of different clues that can assist the player to find a hidden pot of gold.

21.2.1.1 Purposes. Academic games may fulfill any of four purposes: (a) to practice and/or refine already-acquired knowledge and skills, (b) to identify gaps or weaknesses in knowledge or skills, (c) to serve as a summation or review, and (d) to develop new relationships among concepts and principles. Games also may be used to reward students for working hard or as a change of pace in the classroom. Adaptations of Twenty Questions in which the goal is to identify a particular author, chemical compound, or historical event are examples.

21.2.1.2 Design Criteria. Well-designed games are challenging and interesting for the players while, at the same time, requiring the application of particular knowledge or skills. Five design criteria that are important in meeting this requirement are summarized in Table 21.1. As indicated, (1) winning should be based only on the demonstration of knowledge or skills, and (2) the game should address important concepts or content. Third, the dynamics of the game should fit the age and developmental level of the players. For older students, for example, interest may be added by assigning weights to questions according to their difficulty (1 = easy, 3 = difficult), accompanied by team choice in the level of questions to be attempted.

A problem, particularly in computer games, is that the use of sound and graphics may be distracting. Further, the learner is led to enter incorrect responses when the sound and/or graphics

TABLE 21.1. Essential Design Criteria for Educational Games

Criterion	Rationale
1. Winning should be based on knowledge or skills, not random factors.	When chance factors contribute to winning, the knowledge and, effort of other players are devalued.
2. The game should address important content, not trivia.	The game sends messages about what is important in the class.
3. The dynamics of the game should be easy to understand and interesting for the players but not obstruct or distort learning.	The goal is to provide a practical, yet challenging exercise; added "bells and whistles" should be minimal and fulfill an important purpose.
4. Students should not lose points for wrong answers.	Punishing players for errors also punishes their effort and generates frustration.
5. Games should not be zero-sum exercises.	In zero-sum games, players periodically receive rewards for game-sanctioned actions, but only one player achieves an ultimate win. The educational problem is that several students may demonstrate substantial learning but are not recognized as winners.

following a wrong answer are more interesting than the outcomes for right answers.

Finally, (4) students should not lose points for wrong answers (they simply do not advance in the game) and (5) games should not be zero-sum exercises (Gredler, 1992). In Monopoly, for example, one player wins, while others exhaust their resources. Alternatives in the educational setting include providing for several winners (e.g., team with the fewest errors, team with the best strategy) and defining success in terms of reaching a certain criterion, such as a certain number of points.

Advantages of games in the classroom are that they can increase student interest and provide opportunities to apply learning in a new context. A current problem in the field, however, is the lack of well-designed games for the classroom setting.

21.2.2 Simulations

Unlike games, simulations are evolving case studies of a particular social or physical reality. The goal, instead of winning, is to take a bona fide role, address the issues, threats, or problems arising in the simulation, and experience the effects of one's decisions. For example, corporate executives, townspeople, and government officials address the potential tourism threat of a proposed nuclear reactor near a seaside town. In another example, research teams address the health status of an ecosystem, developing and implementing models of the variables in the system, prescribing corrections for problems, and altering their hypotheses based on the effects of their decisions.

In other words, simulations can take any of several directions, depending on the actions and reactions of the participants and natural complications that arise in the exercise. They differ from role plays, which are brief, single incidents (10 to 20 min) that require participants to improvise their roles. An example of a role-playing exercise is a school principal dealing with an angry parent. In contrast, simulations address multidimensional evolving problems, run from 50 min to several days, and use role descriptions including goals, constraints, background information, and responsibilities.

21.2.2.1 Deep Structure. First, unlike games, in which the rules may be imaginative, the basis for a simulation is a dynamic set of relationships among several variables that reflect authentic causal or relational processes. That is, the relationships must be verifiable. For example, in a diagnostic simulation, in which the student is managing the treatment of a patient, the patient's symptoms, general health characteristics, and selected treatment all interact in predictable ways.

Second, simulations require participants to apply their cognitive and metacognitive capabilities in the execution of a particular role. Thus, an important advantage of simulations, from the perspective of learning, is that they provide opportunities for students to solve ill-defined problems. Specifically, ill-defined problems are those in which either the givens, the desired goal, or the allowable operators (steps) are not immediately clear (Mayer & Wittrock, 1996). Although most educational materials address discrete well-defined problems, most problems in the real world are ill-defined.

Third, feedback on participants' actions is in the form of changes in the status of the problem and/or the reactions of other participants. The medical student, for example, may make errors and inadvertently "kill" the patient and the company management team may, through poor decision making, "bankrupt" the company.

In other words, a complex scenario that can take any of several directions is a necessary, but not sufficient condition for a simulation. The related essential requirement, a key feature of the deep structure, is the experience of functioning in a bona fide role and encountering the consequences of one's actions in the execution of that role. This characteristic is referred to by Jones (1984, 1987) as "reality of function," and it includes the thoughts of participants as well as their actions or words. That is, "A chairman really is a chairman with all the power, authority, and duties to complete the task" (Jones, 1984, p. 45).

21.2.2.2 Advantages. The design and validation of simulations are time-consuming. However, simulations provide advantages not found in exercises using discrete, static problems. First, they bridge the gap between the classroom and the real world by providing experience with complex, evolving problems. Second, they can reveal student misconceptions and understandings about the content. Third, and particularly important, they can provide information about students' problem-solving strategies. For example, scoring medical students' treatment decisions in diagnostic simulations identifies strategies as constricted, shotgun, random, or thorough and discriminating (see Peterson, 2000).

The broad category of simulations includes two principal types that differ in the nature of participant roles and interface with the situation. They are experiential and symbolic simulations.

21.2.2.3 Experiential Simulations. Originally developed to provide learner interactions in situations that are too costly or hazardous to provide in a real-world setting, experiential simulations have begun to fulfill broader functions. Examples include diagnosing the learning problems of children and addressing social service needs of individuals in vocational rehabilitation.

Briefly, experiential simulations are social microcosms. Learners interact with real-world scenarios and experience the feelings, questions, and concerns associated with their particular role. That is, the learner is immersed in a complex, evolving situation in which he or she is one of the functional components. Of primary importance is the fit between the experience and the social reality it represents, referred to as fidelity or validity (Alessi, 1988). Well-known examples of high-fidelity simulations are pilot and astronaut trainers.

Three types of experiential simulations may be identified, which vary in the nature of the causal model (qualitative or quantitative) and type of professional role. They are social-process, diagnostic, and data management simulations. In the group interactions in most social-process simulations, contingencies for different actions are imbedded in the scenario description that initiates action and the various role descriptions. For example, the role cards for space crash survivors stranded on a strange planet each contain two or three unrelated bits of information

TABLE 21.2. A Comparison of Experiential Simulations

Defining characteristics	Social microcosms; individuals take different roles with particular responsibilities and constraints and interact in a complex evolving scenario.
Types	
Social process	Contingencies for different actions are imbedded in the scenario and role descriptions (a group exercise).
Diagnostic	Contingencies are based on the optimal, near-optimal, and dangerous decisions that may be made (may be an individual or a group exercise).
Data management	Contingencies are imbedded in the quantitative relationships among the variables expressed in equations (a group exercise).

important for survival (see Jones, 1982). Clear communication and careful listening by the participants are essential if they are to find food and water and stay alive.

In contrast, the model of reality in diagnostic or patient-management simulations is the patterns of optimal and near-optimal decision making expected in the real world. The sequential nature of the task links each decision to prior decisions and results. Therefore, as in real situations, errors may be compounded on top of errors as nonproductive diagnostic and solution procedures are pursued (Berven & Scofield, 1980). Diagnostic simulations typically are computer- based. The student reads a brief scenario and has several choices at each decision point, from requests for further information to solutions to the problem.

In data-management simulations, teams manage business or financial institutions. The basis for a data-management simulation is a causal model that specifies relationships among quantitative variables. Included are relationships among inputted data from participants and profitability, liquidity, solvency, business volume, inventory, and others. Each team receives a financial profile of the business or bank and makes decisions for several quarters of operation. Teams enter their decisions for each quarter into a computer, receive an updated printout from the computer on the financial condition of the institution, and make new decisions.

Table 21.2 provides a comparison of experiential simulations. Of importance in the design of experiential simulations is that the individual who is unsure of an appropriate course of action has plausible alternatives. This requirement is particularly important in diagnostic simulations in which the goal is to differentiate the problem-solution strategies of students in complex nontextbook problems.

21.2.2.4 Symbolic Simulations. Increased computer capabilities in recent years have led to the development and implementation of symbolic simulations. Specifically, a symbolic simulation is a dynamic representation of the functioning or behavior of some universe, system, or set of processes or phenomena by another system, in this case, a computer.

A key defining characteristic of symbolic simulations is that the student functions as a researcher or investigator and tests his or her conceptual model of the relationships among the variables in the system. This feature is a major difference between symbolic and experiential simulations. That is, the role of the learner is not a functional component of the system. A second major difference is the mechanisms for reinforcing appropriate student behaviors. The student in an experiential simulation steps into a scenario in which consequences for one's actions occur in the form of other participants' actions or changes in (or effects on) the complex problem or task the student is managing. That is, the learner who is executing random strategies typically experiences powerful contingencies for such behavior, from the reactions of other participants to being exited from the simulation for inadvertently "killing" the patient.

The symbolic simulation, however, is a population of events or set of processes external to the learner. Although the learner is expected to interact with the symbolic simulation as a researcher or investigator, the exercise, by its very nature, cannot divert the learner from the use of random strategies.

One solution is to ensure, in prior instruction, that students acquire both the relevant domain knowledge and the essential research skills. That is, students should be proficient in developing mental models of complex situations, testing variables systematically, and revising their mental models where necessary. In this way, students can approach the symbolic simulation equipped to address its complexities, and the possibility of executing random strategies holds little appeal.

Two major types of symbolic simulations are laboratory-research simulations and system simulations. In the former, students function as researchers, and in the latter, they typically function as trouble shooters to analyze, diagnose, and correct operational faults in the system.

Important student skills required for interacting with symbolic simulations are relevant subject-area knowledge and particular research skills. That is, students should be proficient in developing mental models of complex situations, testing variables systematically, and revising one's mental model when necessary. For example, interacting with a model of several generations of representatives of a species requires an understanding of classical Mendelian genetics and strategies for plotting dominant and recessive genes. Table 21.3 provides a comparison of the symbolic simulations.

21.2.3 Other Technology-Based Exercises

Two technology-based experiences sometimes referred to as simulations are problem-based exercises that include simulated materials and experiences referred to as virtual reality.

TABLE 21.3. A Comparison of Symbolic Simulations

Defining characteristics	A population of events or set of processes external to the learner; individuals interact with the information in the role of researcher or investigator.
Types	
Laboratory-research simulations	Individual investigates a complex, evolving situation to make predictions or to solve problems.
System simulations	Individuals interact with indicators of system components to analyze, diagnose, and correct operational faults in the system.

21.2.3.1 Problem-Solving Exercises with Simulated Materials. One type of exercise implements discrete problems on a particular topic for students to solve that are accompanied by dynamic visuals. Such exercises, however, are not simulations because they are discrete problems instead of student interactions with a data universe or a complex system in an open-ended exercise. That is, the task is to address well-structured finite problems that relate to a particular visual display. An example is the task of causing a space shuttle to come to a complete stop inside a circle (Rieber & Parmby, 1995). As in this example, the problems often involve only a relationship between two variables.

Other examples are the computer-based manipulatives (CMBs) in genetics developed by Horowitz and Christie (2000). The instruction combines (a) specific computer-based tasks to be solved through experimentation in two-person teams, (b) paper-and-pencil exercises, and (c) class discussions. Of interest is that a paper-and-pencil test after 6 weeks of classroom trials revealed no significant differences in the means of the computer-learning classes versus those of other classes.

Another project in science education has developed sets of physics problems on different topics accompanied by dynamic visuals. Examples include the effects of the strength of a spring on motion frequency and the influence of friction on both the frequency and the amplitude of motion (Swaak & de Jong, 2001; van Joolingen & deJong, 1996). Motion is illustrated in a small window surrounded by windows that provide instructional support to the learner in the discovery process. The learner inputs different values of a particular variable, such as the strength of a spring, in an effort to discover the relationship with an identified outcome variable (e.g., motion frequency).

The developers refer to a "simulation model" that "calculates the values of certain output variables on the basis of input variables" (van Joolingen & de Jong, 1996, p. 255). The "simulation," in other words, is the demonstrated reaction of a specified parameter that is based on the underlying relationships among the quantifiable variables. This perspective reflects the view of a simulation as "a simplified representation" (Thomas & Neilson, 1995).

The task for the learner is to infer the characteristics of the model by changing the value of an input variable or variables (de Jong & van Joolingen, 1998, p. 180). The expectation is that learners will formulate hypotheses, design experiments, interpret data, and implement these activities through systematic planning and monitoring (p. 186). The extensive problems of learners in the execution of these activities described by de Jong and van Joolingen (1998) indicate the high cognitive demands placed on the learner. That is, a lack of proficiency in the processes of scientific discovery learning coupled with the task of discovering aspects of an unknown model overtaxes the limits of working memory and creates an excessive cognitive load that hampers learning (for a discussion see Sweller, van Merrienbaer, & Paas, 1998).

Another approach to solving problems in physics consists of (a) the portrayal, using abstract symbols, of Newton's first two laws of motion and (b) student construction of experiments on the illustrated variables (the mass, elasticity, and velocity of any object, each portrayed as a "dot") (White & Fredericksen, 2000). Students, with support from the software, carry out the process of inquiry (stating hypotheses, collecting and analyzing data, and summarizing the results) with successive modules that become increasingly complex. Also included is reflective assessment, in which students evaluate their work. Data indicated that students who completed the projects with reflective assessment outperformed students who used the software without the reflective assessment component.

These exercises differ from simulations in three ways. First, the visuals illustrate discrete relationships, not a data universe or physical or biological system. Second, in some cases, abstract symbols (e.g., dots and datacrosses) are the components of the illustrated relationships. The "simulation," in other words, is an abstract model and "models, whether on or off the computer, aren't 'almost as good as the real thing'—they are fundamentally different from the real thing" (Horowitz, 1999, p. 195).

Third, a simulation includes the actions of the participants. For example, business simulations also rely on equations to specify the relationships among such variables as balance of payments, exports, price level, imports, world prices, and exchange rate (Adams & Geczy, 1991). Also, a key component is the involvement of participants in the well-being of the financial institution as they execute their responsibilities and experience (not merely observe) the consequences of their actions. In other words, one limitation of defining a simulation as the portrayal of content is that any of a range of student activities may be permitted in the exercises. That is, an exercise as simple as the learner selecting an option in multiple-choice questions could be classified as a simulation.

21.2.3.2 Virtual Environments. The term *virtual environment* or *virtual reality* refers to computer-generated three-dimensional environments that respond in real time to the actions of the users (Cromby, Standen, & Brown, 1996, p. 490). Examples include photographs "stitched together" to produce a computer screen that portrays a navigable 360° panorama of an urban environment (Doyle, Dodge, & Smith, 1998); total immersion systems that require headsets, earphones, and data gloves; and desktop virtual environments that implement a joystick, mouse, touch screen, or keyboard (Cromby et al., 1996). The intent is to convey a sense of presence for the participant; that is, the individual feels present in the computer-generated environment (p. 490). (For examples see Dede, Salzman, Loftin, & Ash, 2000).

Virtual environments, in other words, create particular settings and attempt to draw the participant into the setting. The question is whether virtual environments also are simulations from the perspective of learning. Again, the issue is the nature of the problem or situation the learner is addressing and the capabilities required of the learner. That is, Is it a complex, evolving reality? and What are the capabilities executed by the learner?

21.3 RESEARCH IN GAMES AND SIMULATIONS

Like other curriculum innovations, games and simulations are developed in areas where the designers perceive a particular instructional need. Examples include providing real-world decision making in the health care professions and providing opportunities for laboratory experimentation in science and psychology. Most developers, however, report only sketchy anecdotal evidence or personal impressions of the success of their particular exercise. A few documented the posttest skills of students or, in a simulation, the students' problem-solving strategies. None, however, addressed the fidelity of the experience for students for the types of simulations described in the prior section.

21.3.1 Educational Games

A key feature of educational games is the opportunity to apply subject matter knowledge in a new context. For example, the computer game Mineshaft requires the players to use fractions to retrieve a miner's ax that has fallen into the shaft (Rieber, 1996).

An innovative use of computer technology is to permit students to design their own computer games using particular content. One example, Underwater Sea Quest, involves the laws of motion. The goal is to help a diver find gold treasure while avoiding a roving shark (Rieber, 1996, p. 54).

Although educational games are accepted in elementary school, teacher and parent interest in their use declines in the later grades (Rieber, 1996). However, one use is that of providing health and human services information to adolescents, an area in which maintaining the attention of adolescents is a challenge (Bosworth, 1994). In the Boday Awareness Resource Network (BARN), AIDS information is addressed in an elaborate maze game. The object is to move through and out of a maze that is randomly generated by the computer by correctly answering questions on AIDS (p. 112). A further challenge is the capability of the computer to generate randomly a new maze for each game. Anecdotal evidence from students indicated the success of the game in enticing students to the BARN system (p. 118).

21.3.2 Experiential Simulations

Social-process simulations, one of the three categories of experiential simulations, often are developed to provide experiences in using language to communicate for various purposes. However, advances in programming have precipitated interest in developing desktop visual reality simulations in different educational settings. One suggested application is that of providing environments for learning-disabled students to develop independent living and survival skills (Cromby et al., 1996; Standen & Cromby, 1996). An example is shopping in a supermarket. The computer presented a two-aisle store with five different layouts of goods presented at random each time a student began a session. Participants used a joystick to navigate the aisles and selected items on their list with a mouse (Standen & Cromby, 1996). In the follow-up involving a trip to a real store, severely disabled students were more successful than their counterparts in a control group.

Diagnostic simulations is the second category in experiential simulations. These exercises, in which participants take professional roles that involve problem solving, may be developed for any age group. Although the majority are found in higher education, Henderson, Klemes, and Eshet (2000) describe a simulation in which second-grade students take the role of paleontologist. Entitled Message in a Fossil, the computer-based simulation allows the participants to excavate in virtual gridded dig-sites using appropriate tools (p. 107). Among the 200 fossils are dinosaur bones, fish skeletons, sea urchins, shark teeth, and fern leaves. Students predict the fossil types and then identify them through comparison with pictures in the fossil database. Posttest data indicate positive learning outcomes, internalization of scientific terminology (e.g., habitat, evidence), and personal investment in the exercise. The teacher noted that children felt like scientists by their use of statements such as "We are going to collect data" and "We are going to make observations" (p. 121).

In higher education, diagnostic simulations originally were developed for medical education. They have since expanded into related fields, such as counseling (see Frame, Flanagan, Frederick, Gold, & Harris, 1997). One related area is rehabilitation counseling, where simulations were introduced in the 1980s to enhance students' clinical problem-solving skills (see Berven, 1985; Berven & Scofield, 1980). An important characteristic of the medical model, implemented in rehabilitation counseling, is the identification of the effectiveness of students' problem-solving strategies. For example, a study by Peterson (2000) with 65 master's-degree students found four types of problem approaches. They are thorough and discriminating, constricted, shotgun (high proficiency and low efficiency scores), and random (low on both proficiency and efficiency scores). The study recommended that students with less than optimal approaches work with their mentors to develop compensatory strategies.

The largest group of experiential simulations is the data-management simulations, and their use in strategic management courses is increasing (Faria, 1998). Unlike the other experiential exercises, data-management simulations include competition among management teams as a major variable. This feature is reflected in some references to the exercises as games or gaming- simulations. Some instructors, for example, allocate as much as 25% of the course grade to student performance (Wolfe & Rogé, 1997). However, one problem associated with an emphasis on winning is that, in the real world, major quarterly decisions are not collapsed into a brief, 45-min, time period. Another is that a focus on winning can detract from meaningful strategic planning.

One analysis of the characteristics of current management simulations, a review of eight exercises, indicated that most provide some form of international competition and address, at least minimally, the elements involved in making strategic decisions (Wolf & Rogé, 1997). Identified deficiencies were that simulations did not force participants to deal with the conflicting demands of various constituencies and did not allow for the range of grand strategies currently taught in management courses (p. 436). Keys (1997) also noted that management simulations have become more robust and strategic in recent years, with more industry, realism, and technological support. Further, the simulations have included global markets, and global producing areas and finance options.

Although early research with data-management simulations compared their use to case studies or regular class instruction, the recent focus is on analyses of student behaviors in the exercises themselves. One study found, for example, that a competitive disposition in management teams is not related to performance (Neal, 1997). Further, although winning teams perceived that they had implemented the most competitive strategies, group cohesion was a major factor in performance (Neal, 1997). Another study found that students' self-efficacy (belief in one's capabilities) in using strategic management skills is not explained by the use of case studies and simulations. Predictor variables, which included teaching methods, accounted for only 14.8% of the variance in students' self-efficacy (Thompson & Dass, 2000).

Another study analyzed the factors that contributed to poor performance in a simulation that involved the management of a small garment manufacturing company (Ramnarayan, Strohschneider, & Schaub, 1997). The participants, 60 advanced students in a prestigious school of management, formed 20 teams and managed the company for 24 monthly cycles (3 hr). Factors that contributed to poor performance were (a) immediately making calculations without first developing a coherent mental model or setting goals and objectives, (b) following a "repair shop" principle (wait for problems and then respond), and (c) failing to alter plans in the face of disconfirming signals. Finally, the researchers noted that the participants were proficient in basic knowledge but lacked metaknowledge (p. 41). An important component of metacognition, metaknowledge refers to knowing what we know and what we do not know. This capability is essential to the identification of key issues in data collection to solve problems.

21.3.3 Symbolic Simulations

Symbolic simulations are referred to by some as microworlds. That is, a microworld is "a computer-based simulation of a work or decisionmaking environment" (Sauer, Wastell, & Hockey, 2000, p. 46). Of major importance for participant roles, however, is that the decision-making environment constitute a system. An example is the Cabin Air Management System (CAMS), a generic simulation of the automated life support system in a spacecraft. Developed to research the multiple effects of factors that influence human performance in complex systems, scenarios implemented with CAMS have investigated human adaptive strategies in the management of varying task demands (Sauer et al., 2000).

In science education, simulations often are viewed as a means for students to use discovery learning and usually are considered an alternative to expository instruction or hands-on laboratory exploration (Ronen & Eliahu, 2000, p. 15). In one study, one group of students received a computer disk that contained simulations of electric circuits and activities that were part of their homework. However, at the end of 6 weeks, no significant differences were found between the experimental- and the control-group classes (Ronen & Eliahu, 1998). The posttest data also indicated that both groups held key misconceptions, such as that a battery is a source of constant current. In a follow-up study 1 week later, the classes were assigned the laboratory task of building a real circuit so that the light intensity of the bulbs varied in a particular way. Experimental classes that used the simulation to test their plans outperformed the control groups, whose only opportunity to obtain feedback was in the physical trials of their circuits (Ronen & Eliahu, 2000). However, the simulation served only as a feedback device. Neither the experimental nor the control group designed their circuits using a theoretical model.

In other subject areas, the combination of hypermedia with video images can be used to create a virtual experience for students who are fulfilling roles as researchers. Examples are A Virtual Field Trip—Plant Collecting in Western New South Wales and Blue Ice: Focus on Antarctica (Peat & Fernandez, 2000). In the latter example, in addition to collecting and analyzing data, students research wild life and weather topics. Another example, used in zoology, is Tidepools, in which students (a) explore the ways in which a hypothetical tidepool animal might respond to low oxygen in the low-tide period and (b) predict the responses of four real tidepool animals (Spicer & Stratford, 2001, p. 347). To complete phase 2, students obtain relevant information on each species by searching a virtual tidepool. Students also are provided with a field notebook into which they may transfer pictures and text. Also included is a visible talking tutor who introduces the tasks and explains how to proceed and what can be done (p. 348).

Student responses to survey items were highly positive. Also of interest is that students, in unsolicited comments on their questionnaires, indicated that they learned more quickly and effectively when staff were present to discuss "emerging issues" (p. 351).

Of particular interest is that, immediately following the exercise, students perceived that Tidepools provided the same experiences as a real field trip. However, following an actual field trip, student perceptions changed significantly ($p < .0001$). That is, the majority indicated that the hypermedia experience was not a substitute. Then, following a zoology field course, students indicated that hypermedia, properly designed, can serve as preparation for field study and help them use their time more effectively. This perception is consistent with the views of Warburton and Higgitt (1997) that describe the importance of advance preparation for field trips and the role of information technology in this task.

A different type of student-researcher experience is required in general introductory psychology classes. That is, students require opportunities to conduct laboratory experiments in which they generate hypotheses, set up conditions to test the hypotheses, obtain reliable and unbiased data, and interpret the collected data.

In one software model developed for this purpose, student researchers use the clocks and counters at the bottom of the computer screen to document the extent to which an infant attends to a particular stimulus (Colle & Green, 1996). The screen portrays an infant's looking behavior, which includes both head and eye movements. In another simulation, students study the flash exchanges between fireflies during the courting behavior that precedes mating.

Other software products address the challenges involved in the operant conditioning of the bar pressing behavior of a laboratory rat. One exercise, in which the screen portrays a drawing of the side view of rat with a front paw on a bar (Shimoff & Catania, 1995), lacks the fidelity required of a simulation. Also, the exercise did not provide information to students on their skill in shaping (Graf, 1995). In contrast, Sniffy, the Virtual Rat shows Sniffy in an experimental chamber with three walls, a lever, a food dish, and a water tube. Sniffy engages in actual behavior, including wandering around, sniffing, and stretching. The program also shows the cumulative record of Sniffy's bar pressing behavior during the conditioning process (Alloway, Wilson, Graham, & Kramer, 2000).

An example of the troubleshooting role in relation to a system is the research conducted with a computer-based simulation of an oil-fired marine power plant, Turbinia (Govindaraj, Su, Vasandani, & Recker, 1996; Recker, Govindaraj, & Vasandani, 1998). Important in such simulations is that they illustrate both epistemic (structure of knowledge) fidelity and fidelity of interaction (Recker et al., 1998, p. 134). That is, the exercise should enable students to develop strategies that are consonant with the demands of real-world situations (reality of function).

The simulation models approximately 100 components of the power plant and illustrates the hierarchical representation of subsystems, components, and primitives, as well as the necessary physical and logical linkages. However, the physical fidelity is rather low.

The simulation also is accompanied by an intelligent tutoring system, Vyasa. The reason is that the purpose of the simulation is to teach diagnosing strategies and not to serve as a culminating exercise after the acquisition of basic knowledge of system faults and corrective actions. Results indicated that the less efficient students viewed more gauges and components than the efficient problem solvers. Students also seemed to implement a strategy of confirming leading hypotheses instead of choosing tests that served to disconfirm a maximum number of possible hypotheses (Recker et al., 1998, p. 150).

21.3.4 Discussion

Both experiential and symbolic simulations continue to be developed in different subject areas to meet different needs. Areas that deliver patient or client services implement simulations in which students diagnose and manage individuals' problems. Business education, in contrast, relies on team exercises in which students manage the finances of a company or institution. Implementation of simulations in both these areas identifies students' strengths and weaknesses in planning, executing, and monitoring their approaches to solving complex problems. Similarly, research in symbolic simulations that require troubleshooting also indicates differences between effective and less effective problem solvers. One is that less effective problem solvers check a greater number of indicators (such as dials and gauges) than effective problem solvers.

Of importance for each type of simulation are the design and development of exercises with high fidelity. Required are (1) a qualitative or quantitative model of the relationships among events in the simulation, and (2) materials and required actions of participants that result in a realistic approximation of a complex reality. Hypermedia combined with video images, for example, can be used to develop virtual field trips that serve as preparatory research experiences for students (simulations). Similarly, hundreds of photographs of subtle changes in the movements or actions of laboratory-research subjects, properly programmed, can provide laboratory settings that are highly responsive to students' research designs. In contrast, photographs and video clips accompanied by explanatory information that provide a guided tour can be a useful experience, but the product is not a simulation. An example is The Digital Field Trip to the Rainforest, described by Poland (1999).

One concern for simulation design is the general conclusion that there is no clear outcome in favor of simulations (de Jong & van Joolingen, p. 181). This inference, however, does not refer to the conception of simulations that addresses the nature of the deep structure of the exercise. Instead, it refers to discrete problems with simulated materials where the student is required to engage in "scientific discovery learning" to infer the relationship between particular input variables and an outcome variable. The high cognitive load imposed on students by learning about implementing the processes of scientific discovery learning while also attempting to learn about a relationship among two variables has led to the introduction of intelligent tutoring systems to assist students. However, as indicated in the following section, instructional theory supports other alternatives that can enhance learning and contribute to the meaningfulness of the exercise for students.

21.4 DESIGN AND RESEARCH ISSUES

The early uses of simulations for military and political planning bridged the gap between the conference room and the real world. Initial expansions of simulations, particularly in business and medical education, also were designed to bridge the gap between textbook problems in the classroom and the ill-structured problems of the real world. In these exercises, participants are expected to apply their knowledge in the subject area to complex evolving problems. In other words, these simulations are culminating experiences; they are not devices to teach basic information.

In contrast, the development of interactive exercises in science education, some of which are referred to as simulations, take on the task of teaching basic content. Not surprisingly, the few comparison studies reported no differences between the classes using the computer-based exercises and control classes. These findings lend support to Clark's (1994) observation that methods, not media, are the causal factors in learning.

From the perspective of design, the key issue for developers involves two questions: Does the simulation meet the criteria for the type of exercise (symbolic or experiential)? and What is the purpose of the simulation? If the simulation is to be a culminating experience that involves the application of knowledge, then instruction must ensure that students acquire that knowledge. Research into the role of students' topic and domain knowledge indicates that it is a major factor in subsequent student learning (see, e.g., Alexander, Kulikowich, & Jetton, 1994; Dochy, Segers, & Buhl, 1999).

Interactive exercises that expect the student to infer the characteristics of a domain and to implement discovery learning face more serious difficulties. In the absence of prior instruction on conducting research in open-ended situations, the potential for failure is high. de Jong and van Joolingen (1998) note that student difficulties include inappropriate hypotheses, inadequate experimental designs, including experiments that are not intended to test a hypothesis, inaccurate encoding of data, misinterpretation of graphs, and failure to plan systematically and monitor one's performance. Hints can be provided to students during the exercise. However, this tactic of providing additional support information raises the question of what students are actually learning. Also, Butler and Winne (1995) report that students frequently do not make good use of the available information in computer exercises. Moreover, the practice of relying on hints and other information during the student's interactions with the domain runs the risk of teaching students to guess the answers the exercise expects. In that event, the exercise does not reinforce thoughtful, problem-solving behavior.

Prior to student engagement in a simulation, instruction should model and teach the expected research skills, which include planning, executing the experiment and collecting data, and evaluating (de Jong & van Joolingen, 1998, p. 180). In this way, students can acquire the capabilities needed to develop conceptual models of an aspect of a domain and test them in a systematic way. Davidson and Sternberg (1998), Gredler (2001), Holyoak (1995), and Sternberg (1998), for example, address the importance of this course of action in developing both metacognitive expertise (planning, monitoring, and evaluating one's thinking) and cognitive skills. A second reason for modeling and teaching the research skills first is to avoid the problem referred to by Sweller, van Merrienbaer, and Paas (1998, p. 262) as extraneous cognitive load. In such a situation, the limits of students' working memory are exceeded by inadequate instructional design.

Explicit teaching of these capabilities prior to engagement in a simulation is important for another reason. Specifically, it is that learners cannot develop advanced cognitive and self-regulatory capabilities unless they develop conscious awareness of their own thinking (Vygotsky, 1998a, 1998b). This theoretical principle addresses directly the concern of some researchers who note that students interacting with a simulation environment appear to be thinking metacognitively in discussions with their partners, but these skills are not evident in posttests. Students' lack of awareness of the import of a particular observation or happenstance strategy, however, may account for this phenomenon. That is, they are searching for solutions but are not focusing on their thinking.

Finally, an important issue for both design and research is to examine the assumptions that are the basis for the design of interactive exercises. One, for example, is that discovery learning environments, such as simulation environments, should lead to knowledge that is qualitatively different from knowledge acquired from more traditional instruction (Swaak & de Jong, 2001, p. 284). Important questions are, What is the nature of the knowledge? and Why should this occur? For example, if the goal is to teach scientific reasoning, as Horowitz (1999) suggests, then simulations and the associated context must be developed carefully to accomplish that purpose. In other words, addressing the prior questions is important in order to explore the potential of simulations for both cognitive and metacognitive learning.

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