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ABSTRACT

Problem-solving skills are higher level cognitive processes which involve the invention of complex organizational schemes to resolve conflicts or confusion. These skills cannot be acquired by mastering a hierarchy of prerequisite skills; rather, their mastery is best facilitated by placing the student in an environment which forces him to apply the skill. Computer simulations can provide rich stimulation and can incorporate complex interrelationships between variables while avoiding the ambient distractions and over-complexity of real-life situations. Simulations can force students to: (1) identify relevant issues; (2) determine sequences; (3) collect and interpret data; (4) avoid unnecessary actions; (5) manipulate situations; and (6) evaluate the effects of those manipulations. (EMH)

# Simulation to Teach or Evaluate Problem-Solving in Professional Programs



by

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In the professions, notably medicine, law, and education, an instructional goal of primary importance is the development of students' abilities to identify, analyze, and solve problems, applying substantive knowledge in the process. Teaching and eliciting such problem-solving skills is accompanied by the need to evaluate the problem-solving skills of the would-be doctor, lawyer, or educator.

A variety of strategies has been used to teach problem-solving skills. The least costly has usually been demonstrated to be also least effective. In legal education, for example, the predominant technique used to aid beginning law students in developing these skills is the case or Socratic method. Students are expected to analyze a case and respond when called upon in class, in a Socratic dialogue with the law professor. The classes, however, typically have between seventy-five and one-hundred students, severely limiting the amount of interaction an individual student can expect to have with the professor.

A more successful approach has been the "clinic" or "internship", which places a student in a real-world situation where she or he can observe practicing professionals solving problems, and can participate in the process, under supervision. Clearly, the cost of such instruction is very high, even prohibitive.

Evaluation of problem-solving skills has proven to be equally difficult. Traditional paper-and-pencil objective tests are more appropriate for measuring lower-level cognitive skills. It is a considerable challenge to evaluate clinical higher-level cognitive skills of the type required for interaction with a client (e.g., a patient, a person in need of legal assistance, or a child with a learning deficiency).

The Committee on Examinations of the American Academy of Orthopedic Surgery abandoned paper-pencil Board Examinations in favor of a more valid and relevant evaluative interview of each candidate by a review board of physicians. The cost of administering such an examination is prohibitively high. A reasonable compromise was found in the form of a set of paper-pencil simulations called Patient Management Problems (McGuire, undated).

The use of a simulation to teach or evaluate problem-solving skills has found many applications in medical education and the training of teachers, as well as experimental application in legal education (Edwards, 1975).

## The Nature of Problem-Solving as an Intellectual Skill

"Problem-solving" appears to be an intellectual skill which is not simply an extension of lower-order skills such as "concept learning" or "rule learning." In fact, it appears to be qualitatively different from these less complex kinds of intellectual processing.

The variation in the terminology used when discussing higher-level cognitive processes reflects the state of what is currently known. Terms such as "problem solving," or "heuristic," are sometimes used interchangeably. However, the terms may have quite different meanings to some investigators, fuzzily defined and difficult to communicate as those meanings may be.

Solving a complex problem in law, for example, requires, first, a substantive knowledge of legal procedure, fact, and precedent. A lawyer in practice must also possess and apply skills in analyzing a case to identify the relevant and important issues, and must then be able to apply the knowledge to resolve the case as successfully and efficiently as possible. Clearly, this requires a complex interaction of skills and knowledge. For the purposes of this paper, the cognitive processes a student engages in while developing and practicing these skills in a simulated environment is called "problem solving."

Gagne (1970) identifies a hierarchy of intellectual skills, classified by level of complexity. At each level of the hierarchy, the simpler skills are prerequisite conditions for the more complex intellectual skills. Most instructional design models specify a task analysis based on Gagne's hierarchy to identify the level of skill involved, followed by the planning of a sequence of learning events external to the learner. These instructional events will lead to the acquisition of the prerequisite skills lower in the hierarchy, which then act as "sufficient conditions" which insure the acquisition of the identified higher-level skill.

Gagne & Briggs (1974) suggest that problem-solving skills (cognitive strategies) are internally organized skills which manage or guide the individual's learning, remembering and thinking behavior. Because they are internally organized, cognitive strategies cannot be directly controlled by external "sufficient conditions," in the way that lower-level skills can. Rather, the designer plans "favorable conditions" to increase the probability of certain internal events which in turn determine the learning of the cognitive strategy. "Favorable conditions," according to Gagne and Briggs, are those which provide opportunities to think--to develop and use cognitive strategies.

Gagne (1970) and Gagne & Briggs (1974) characterize problem-solving behavior as the invention of complex combinations of rules to solve a problem or a class of problems. For learning to be a "problem-solving event" they would require the learning guidance to be provided by the problem solver himself, rather than the teacher or other external source. The learner thus engages in "discovery learning." Once acquired, the higher-order rule should exhibit transfer to other physically different, but formally similar, situations. The writers suggest that:

> In attaining a workable solution to a problem, the student also achieves a new capability. He learns something which can be generalized to other problems having similar formal char-

> acteristics. This means he has acquired a new rule, or perhaps a new set of rules. (1974: 45)

Although Bruner (1970) would not agree with Gagne that a new rule or even a new set of rules had necessarily been acquired in such a situation, he agrees that the cognitive strategies acquired in learning problem solving can be used to solve new problems--that is, they exhibit transfer. Bruner points out the difficulty in applying "conventional learning theories" to problem-solving behaviors:

> Rather, what seems to be at work in a good problem-solving 'performance' is some underlying competence in using the operations of physics or whatever, and the performance that emerges from this competence may never be the same on any two occasions. What is learned is competence, not particular performances. (1970: 67)

Gagne's hierarchy, in which lower-order intellectual skills act as "sufficient conditions" for acquisition of higher-order skills, does not appear to apply as appropriately for problem-solving behaviors. The hierarchy, as it is employed in task analysis, deals with the <u>structure</u> of the content to be taught. Problem-solving behaviors, however, depend on the learner's application of previously learned content, and no new content is actually taught. Thus the hierarchical task analysis appears to be inappropriate in design of instruction for problem solving. Rather than analyzing the sequence of prerequisite skills and designing instruction to provide these skills as "sufficient conditions" for acquiring problem-solving skills, the designer assumes the lower-level skills as entry skills and determines how to provide for the learner the most "favorable conditions" under which to practice problem solving. Simulation appears to be an instructional technique which can provide these necessary "favorable conditions."

## Simulation in Learning

As a strategy for teaching, eliciting and evaluating higher-level problem-solving skills, computer-based simulation has gained considerable attention recently. Simulation as a technique provides richness of stimuli, complex interrelationships between variables, and multiple possible responses and outcomes. The computer provides a viable means for managing this complexity.

In the simulation setting, the learner is part of a dynamic, self-regulating system. Human information processing in this context relies on continuous evaluation or monitoring of behavior (including thinking behavior) with consequent adjustments. Miller, Galanter, & Pribram (1960) have conceptualized this type of information processing as a feedback loop they call a TOTE (for test-operate-test-exit). Simulation provides flexibility in the learning situation so that the learner can use feedback to test a thinking process or an action, modify it, test again, and continue in the loop until an objective is reached.

Simulation is reality simplified. While students are learning to identify the relevant variables in a situation and to combine those variables to achieve an optimal solution, they are exposed to sufficient richness to provide credibility. At the same time they are protected from some of the "noise" that exists in the real decision-making setting.

Bobula & Page (1973) describe the essence of simulation as

> . . . placing an individual in a realistic setting where he is confronted by a problematic situation that requires a sequence of inquiries, decisions and actions. Each of these activities triggers appropriate feedback which may modify the situation and be used for subsequent decisions about what to do next. The examinee's next action in turn may further modify the problem. Thus a problem evolves through many stages until it is terminated when the individual reaches an acceptable solution or is faced by unacceptable consequences brought about by his own choices and actions. (1973: 1-1)

The individual in the simulation setting practices and refines skills and strategies for recognizing, identifying and resolving problem situations. The cognitive strategies or competencies thus acquired should generalize, or transfer, to other similar problems: other simulations, or similar situations in real life.

McGuire (1973) sees simulation as superior, not only to conventional methodology for teaching and testing, but also to reality. The advantages she suggests include perceived relevance, predetermination and preselection of the task (as opposed to reality), standardization of the task (for testing), improved sampling of performance, improved rating of performance, and increased responsibility and realistic feedback in a practical time frame.

Simulation is a technique which can provide the "favorable conditions"--the necessary realism, richness and complexity--for teaching and eliciting problem-solving behavior. More specifically, computer-based simulation can provide a flexible and individually responsive dimension, while automatically scoring and maintaining detailed records of each student's performance. Computer simulation, then, appears to provide a strategy and a medium uniquely suited to instruction in problem-solving for large numbers of students.

## Evaluation

In addition to providing practice in problem-solving, a simulation of a patient management problem, a learning disability diagnostic problem, or a pre-trial legal procedures problem may be used to evaluate a students' problem-solving ability. In this instance, it is necessary to somehow score the "goodness" of the student's strategies. An objective evaluation requires that, somehow, problem-solving behavior be broken down into the skills demonstrated by a proficient problem-solver. Bobula and Page have suggested these generally applicable decision-making skills to be:

1) discriminating between relevant and non-relevant issues
2) recognizing the most important issues in the problem
3) determining what sequence to follow in order to solve the problem
4) obtaining appropriate and relevant information or data

5) interpreting data
6) avoiding uncecessary and wasteful actions (efficiency)
7) manipulating a situation to alter it
8) monitoring the effects of this manipulation and taking corrective action in reaction to adverse effects
9) applying substantive knowledge in solving the problem
10) resolving the problem most effectively (proficiency) by making the most appropriate decisions

Before scores can be assigned to the student's decision-making skills, criteria must be established by the subject matter expert and the instructional designer to judge the adequacy of each decision made by the student. These criteria reflect the complexity of the decision at each key decision point. "Correctness" of the option selected depends upon the conditions which exist at that point--conditions such as information that has or has not been provided, decisions previously made or not made, and changes that have occurred in the problem setting in response to the student's decisions. Usually there is no single correct decision but a number of possible decisions varying in degree of correctness or appropriateness depending on existing conditions.

These decision-making skills, which a student is to practice and improve by using the simulation, characterize a general problem-solving process, involving the application and <u>interaction</u> of these and other skills. Thus it is difficult to develop relevant, non-trivial criterion-referenced test items to measure the behaviors associated with the skills.

| Score | Formulation: | Example: |
|---|---|---|
| Errors of Ommission (%) | 100% minus (the sum of the positive points chosen, divided by maximum possible score), converted to percent. $$E.O.\% = (100) - \frac{(+)}{\text{Max. Score}} \times 100$$ | For the above examinee: $E.O. = 100 - \frac{72}{90} \times 100$ <br> $E.O. = 20\%$ |
| Errors of Commission (%) | The sum of the negative points chosen, divided by maximum possible score, converted to percent. $$E.C.\% = \frac{(-)}{\text{Max. Score}} \times 100$$ | For the above examinee: $E.C.\% = \frac{10}{90} \times 100$ <br> $E.C.\% = 11\%$ <br> NOTE: <br> 100%-[E.O.% + E.C%] = P% <br> 100%-[20% + 11%] = 69% |
| Efficiency (%) | The number of positively weighted choices made, divided by the total number of choices made, converted to percent. $$E\% = \frac{\text{No. of (+) choices}}{\text{No. of all choices}} \times 100$$ | For the above examinee: <br> 9 choices were + <br> 2 choices were 0 <br> 5 choices were - <br> 15 <br> $E = \frac{9}{15} \times 100$ <br> $E = 60\%$ |
| Competence Index (%) | The Proficiency Index weighted by the Efficiency Index. $$C = \frac{(P \times E/100) + P}{2}$$ | For the above examinee: $C = \frac{(69 \times 60/100) + 69}{2} = 55\%$ |

NOTE: Any rational method of weighting proficiency can be employed to yield a competence score. The Competence Index shown here is in use at the University of Illinois College of Medicine in scoring Simulated Problems in Patient Management.

McGuire (1963; undated) and Levine & McGuire (1969) describe the use of simulations to evaluate such decision-making skills in doctors. McGuire has developed exacting scoring procedures (Center for Educational Development, 1973) for these simulations. Her scoring techniques can be used effectively in various settings.

McGuire's scoring scheme, as adopted and modified by Bobula and Page (1973) yields five scores, or indices of performance. The scores are based on weights assigned to each option in the simulation. The weights may, for example, range from +16, +8, +4, +2 for desirable actions to -2, -4, -8, or -16 for undesirable actions. In some cases, failure to take a particularly crucial action may be scored as -16, while taking the action is scored as +16; the effective score for a person taking the action is thus +32.

The scoring formulas for evaluative simulations are defined as:

| Score | Formulation: | Example: |
|---|---|---|
| Proficiency (%) | The sum of (+) and (-) points for options chosen divided by the maximum possible score, converted to percent. | Examinee X made the following choices on a written simulation where 90 was maximum score. |

$$P = \frac{[(+) + (-)]}{\text{Max. Score}} \times 100$$

| No. of Choices | Weight | Sum |
|---|---|---|
| 3 | 16 | 48 |
| 2 | 8 | 16 |
| 4 | 2 | 8 |
| 2 | 0 | 0 |
| 2 | -1 | -2 |
| 2 | -4 | -8 |

$$P = \frac{[72] + [-10]}{[90]} \times 100$$

P = 68.8 or 69%

When the formulas were used to score performance on simulations in Civil Procedure (Edwards, 1975), students' Proficiency and overall Competence scores improved significantly on a second simulation. At the same time, however, it is interesting to note that in many cases the Efficiency score decreased slightly. This is not surprising -- students interacting with an initial simulation took far fewer actions, and those actions were likely to be obvious and correct. In dealing with a second simulation, students were aware of a much broader set of possible actions, although a few of those turned out to be inappropriate.

A student's score on a simulation problem therefore depends on his/her thoroughness in choosing all those actions the expert, or practicing professionals, agree are important and discrimination in avoiding all those actions the experts agree are useless or harmful. The scores for Errors of Omission (failure to take desirable action) and Errors of Commission (taking an undesirable action) are helpful in analyzing the nature of the students' deficiencies.

## Some Advantages and Limitations of Simulation as an Educational Tool

Those who advocate the use of simulations for both teaching and testing are sometimes challenged with the question, "If simulations of reality are so effective, why not use reality itself?" Assuming it is possible to use reality (i.e., a real patient, a real client, a real student), there are powerful arguments against it. For many purposes, practitioners find simulation to be superior not only to traditional methodology but also to reality itself. Simulation does not duplicate life, it imitates it. This may be, in the minds of some, its greatest limitation. To others, it is its greatest advantage.

Often, an actual problem situation may be too complex for a student to deal with effectively. In a confused or chaotic real life setting it is difficult to segregate the important variables and see the relationships between them. In a simulation, the problem situation 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.

A delicate balance must be achieved between realism and simplicity. We don't want to reproduce reality; rather, we want to isolate and highlight the important interrelationships in it.

No claim should be made that simulations are sufficient in and of themselves, or exhibit unqualified overall superiority over other media and techniques for instruction and evaluation. Clearly, some aspects of reality cannot at the present time be economically simulated, if they can be simulated at all. In addition, it is important to realize that simulation is not appropriate for teaching or for testing all aspects of performance. For example, conventional objective tests are still most economical and direct for measuring recall of factual information. At the opposite extreme, professional effectiveness can only be evaluated by observation over a long period of time in a diversity of settings. Simulation can provide important advantages between these two extremes. Simulation can be, and should be, successfully combined and integrated with other instructional and evaluative approaches so that all students are reached by one or more techniques suited to the nature of the problem and their individual learning style.

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