Computer Simulations of Laboratory Experiences

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During the last five years, a strong interest in computer simulations has emerged in computer education journals and magazines. This echoes a request or desire on the part of teachers for computer simulations, probably as a reaction against the preponderance of “poor” software available for micro-computers. A simulation according to McGuire (1976) is “placing the individual in a realistic setting where he is confronted by a problematic situation which requires his active participation in initiating and carrying through sequences of inquiries, decisions, and actions.” Lunetta and Hofstein (1981) state that a “simulation is the process of interacting with a model that represents reality.” Are computer simulations the vehicle that can unlock the promised but not yet achieved potential of the computer in our classrooms?

Overview

Gagne (1962) identified the following characteristics of a simulation:
1. A simulation represents a real situation in which operations are carried out.
2. A simulation provides the user with certain controls over the problem or situation.
3. A simulation omits certain distracting variables which are irrelevant or unimportant for the particular instructional goals.

\[ \text{Simulation} = (\text{Reality}) - (\text{Task irrelevant elements}) \]

Do these qualities of simulations imply any inherent improvement over current computer use in the classroom setting? In our minds, we must be clear to separate the appeal of a “good” (well designed) computer simulation from a “bad” (poorly designed) computer drill and practice program (computer drill and practice can and should be well designed). By their very nature, simulations are harder and more expensive to design and so will tend to be better than a run-of-the-mill program.

The purpose of this paper is to consider the aspects and qualities of computer simulations in the simulation of science laboratory experiments specifically, and relate this to general simulation applications. This paper will attempt to answer the following questions:

1. Is there evidence to indicate that computer simulations of science laboratory experiments compared to actual science lab experiences will result in improved achievement?

2. What recommendations for computer simulation design and application are suggested by current research? (transfer, feedback, learner control, ...).

When Should Simulations Be Used?

In a study by Cavin and Lagowski (1978) of students using a computer simulated chemistry experiment compared to students actually doing the experiment; the students made readings from a spectrophotometer, recorded this in a data table, then performed the necessary calculations to determine the results and form conclusions. The computer simulation groups achieved as well or better than the other groups. Also, the simulation took significantly less time. (In some cases, simulation students took more observations and so more time was used.) No relation was shown between the amount of time taken and aptitude. Computer simulations were effective for both low and high aptitude students. In a study by Boblick (1972) of students using a computer simulated physics experiment compared to students actually doing the experiment, the students made time measurements and observations of the results of a one dimensional elastic collision (both were discovery type activities with the student choosing values for the independent variables). Both groups showed learning gains, but the computer simulation group had significantly higher scores on the posttest. It was suggested that the simulation more closely represented a real elastic collision and also was easier to use than the real experiment.

"The computer simulation provided an environment which focused on the essential aspects of this experiment, eliminated the unnecessary consideration of variables not required in the study of momentum, provided a greater flexibility in the selection and employment of values for the essential variables, operated with sufficient speed to enable the student to gather large amounts of data in a short period of time, and furnished a means for rapid analysis of the data collected" Boblick (1972).

In these studies and also in Hedlund & Casolara (1986), Johnson and Johnson (1986), McGuire (1976), Sherwood & Hasselbring (1984), and Vockell & Rivers (1984); students achieved as well and usually better on the posttests through computer simulations. The point is not that computer simulations are better than any particular instructional approach, but...

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rather, that computer simulations are a viable means of instruction.

Conditions Under Which Computer Simulations Should Be Used?

Science teachers are obliged to teach both science content and science process. Computer simulations should not completely replace traditional science lab learning experiences, but may easily replace or supplement some lab instruction. We suggest that in well defined contexts and where the context is important to the learning, a computer simulation of the reality may be as good or better than the actual reality. This is due to a simulations ability to simplify or focus the learner's attention on the task and context, which allows the learner to process the critical aspects of the learning with less distraction.

"The author of the simulation decides which elements of reality to include and which to omit on the basis of instructional goals and the nature of the system being simulated. While simulations are sometimes used for logistical reasons such as expense, danger, or lack of equipment or space, they are sometimes justified because they simplify practice by reducing the number of variables active in the situation." Lunaeta & Hofstein (1981).

Also, the reduction of time between learner action and simulated response, and the reduced ambiguity of the task, would significantly simplify the classifying and memory storage tasks required in the learning process. In some cases, such as in dangerous or expensive "real" learning situations, computer simulations would be adequate for the instructional task even if the simulation might produce less learning than the real experience. Also, if time is a limiting factor, it may be better to use computer simulations.

Reduced ambiguity may result from decreasing nonessential complexity or by increasing required complexity. Ambiguity is an internal state of uncertainty which results due to a lack of connection in the learner between the learning experience and previous experiences. Adding additional elements to an instructional computer simulation adds to its complexity but may actually reduce its ambiguity thus making it seem less complex and easier to the learner. Increasing the complexity of the simulation may reduce its ambiguity. Therefore, the potential efficiency of a computer simulation depends on the quality and not necessarily the quantity of reality included in the simulation.

In summary, simulations should be favored over other instructional approaches when:
1. the learning task is complex for the learner (a simulation can reduce ambiguity, and can demonstrate or model correct options),
2. the learning task is too long (a simulation can help the learner identify the cause-effect relationship that might be obscured by time or bulk of material),
3. alternative approaches are not available (due to cost, danger, context, etc.), or
4. discrimination of the context of the solution set is important for deciding the content of the decision made.

Suggestions for Selecting or Designing Computer Simulations

Many of the factors (learner control, transfer, type and amount of feedback, levels of questions, individualization, debriefing, the use of branching to probe and develop conclusions) that are part of any instructional method would also apply to computer simulations. Because of its potential for providing a realistic context, though, computer simulations have special requirements (and applications) that should be identified and then incorporated into their design. We address this by looking at several studies that can offer some suggestions.

Learner Control / Program Control

In one study, a set of 6 biology laboratory computer simulations were included in ninth grade biology classes in 5 schools spread through the school year. The conditions were regular instruction, computer simulated guided instruction and computer simulated non-guided.

"Students using computerized science simulations... met the unit objectives at least as well as the control students. In addition, the students using the simulation often surpass the control group students on the pretests for subsequent units, on tests measuring scientific thought processes, and on tests of critical thinking. In most cases, the students using the guided versions of the simulations developed these generalized skills more effectively than those using an Unguided version" Vockell and Rivers (1984).

The guided version was the addition of instructions that required about 30 seconds to read. The learning transferred to subsequent simulations (near transfer). The students were not under time constraints and this is a significant point for this study which compared both guided discovery and free exploratory discovery. The effects of free exploratory discovery are highest when there is unlimited time to explore possibilities, and this would certainly represent the highest form of learner control. That guided discovery computer simulations were generally better than the exploratory computer simulations, particularly in the development of general problem solving skills inferred from learner control studies, suggests that some learner guidance is valuable in computer simulations. This is contrary to the position held by some that free exploratory discovery is best for learning science process (methods) and guided discovery is best for learning science product (content). In this study, the guided discovery treatment may support the use of an advance organizer rather than guided discovery since
the treatment described is probably not a guided discovery. However, either position supports the use of some form of learner guidance and a reduction of learner control in computer simulations, especially when instruction time is limited.

Near and Far Transfer

Transfer, both near and far, may be a forte of computer simulations. "...there is considerable evidence that much of what is learned can only be applied to problems that are similar to those that are experienced in training (transfer failures)." Clark and Vogel (1985). As mentioned earlier, simulations simulate a reality, preferably the reality in which the learning will be used later. In the Vockell and Rivers (1984) study mentioned previously, the learning transferred to subsequent simulations (near transfer). Thorndike and Woodworth's (1901) identical element hypothesis suggests that transfer is best when training is like the reality for which the learning is intended and such obvious logic is easy to accept. Gagne's (1962) definition of simulation as previously mentioned is represented in this formula:

\[
\text{Simulation} = (\text{Reality}) - (\text{Task irrelevant elements})
\]

In fact, a computer simulation can go at least one step further. Reality can be an enhanced reality that highlights the most important cues while removing the task irrelevant cues. The formula might then become:

\[
\text{Simulation} = (\text{Enhanced reality}) - (\text{Task irrelevant elements})
\]

Presumably, the more like reality the simulation is, the easier or more efficient the near transfer. This may be complex because it can involve the context of the reality, past experiences, attitudes about self, feelings of self worth, and other factors that are not part and parcel of a computer simulation design. Clark and Vogel's (1985) general recommendations on transfer are helpful:

1. The extent of transfer is determined, in part, by the amount of decontextualization achieved during instruction (amount of reality included in the design through the removal of irrelevant cues).
2. Simulations that employ relevant analogies will promote farther transfer than instruction employing rule use and practice in different contexts. (Assumes a large quantity of previously learned meaningful examples as the analogy base.)
3. If analogous prior knowledge used in transfer contains operations that are not permitted in the application task, negative transfer may occur.
4. Other things being equal, procedural objectives will produce nearer transfer learning and declarative objectives will result in far transfer learning.
5. Other things being equal, far transfer is achieved at the expense of near transfer.

First, simulations are more or less context bound by their very nature. This variable can be manipulated by the designer to increase either far or near transfer depending upon the instructional objectives.

Second, rule use and practice in different contexts is the main emphasis of most types of simulations, implying that near transfer can be expected when using most computer simulations, however certain types of simulations can incorporate use of analogies allowing for far transfer.

Third, all analogous prior knowledge should not be generalized to every new situation. That is why this negative transfer is part of our normal cognitive processing as viewed from a natural selection viewpoint. For example, a prehistoric man that waves a stick at one type of predator frightens that predator away, but waving that same stick at a different predator may invite a quick snack. The key to survival is immediate negative transfer based upon discrimination of the context, the learned task of stick waving should not be generalized to every similar situation.

So in developing simulations, the analogies chosen must be similar to the near transfer task, and one of the key learning outcomes must be discrimination of the context of when this learning should be used as well as performance of the learning itself.

Fourth, procedural objectives of this type are probably stored in long term memory in a different way than the declarative knowledge and as such are nearly an automatic process. This implies that these procedural objectives would be stored in a way that allows for a more rapid recall and an intuitive action or reaction based upon the context, along with information about that specific context, almost as an automatic system. These may best be learned through rule use with practice until it is overlearned (automated). The learning may involve simple or complex behaviors. This idea may be summarized as:

\[
\text{Learning experience} = \text{Content of procedure} + \text{Context of procedure (specific)}
\]

Declarative knowledge, on the other hand, is probably stored with the fund of other similar declarative knowledge and would be less context bound. This knowledge can be generalized to new situations and would be available for heuristics development. This idea can be written as:

\[
\text{Learning experience} = \text{Content of declarative info} + \text{Analogous context (general)}
\]

Journal of Computers in Mathematics and Science Teaching
Last, when you go for far transfer, you sacrifice near transfer. This may be due again to the way each would be stored in long term memory. Instruction designed for far transfer would lack the context specific discriminators that would allow for an automatic algorithmic selection of the learning associated with it, and so this learning would be filed in the broad field in memory with which it is most closely linked. This field contains many other general experiences, and when this learning is called upon, only a generalized “best answer with other information attached to it” is available from the long term memory store, rather than the specific learning only. This then would be far transfer at the expense of near transfer.

In summary, we suggest that transfer is a function of the reality or specificity of context built into the computer simulation, and that both near and far transfer can be achieved most effectively through computer simulation.

Levels of Questioning

Some simulations depend upon questioning for the development of cognitive processes in the learner. The current suggestion is that higher level questions (Bloom’s Cognitive Taxonomy: Analysis, Synthesis, Evaluation, ...) are more effective because they may cause deeper level processing in the learner.

In a study by Merrill (1985), the effects of low or high level questions with corrective feedback (CF) or attribute isolation feedback (AIF) were examined. AIF informs learner of correctness or incorrectness and isolates the attributes of the concepts being studied, thus focusing attention on the critical and variable attributes of a concept. Four groups were established: LO/CF, HI/CF, LO/AIF, HI/AIF. All were Junior chemistry students, n=154. Time on task was the same. HI cognitive level questions were better than LO level questions in causing higher scores on posttests (at the .001 level). Effects of CF versus AIF were not established. It was suggested that the concepts measured by the posttests were not hard enough nor the instructional time long enough to show an advantage for AIF.

Generally, the results of this study support the use of higher level questions in computer simulations, but not AIF.

Feedback

The amount and type of feedback in a computer simulation is a central question that must be answered. Content is the critical factor because the content will determine the presentation mode, and the presentation mode will require a specific feedback approach. Gredler (1986) has suggested the following taxonomy of computer simulations:

1. Structured questions with associated graphics
2. Assignment of variables with results exercises
3. Diagnostic simulations
4. Group-Interactive

Structured questions with associated graphics would present content, the images would represent the reality (context) portion of the simulation. This category would probably be best for developing the cognitive processes related to analysis/deductive reasoning and would require observation, interpretation, interpolation, extrapolation and other skills. The content might be explained by the graphics. The presentation mode would be episodic, each question would represent a learning episode and immediate feedback would be inherent in the episode, there is probably one right answer. Each additional episode may or may not build upon previous episodes. This model is fairly structured. Assignment of variables exercises describe many or most science laboratory computer simulations. Basically, an independent variable is set by the learner and the results on the dependent variable are observed through several trials, much like a real laboratory experiment. This category of simulation would be best for developing inductive or synthesis processes. The nature of this simulation is cyclic, feedback is related to variables effecting other variables. There may be one right answer, but it is a large concept (declarative knowledge) that must be induced after many variable-response episodes, also incidental learning may occur involving efficient selection of values for the independent variable (a process skill).

Diagnostic simulations could be considered to be a form of expert system. This type of simulation usually involves applied decision making in a professional content area (a large field of related information within the professional allows for generalized decision making as well as a large body of procedural or algorithmic information in specific context allows for specific decision making; the crux is to decide which is called for and then act). A decision variable is selected by the learner after several episodes, and the episodes tend to blend into one large scenario (definition of context). The results of the decision may be immediate or delayed and may or may not be easy to interpret (again calling upon previously learned knowledge). The purpose of the simulation may be to interpret the situation or context as well as to make the appropriate decisions. Normally, one right answer is impossible to define. The results of many scenario decision making events will eventually develop in the learner super-concepts (algorithms and heuristics) that may be considered “expert knowledge”.

The group interactive simulation would be applied decision making in a real social context. Each social context is different. Distinguishing the correct approach in context is the principle learning outcome. There is not a suggestion of a right or wrong answer but rather the question “is the solution appropriate in this context?” As in diagnostic simulations, the episodes blend together into a scenario that has occasional decision making points. Results of decisions made are often quite difficult to determine because these are effecting the emotions of the individuals involved. Feedback in both cate-
gories is variable at best, and approaches the form of feedback that occurs in a real life situation.

In experiential type computer simulations (Diagnostic simulations and Group Interactive simulations), it may often be difficult or inappropriate to “break-in to” the simulation to provide feedback in the form of intrusive questions. Often, if the simulation is of short enough duration, questions and feedback may be provided at the conclusion following the traditional adult experiential learning cycle:

1. experience (SIMULATION)
2. describe what happened (FEEDBACK)
3. describe how it made you feel
4. what would you do differently next time? (return to #1)

This model assumes that timely feedback is best. Also, to be most effective, feedback should be solicited or requested by the learner.

The timing of feedback in these experiential simulations then, seems to be a function of the amount of reality built into the simulation. Sometimes reality gives instant feedback and sometimes reality requires solicitation of feedback after performance, any other approach would seem to be intrusive and artificial.

In summary, feedback in computer simulations depend upon the content of the instruction which determines the form of the simulation.

Individualization / Grouping

Should learners use computer simulations in large groups, in small groups, or alone? There is no easy answer. Individualized instruction unlocks the instructional potential of the computer (which is in fact, the ability to individualize), while group co-operative instruction allows group processing of the information with a certain amount of peer tutoring.

Sherwood and Hasselbring (1984) in a study using O'dell Woods and O'dell Lake simulations examined groups working individually, in small groups, and in whole class groups. All groups did equally well on the posttest. Girls did better in larger groups than individually.

A question arises over the quality of instruction delivered by these simulations. Because computer simulations have the potential to individualize instruction does not mean that every program actually does. For simulations with low ability to individualize, a group approach would seem best, particularly if the content is difficult to grasp (allows peer tutoring). As better simulations are developed, perhaps these will be individualized with resulting improvement in individual learner achievement over group instruction achievement. This individualization may include type, level, and number of examples given and type and amount of other supporting material.

In summary then, the general quality or the ability of each simulation to individualize should be considered before deciding on a group or individualistic approach in its use.

Summary / Conclusion

There is some consistent evidence that computer simulated science experiments of the type described as “assignment of variables simulation” by Gredler do result in improved learning both of specific content and also of more generalized cognitive processes.

We recommend that computer simulations are viable means of instruction especially when:

1. Support and learner guidance with some program control are included in the design.
2. Both near and far transfer of the learning is desired.
3. Higher level questions are incorporated into the design.
4. The type or structure of the simulation design is selected based upon the learning outcomes desired, which then defines the amount and type of feedback.
5. The general quality or the ability of each simulation to individualize is considered before deciding on a group or individualistic approach in its use.

Finally, we suggest that computer simulations simplify the cognitive processing tasks associated with learning both procedural and declarative knowledge through removal of distractors to learning, and also provide practice in context that will allow for efficient near and far transfer of the learning.

Good simulations can be the vehicles that teachers are looking for to unlock the promised potential of computers in their classrooms. Further studies should be undertaken perhaps related to the most efficient depth of content and length of time for each type of simulation described, especially related to episodic and non-episodic computer simulations. Also, interactions of types of simulations with cognitive style dimensions, and also with other forms of instruction for the enhancement of both may be viable areas of investigation. Finally, a third area would consider the amount of challenge to include in a simulation as related to variables such as student achievement, or past experiences with the reality being simulated.

References


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