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ABSTRACT

Simulations, which can be defined as formalized techniques for studying complex systems by manipulating the variables in a scaled-down model and observing the results, are useful instructional tools. They provide individualized, self-paced, learner-controlled education, offer discovery experiences which are realistic, and promote problem-solving, decision-making, and immediate feedback. They seem to motivate students and provide them with a means of studying complex systems. Limitations of simulation include the tendencies to over-simplify and over-systematize reality and to stereotype complex situations. Simulations will be even more useful if they are systematically developed, with instructional design following these steps: 1) analysis of instructional content, 2) specification of objectives, 3) definition of target audience, 4) identification of suitable simulation topics, 5) analysis of the feasibility of each topic, 6) design of the simulation, and 7) evaluation. This kind of systems approach to design will remove educational simulations from the realm of the haphazard and provide educators with a demonstrably effective instructional tool. (PB)

Simulation for Instruction: Some Considerations for Users and Designers

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For many years, simulation has been used for a variety of purposes, from the staging of mock battles and wars to predicting elections to designing harbors. This use of simulation in society has stimulated the growing use of simulation for educational purposes. In universities and high schools, students now may interact with a computer-based simulation to learn laws of physics, to see the results of decision strategies in business or government, to practice diagnosing patients, or to conduct dangerous experiments with (simulated) radioactive material. Many educators have been persuaded that the use of simulation is an instructional strategy of unparalleled effectiveness. Indeed, the fascination of a game-like situation coupled with the glamor of the computer offer a compelling combination.

Simulation as an instructional strategy has become rather widely and enthusiastically accepted to the point that it is now possible to discuss the "state of the art". We are going to do exactly that--with a lament that at this stage it is indeed an art and not the science it could be. Little data exists to support the subjective claims of the enthusiasts, and few explicit rules can be named for the design of a simulation. Nevertheless, it is clear that simulation is so powerful as pedagogy that careful planning and use is essential.

It is the purpose of this paper to examine the realities of computer-based simulation for instruction. The following questions are addressed:

- What is simulation, particularly for instruction?
  **advantages **limitations
- What are some guidelines for use and design of simulation packages?
- What kind of data is available, and what kind is needed, to guide users and designers?

The type of simulation we will discuss is computer-based. The computer represents physical, economic, and other well-defined processes, in interaction with students, who play human decision-making roles. Since this definition of the term "simulation" incorporates some features (i.e., a human factor) more commonly associated with gaming, let us take a closer look at the generally accepted definitions.

Simulations, Games, and Models

The terms "gaming" and "simulation" have often been used interchangeably in education. However, there are differences that are important for our discussion. Both gaming and simulation rely upon an intrinsic model, defined as a "scaled down representation of some object, process, or concept." (1) A model may be concrete (e.g. a wind tunnel or a scale model of a building site), or it may be abstract (symbolic). The abstract model is usually a mathematical model which expresses the relationships between the relevant variables in the form of equations.

A *game* is a human exercise. It is usually a sequential decision-making operation, with each participant playing a role. Structured interactions take place between the players of roles. In high school social studies classes, for example, games have become a very popular means of studying social phenomena (such as the relationships between the American colonies and Great Britain before the Revolution) by having students play roles (such as the British government, colonial merchants, and British and American bankers). A model exists in the form of rules for the game, and interaction between players must proceed according to these rules. Usually, the object of the game is to "win", which encourages students to develop effective strategies.

Gaming is an ancient technique, particularly useful for military experiments with "war games". The model is usually more informal and tentative in a game than in a simulation, since human participants provide an intrinsic component of the model. Many authors describe gaming as a "form of simulation".

The term "simulation" refers to a more formal, explicit and scientific model, and is defined by computer operations on a model of reality comprising a bundle of interrelated variables. Simulation is a technique for studying the behavior of complex systems by using a computer to manipulate the variables and observe the behavior of the model.

The kind of instructional simulation we will discuss might most accurately be called "gaming/simulation". Although the model is computer-based, there is an important human component--the student. In addition, many of the simulation packages available incorporate the "win or lose" characteristic. However, we will use the briefer term "simulation" in referring to the whole range of computer-based simulation for instruction.

At one end of the gaming/simulation continuum are the computer-based simulations in social studies. In one unit called *Judge* (2), a simulation of an urban judicial system, the student plays the role of the accused. The "win" objective is to obtain a favorable judgment. In another, called *Balance of Payments* (3), the student plays the role of chief decision maker in a country which is in a poor balance of payments position. The objective is to "win" by bringing the country to a favorable balance of payments position within a specified number of years.

Other social studies simulations do not have the "win or lose" characteristic. Instead, students manipulate variables in order to observe the effect on the phenomena being studied. An example is *Mass Participation* (2), in which variables such as socio-economic class and education are manipulated to explore their relationship to the political participation rate of a group of citizens.

Simulation in science is more often similar to the *Mass Participation* example, where winning is not an objective. Except in the sense that students are "playing against nature", there is no competition. Students cannot change natural forces or laws (like genetic laws or the law of gravity); they can only test alternative courses of action against these laws and evaluate the results. If there is a "winner", it is the student with the most complete understanding of nature.

These simulations are simpler than all-human games with opposing role-playing participants, but the simplicity of the interaction is counter-balanced by the difficulty of the objective--forming theories of relativity is harder than becoming a Congressman.

The Advantages of Simulation for Instruction

Various theories about how people learn appear to be served by simulation. Bruner (6) reports a conference consensus that the fundamental structure of a discipline--as opposed to factual detail--is the proper stuff of education. A well-designed simulation forces attention to the inherent structure and fundamental themes at hand.

Related to Bruner's theory is the notion of "discovery"--the idea that mastery of the fundamental structure of a field involves development of an attitude toward learning and inquiry, guessing and hypothesizing, discovering relationships and generalizations for one's self. In the responsive environment provided by a simulation, the student has the opportunity to discover or uncover a series of fundamental relationships. He is encouraged to explore the system with freedom, to ask "what if?" and to actively experiment with the system. Independent variables can be freely manipulated to test guesses and hypotheses.

Another notion inherent in Bruner's theory is that the best stimulus for learning comes from the subject matter itself, from an intrinsic student interest in the material. Simulations appear to be intrinsically interesting, if one can judge subjectively. The superior motivation of students in educational simulation is widely recognized. In fact, the motivating effect is probably the only indisputable claim for the value of using simulations. One research study (7) showed little gain in learning or retention in the experimental (simulation) group, but a significant gain in motivation.

Research has presented evidence that it is important in both behavior and learning for a student to believe he has control over his own environment. Such a belief is a good predictor or school achievement. Simulation can provide opportunity for the student to experience situations where the outcomes are clearly contingent upon his own behavior, and which are similar enough to real life situations to allow generalization.

The "identical elements" theory of transfer in learning holds that maximum transfer takes place when the learning is as nearly like the real world as possible. There is difficulty in bringing "real world" problems into the classroom. The result is that students see little relevance in school activities for their real life.

Simulations bridge the relevance gap by bringing a representation of the real world into the classroom.. Students may practice interacting with this model, making decisions and exploring hypotheses, without suffering the real life consequences of their actions. The student is protected from the dangers of reality as he develops and tests strategies for coping with reality. As well as being safer, the simulated system is probably cheaper, simpler, less time-consuming and more readily reproducible than comparable experience in real life.

Opportunities for individualization of instruction are provided by simulation. Even relatively simple simulations can be sufficiently rich in content to provide several levels of learning for students of varying abilities. Slower learners can focus on the concrete, static elements while faster learners can attempt to apply concepts of cause and effect.

It is possible in designing a simulation to provide for variations in content, length of segment, style, and mode of presentation, as well as the sequence and difficulty of the problems presented.

Finally, the self-pacing nature of a simulation contributes to individualization. A simulation is able to focus the attention of the student in much the same way as programmed instruction does, by requiring active participation. Participation in a simulation as decision-makers gives students insights into decision-making processes. They also gain empathy and a greater understanding of the world as seen and experienced by real decision-makers.

The responsive environment of a simulation provides feedback on the consequences of actions. Thus the learner can play out a strategy over a period of time and determine from the feedback how effective was the strategy. The feedback gained is not only more lucid and faster than that provided in other settings, but it is perceived as less arbitrary.

Many ideas we may wish to present to students are either too abstract, too difficult, too remote from students' experiences, or too complex for them to understand. In real life, a system (a social system, for example) may be so confused and chaotic that it is hard to segregate the important variables and see the relationships between them. In a simulation, the phenomenon under study may be highlighted by abstracting simple elements from the confusion of reality. The effects of interactions are intensified. A simulation can be complex compared to verbal models, but simple compared to the real world. This is a rewarding compromise: the simulation has enough complexity to account for the significant sources of variance in the real world, but is simple enough to be understood.

It has been claimed that instructional simulation helps to "build intuition" or "encourage intuitive problem solving" (8). Perhaps this is so. Certainly a student is encouraged to test hunches and is rewarded for the superior problem-solving speed of effective intuition.

Enthusiasts have claimed further advantages for simulation in instruction but this discussion should suffice as a review of the many virtues of the technique. Now for a look at the limitations.

Limitations of Simulation

In contrast to the advantage of dealing with a streamlined, simplified version of reality, some argue that simple abstractions from reality do not sufficiently mirror the richness of reality. There is danger that the student, having understood the model, may believe that he understands the reality as well.

A delicate balance must be achieved between realism and simplicity. Detractors often point out that the assumptions upon which a simulation is based distort the real world in the process of simplifying it, and that we should try to more closely approximate reality. Indeed, if a simulation is too simple, students may develop an attitude of "beat the game", which is alien to the purpose of the simulation.

On the other hand, as designers, we cannot produce the real world, even if we presume to know what the real world is. We don't want to produce reality; instead, we want to isolate the important interrelations in it. If we succeed in reproducing the real world, simulation will be indistinguishable from reality and we will be no closer to isolating important relationships. A most important caution for a designer or user of a simulation is to be aware of the exact nature and extent of the simulation's departure from realism.

Another limitation is that the computerization of games and simulations may actually work against individualization of instruction, in one sense. If the program is stereotyped and universally applicable, with invariable parameters, it will be impossible for the individual teacher to adapt it to his own needs.

One pervasive problem, of much concern to teachers, is the fact that simulations reflect the bias of their designers, a bias that may be conveyed to the student in an insidious way. Thoughtful designers will openly state the assumptions and biases under which they operate, so that the teacher can present the underlying "realities" to his students.

One might ask, how is the problem of the designer's bias diferent for a simulation from that of any other instructional resource, such as a textbook or a film? Perhaps it is that the computer program is "closed" to the lay teacher, who may not be able to identify the parameters that are set by the designer, or to fully understand the model that is incorporated in the computer program. Again, a full explanation of the model by the designer is necessary if teachers are to have confidence in using the simulation.

One objection to the computerization of some games is that relationships in the social world cannot be accounted for systematically, that human behavior and social systems incorporate too much randomness. Indeed, if the objective of the simulation is to give students experience in interaction with other human beings, then a machine version would be unacceptable. Otherwise, it can be argued that despite the randomness and complexity of human behavior and social structure, we can assume that there are identifiable patterns, regularities and laws which can be explored profitably through the medium of simulation. In his book (9), Rashevsky describes mathematically some general characteristics of sociological changes leading to instabilities, and deals in mathematical fashion with complex cases of interaction of social classes. He even develops a quantitative definition of "individual freedom".

These limitations seem rather few in comparison to the advantages cited earlier. The literature reflects the same imbalance. There are other issues that need to be confronted, however: the frequent lack of specification of the instructional objectives of a simulation, and the lack of empirical testing. There is clearly a lack of forethought in the design of some instructional simulations. It is sometimes difficult to determine the objectives of the designer, if indeed he had any beyond "have fun". An even more serious problem is that many simulations and games are never tested, but are simply installed in the curriculum. There is no attempt to do developmental testing followed by revision, or to validate the finished product with a sample of learners from the target population. It is assumed that the simulation teaches, and that it teaches something worth learning. We will deal with this subject further in the final section. Meanwhile, let us turn to the considerations involved in designing and choosing) simulations.

Developing an Instructional System

In view of our previous remarks concerning the nature of simulation design as more art than science, it may appear presumptuous to now offer guidelines for design. However, these suggestions represent an attempt to narrow the gap between art and science, to provide the artist with a more precise framework within which to be creative: an instructional system.

The use of computers, characterized by inexorable logic paired with complete lack of judgment, imposes certain highly realistic constraints on simulation designers. We propose a further constraint: that we should deliberately design and use specific simulations to produce desired learning, to teach specific intellectual (and perhaps some social) skills. Before we can do this, we must know our objectives for the entire course, our target audience, and we must have determined that simulation is the most appropriate instructional strategy to use in reaching our objectives.

The "deliberate design of specific simulations to teach specific skills" requires that the teacher and/or designer:

- carefully analyze the course
- state specific instructional objectives
- define the target audience
- identify those topics potentially suitable for simulation
- do a "feasibility study" for each topic
- design the simulation
- test, revise, and refine

Too often designers skip the first three steps above. If these essential tasks are ignored, simulation design must be called "art" in the worst sense of the word. A simulation may be developed because it is intrinsically interesting to the designer, but may not be interesting, or even important, as a learning objective.

Identifying potentially "simulatable" topics is simply the next logical step in design of any instructional system: once the objectives and target audience have been defined one is able to select the most appropriate instructional strategy for each objective. For one objective, it might be a field trip; for another a demonstration, or a lecture. For another, a simulation, or perhaps a combination of several strategies. It is important to recognize that simulation is only one of a wealth of available instructional strategies. A simulation will never be the "ideal" way for all students to learn all concepts. Instead, we should seek ways to combine and integrate simulation and other methods to reach all students by an approach which suits their individual learning style. The emphasis here is on integration: where several methods are being used, they should reinforce each other. Once a set of potentially suitable topics has been identified, it is time to do a feasibility study to determine just how suitable each topic is for simulation.

Feasibility Study

In deciding to use or develop a simulation, the following considerations are relevant:

- the designer should have substantive knowledge of the simulation topic
- the designer should have some substantial hypotheses about how the variables in the system change under various circumstances (i.e., a model)
- the designer should have some data describing the initial state of the system (i.e., the values of parameters)
- the designer must be able to assign a quantitative value to all qualitative variables, or must leave the values of such variables to the user to specify
- one or more of the following conditions should exist:

a. study of the real-life system
   *is dangerous
   *is too expensive
   *requires equipment or facilities impossible to obtain
   *involves time scales too short or too long for analysis
   *requires lengthy or complex calculations
   *is too close to the participants to allow them to perceive and understand important interactions (a parent-child simulation, for example)
b. a manual game would overload participants with the sheer mechanics of operation, obscuring important relationships
c. students will be future participants in a situation (business management, for example), and simulation can allow them to study the dynamics of the situation now, to learn strategies which will be directly relevant to their lives

- the designer should be able to see ways to individualize the simulation by varying the pace, scope, content, style, mode or sequence according to individual learner characteristics
- the designer should have available the following resources:

   a. time--for development, testing, revision, and program debugging
   b. personnel--programmers and test subjects
   c. computer--the available computer should be large enough and fast enough to efficiently handle the proposed simulation, and appropriate terminals should be available*

Steps in Design

Once the topic has been identified and judged feasible for simulation, we can begin to construct the simulation. The basic tasks in development are:

- specify the instructional objectives of the simulation
- define the target audience
- define the model
- design the simulation
- test, revise, and refine

Notice that the first two steps are identical to those in the larger task of developing an instructional system. Here, we are concerned with the specific objectives and the specific audience for this specific simulation.

Instructional Objectives

Objectives should be detailed in highly specific and behavioral terms.

Target Audience

Whether the simulation is intended for widespread use with a specific group of students, it is important to specify the characteristics of the intended recipients, preferably in quantitative terms. These characteristics may include grade level, learning ability, reading ability, socioeconomic status, and needs, as well as prerequisite skills and abilities.

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* For example, if the simulation requires volumes of printout, a fast display-type terminal would be preferable to a slow teletype (or is all that printout really necessary?).

The Model

Before progressing too far in the design of the simulation, the model must be specified. This is usually a simpler task for simulations in the "hard" sciences than in social science. The steps are essentially the same for both, however.

First, identify the components of the system to be simulated--the variables and the parameters. Then specify the relationships among them. A process of simplification is usually necessary. Redundant or distracting variables are eliminated in order to highlight the important interactions and effects.

During this phase it is particularly important that the subject matter expert be separated from the computer programmers, particularly if it is a social science model. It is the job of the subject matter expert to completely define the model and then to describe this model to programmers or system analysts who will construct appropriate algorithms. Programming is a technical job, definitely a second stage in the design of the model.

The Simulation

It remains to translate this analytical model into a computer program and supporting curriculum materials. The curriculum materials should guide both the student and the teacher. For the teacher, the package should include:

- background information about the topic and references for further study
- complete description of the model and its underlying assumptions
- student prerequisites
- specific instructional objectives for the simulation
- pre and post tests
- preparatory classroom activities
- guidelines for individual or group use by students
- follow-up activities
- instructions for using the computer to run the simulation

A set of laboratory exercises can guide the student through the simulation to insure that he will discover the appropriate relationships and apply the appropriate strategies. The development of the supporting curriculum material will probably parallel the programming, and should require at least as much care, time and effort and "debugging" (developmental testing).

Test, Revise, and Refine

Two kinds of testing are needed at this point--test runs of the program, for debugging, and test runs of the program and the curriculum material together, to identify and correct distortions in the model, identify instructional objectives that are not met, and revise the material accordingly. This developmental process of test, revise, test, revise, test, and revise is repeated until test subjects can achieve the instructional objectives. A single test subject, representative of the target audience, is sufficient for each test-revise cycle during the developmental stage.

Finally, the tested and refined version is ready for validation. Validation testing should be done under "real" conditions, with a teacher and students who are typical of the target audience. Pre- and post-test data should be reported in the final document, along with data about the validation test group.

Evaluation: Some Problems

In trying to evaluate simulations, two things become evident: first, nearly everyone who designs or uses simulations, or observes their use, is enthusiastic. Second, this enthusiasm is based largely on subjective estimates of what the simulations accomplish. There is very little testing done to validate that instructional objectives are achieved. And no data has been reported regarding what must be the ultimate test of effectiveness: does study of the simulation lead to better understanding of (and hence better predictions of) the real world?

Boocock (7), after reviewing attempts (during 1963-65) at controlled experiments with games, suggested that two attitudes toward the technique are possible; games teach, but we don't know how or why: or, games probably can not teach, but they do motivate.

Hard data is difficult to find, because evaluating a simulation (particularly a simulation game) is problematic. Some of the difficulty is related to the problem of evaluating instructional methods in general. Determining exact educational objectives for a particular set of materials, and designing reliable ways to measure learning, are ambitious tasks, seldom achieved well for any pedagogy. The abstract kinds of learning claimed by simulation enthusiasts further complicate the problem of objective evaluation. No tests have been devised to measure insight, understanding of the complexities of social relationships, or a new way of integrating information.

Obviously, the more complex the simulation or game, the more intricate is the problem of evaluation. For some straightforward simulations in the field of science, objectives may be fairly specific and evaluation equally direct. But a management game with various levels of decision-makers and many types of interactions is not so readily subjected to performance measurement.

In evaluating a simulation relative to other methods of teaching the same topic, some special problems arise:

- setting up comparable experimental and control groups in a school setting is next to impossible
- even if "matched" classes are identified, a valid test would turn over the simulation to a teacher who had not been involved in the design, resulting in less control over the use of the simulation
- if two or more teachers are using the "same" techniques, how can one be sure the materials are being presented in the same way?
- the same teacher teaching both groups is likely to have an emotional investment in the success of one of the techniques
- even minor changes in teaching materials can change the results; how does one match simulation with other methods in terms of difficulty level, content, and so on?
- the Hawthorne effect is sure to be present because of the double innovation of the computer and the simulation

Nevertheless, objective data is needed--data concerning effectiveness of simulation vs. other instructional methods, data concerning the mechanisms by which a simulation teaches, and data about the appropriate type of learner for a given type of simulation.

When Western Behavioral Sciences Institute (1) collected and analyzed the observations of hundreds of simulation users, they produced not a report of evidence, but a list of hunches regarding simulation. Some of the hunches are presented here in condensed form, as a tentative list of outcomes that need to be investigated more formally:

- maybe simulations motivate
- maybe a simulation experience improves inquiry skills
- maybe the greatest learning occurs when students build their own simulations; (Dorn (10) would agree, but only for deductive learning)
- maybe simulations help students see the interconnectedness of factors in a social system
- maybe participants learn skills like decision-making and resource allocation
- maybe simulations affect attitudes
- maybe participants learn the form and content of the model which lies behind the simulation

Some progress has been made recently in the field testing of several simulations in a variety of settings, yielding objective data concerning some of these hunches. If these hunches are correct, then simulation clearly is a valuable educational tool.

Simulation: a Systems Approach

In education, we have for centuries pursued relatively haphazard procedures for developing instructional strategies and materials. In recent years, however, educators have demanded a more systematic approach to instructional design. Simulation has been an example of the "haphazard approach"--let us compare it with an example of the systematic approach: programmed instruction, or P.I.

P.I. is an example of a technology emerging from basic knowledge and a large base of research on the shaping of behavior. Simulation represents the opposite case: a technology which works, but no one really knows why.

P.I. is the first real attempt in education to specify a system for instructional design. Strictly defined, P.I. usually includes a format of subunits (" frames"), each of which contains both some informational text and some form of test item. The more generally accepted principles of P.I. are:

- specification of objectives, or "intended outcomes"
- empirical testing--used during program development as a guide to revision, and also in program validation with a sample of learners from the target population
- self-pacing--learner sets his own rate of progress
- overt responding, or active involvement of the learner
- immediate feedback
- small step size

Most programmers agree that the first two principles are indispensable to P.I. We submit that these two principles are also indispensable to instructional simulations. The reality is, however, that the last four principles are usually inherent in the simulation, while the first two principles are ignored. The result is that simulations are generated and used for instruction, but are judged only subjectively. The students are "turned on", the teacher is enthusiastic, and everyone enjoys the experience. But the technology can not be fully explored and effectively used until more systematic development and evaluation methods are employed.

The effectiveness of P.I. in achieving stated instructional objectives has been demonstrated over and over. The same effectiveness can be achieved for simulation, if

- designers of simulations will undertake the basic research necessary to identify important variables
- instructional objectives are specified as a first step in simulation design, and
- empirical testing is employed during development and in validation of the completed simulation.

This kind of systems approach to design and use could forever remove educational simulations from the realm of the haphazard and mysterious, and provide educators with an important, solidly justified and demonstrably effective instructional tool.

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