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AN INSTRUCTIONAL THEORY FOR THE DESIGN OF COMPUTER-BASED SIMULATIONS

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A simulation is described in terms of its three major design aspects: the scenario, the underlying model, and the instructional overlay. The major focus of this paper is on the instructional overlay, which serves to optimize learning and motivation. The instructional functions of simulations and the instructional features that should be used to achieve these functions are described. Prescriptions for the design of computer-based simulations are presented in the form of a general model and variations on the general model. The general model offers prescriptions for the design of the introduction, acquisition, application, and assessment stages of simulations and for dealing with the issue of control (system or learner). Variations on the general model are based on the nature of the behavior (using procedures, process principles, or causal principles), complexity of the content, form of learner participation, form of changes being simulated (physical or non-physical), and motivational requirements.

The advent of the computer has made possible a new and exciting form of learning environment, the simulation. We now have the technology for a powerful form of instruction that is both dynamic and interactive and that can provide considerable variety within a simulated environment. Even a personal tutor is incapable of such versatility. Computer-based simulations can provide efficient, effective, and highly motivational instruction that can readily serve the need for individualization. Simulations also enhance the transfer of learning by teaching complex tasks in an environment that approximates the real world setting in certain important ways.

Based on an extensive review of simulations and literature on simulations, we propose that the instructional effectiveness of a simulation is determined by three major aspects of its design: the scenario, the underlying model, and the instructional overlay. The **scenario** of a simulation recreates to a greater or lesser degree a real life situation. It determines what happens and how it takes place, who the characters are, and what objects are involved, as well as the learner's role and how he or she will interface with the simulation. To simulate a situation, the computer must respond to learner actions in a way that reflects that situation. This requires a **model**, usually a mathematical formula determined by an expert, which reflects the causal relationships that govern the situation. Finally, the simulation should have an **instructional overlay** to optimize learning and motivation.

This paper focuses on prescriptions for designing the instructional overlay, for our analysis of simulations has revealed that this is by far the weakest of the three aspects of simulation design in educational simulations that have been created to date. However, a brief comment about the other two aspects is in order.

The scenario and underlying model should reflect, to some degree, the situation being simulated. But to what degree? Should we always attempt to create maximum fidelity, or is it sometimes more effective to alter or simplify reality? Alessi (1987) suggests that maximum fidelity does not necessarily provide the most effective instruction. It was evident from the simulations which we reviewed that certain aspects of the real world situation should be represented with high fidelity in the simulation, while some need not, and, indeed, some should not. We suspect that the "fundamentals" of the real situation should have high fidelity: those basics which determine the nature of the mental and in some cases physical activities required of the learner in the real situation. More superficial aspects of the real situation are less likely to improve transfer to the real situation when designed into a simulation and may in fact create overload, which impedes learning and motivation. We have identified four factors that should be considered in all decisions about fidelity of the scenario and model:

- **Overload** - the degree to which details or complexities of the real situation provide too many new stimuli for the learner to be able to acquire the desired content.

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- **Transfer** - the ability to use what has been learned in the real situation(s).
- **Affect** - the motivational appeal of the simulation.
- **Cost** - design, development, and production expenses for creating the simulation.

Overload and cost generally argue against fidelity for superficial aspects of the real situation, whereas transfer and affect generally argue for it. Often the best design is one which begins with low fidelity and progresses by levels to high fidelity at the end of the instruction.

The remainder of this paper addresses the third aspect of simulations, the instructional overlay, which includes all the instructional design features of a simulation and how they should be used to optimize instruction.

Instructional Overlay

Despite the existence of a considerable number and variety of simulations, our literature review for the instructional overlay has revealed that few empirically based prescriptions have been offered to guide the design of instructional simulations. Most simulations have been produced using a "seat of the pants" approach. Some are quite good. Many are nothing more than video-type games or drill-and-practice exercises. Almost none provide a complete instructional package. In our attempt to formulate an instructional model for the design of computer-based simulations, we have addressed the following questions:

- What are the different kinds of instructional simulations?
- When should each kind of simulation be used?
- What characteristics should each kind of simulation have to provide optimal instruction?

We conducted a survey of the literature and analyzed a variety of simulations to provide answers to these questions.

The dynamic and interactive nature of computer-based simulations provides an ideal medium for teaching students content that involves changes. Such content includes what Merrill (1983) refers to as principles and procedures and Gagné (1985) refers to as rules, a subcategory of his intellectual skills. While simulations may also be used to teach facts and concepts, the nature of this type of simulation would be very different. Our prescriptions have been developed only for simulations that teach principles and procedures.

In our analysis of simulations and related literature (e.g., Gagné, 1985; Gropper, 1983; Merrill, 1983), we have found that the nature of the content or behavior being taught is the major influence on the instructional features a simulation should have. For example, mastery of many procedures, such as flying an airplane and writing a good paragraph, is gradually acquired over time. But for most principles, mastery is an instantaneous, all-or-nothing, flash of insight or understanding. Therefore, methods of instruction must be very different for each of these two kinds of learning (Merrill, 1983), and the design of a simulation will need to be very different for each. In fact, we have identified three major types of simulations: those that teach procedures, those that teach "process" principles, and those that teach "causal" principles.

Procedural simulations teach the learner to perform a sequence of steps and/or decisions, as in flying an airplane or adding fractions. They include both the physical and procedural categories described by Alessi and Trollip (1985). We have combined their two categories because it appears that the nature of the instruction should be essentially the same for both. A **process simulation** teaches naturally occurring phenomena composed of a specific sequence of events. Unlike procedures, processes are not purposely performed by people, but are naturally occurring, as is the action of a volcano or the process of photosynthesis. A **causal simulation** teaches the cause-effect relationship between two or more changes, such as the law of supply and demand or the theory of natural selection.

Possible Functions of Simulations

It is useful to think in terms of three phases in the learning process that should be activated by educational simulations, unless other media of instruction do so. The learner must first **acquire** a basic knowledge of the content or behavior. Then he or she must learn to **apply** this knowledge to the full range of relevant cases or situations. The final stage is an **assessment**, in some cases a self-assessment, of what has been learned. Therefore, the first set of instructional features in a general model for simulations should be concerned with **acquisition** of the content, the second set with **application** of the content, and the third with **assessment** of learning.

The first function, acquisition, is to present the content, which in our case is either principles or procedures. For principles the learner must acquire a meaningful understanding of the change relationships (natural processes or causes and effects). For procedures the learner must acquire knowledge of what steps to follow and how and when to do each step.

After the learner has achieved acquisition, he or she must then learn to apply this knowledge. For both procedures and principles, **generalization** is required. For example, the learner must develop the ability to apply the steps of a procedure to the full range of inputs and conditions that may exist.

Mastering a procedure often requires **automatization** as well as generalization. The learner must develop the ability to perform the sequence of steps and/or decisions almost without thinking. This is generally achieved through timed repetition of practice (Lesgold, 1983; Logan, 1985; Salisbury, 1985).

Application of causal principles requires **utilization** in addition to generalization. A performance routine, or what Landa (1976) refers to as a transformational algorithm, that governs the application of the causal principle must be learned or invented by the learner. Utilization refers to the ability to use the appropriate performance routine to apply the principle.

The assessment function of the simulation determines if the learner has achieved mastery. Mastery is a specified criterion for the number of correct responses and/or speed of response on a set of divergent and difficult, previously unencountered, practice situations.

It is not always necessary for all three of these instructional functions to be served by a simulation, for any one or two of these functions can be accomplished outside of the simulation. However, often no provision is made for a function to be accomplished if it is not specifically included in the simulation. And there is usually no valid reason for not including all three within a simulation.

Features of Simulations

Based on instructional theory and an examination of many simulations, we have identified five simulation features that act as vehicles for achieving acquisition, application, and assessment. These include the generality, example, practice, feedback, and help. These basic features of simulations correspond to the presentation forms of Merrill's (1983) Component Display Theory and four of Gagné's (1985) events of instruction: present the stimulus, elicit a response, provide feedback, and provide learner guidance.

The **generality** is a statement of the relationship among changes that characterizes a procedure or principle. It may take the form of a verbal presentation, for example, a statement of the law of supply and demand, or it may be a visual representation, such as a set of graphs showing the relationship between supply and price and between demand and price. This is never an integral feature of a simulation, but can be superimposed on one.

An **example** is a specific instance or case that shows the relationship among changes described in one or more generalities. It may be presented as a **demonstration** with no active learner participation or as an **exploration** in which the learner manipulates the example to see what happens. The nature of this type of learner participation is different from that required for application of the generality, in that the learner's behavior is not the one specified by the objective. This is an expository form of simulation.

Practice provides the learner with the opportunity to apply one or more generalities to diverse situations. It consists of two components: a **stimulus** situation presented by the simulation and a learner **response** that is consistent with the instructional objectives. This is a more participatory form of simulation.

Feedback provides the learner with confirmatory or corrective information regarding his or her responses. Alessi and Trollip (1985) note that there are two forms of feedback for simulations: natural and artificial. **Natural feedback** is a real-life consequence of a response (or simulation thereof); **artificial feedback** is a contrived consequence which would not occur in the real situation. In the "Flight Simulator", dials showing altitude and fuel level are forms of natural feedback, as is the view through the cockpit window.

In our review of simulations, we found that natural feedback is usually sufficient for simple tasks but does not provide enough information for complex tasks that require a chain of responses before the natural consequences manifest themselves. In such cases artificial feedback may be used to provide the learner with additional assistance, and may be either **informational** or **motivational** in nature. A statement in a flight simulation that tells the learner to check his fuel gauge is informational feedback, because it provides additional information that would not occur in the real situation. Phrases such as, "Keep up the good work!" or "Try again, you can do it!" provide praise or encouragement to the learner and so are motivational types of artificial feedback. Natural feedback is an integral part of a simulation, whereas artificial feedback is part of the instructional overlay.

Help provides the learner with direction and assistance during the presentation of the generality, examples, practice, and feedback. It appears that both the difficulty of the content and the instructional approach (expository or discovery) should determine what type and how much help is needed. We have identified three different types of help based on function. The first **directs attention** using flashing, color, bold, arrows, labels, etc. to emphasize important aspects of the presentation. The second **relates the instance** (example or practice case) **to the generality** by providing commentary. The third type **facilitates encoding** by providing an alternative representation, such as a diagram, along with a definition. This tends to increase the depth of processing and enhance understanding and retention (Bruner, 1960; Paivio, 1979).

Another feature of simulations is the **representation form**, the way in which material is displayed on the screen. We have adapted Bruner's (1960) classification to characterize four representation forms: enactive, iconic, visual symbolic, and verbal symbolic. The **enactive** form uses equipment along with the computer to provide the most realistic simulations. An **iconic** form, the second most realistic, consists of video or graphic displays. Less realistic but very effective for simplifying difficult content, **visual symbolic** uses symbols or icons, and **verbal**

symbolic is composed of words and numbers.

All four representation forms may be used to produce a dynamic presentation that requires learner participation, but the degree of realism will differ depending on the nature of the content and the instructional objectives. As was discussed above regarding the fidelity of the scenario, the simulation can often be most effective if it is simplified to eliminate distracting and unimportant aspects of the real situation or if the speed of a process is altered to reveal what is not normally evident. In other situations the closest approximation of reality may be desirable to enhance learning transfer.

Table 1 presents a summary of the available features that can be used to achieve the functions of simulations. During acquisition, if the learner is not required to figure out the generality, an **expository** approach is being used, and the learner should receive the simulation in example form with the generality(ies) provided as instructional overlay. Application with no performance of the criterion behavior is an **example form** of simulation. When learner participation is utilized, the approach and features are different. In the case of acquisition, if an example is presented and the learner is required to "figure out" the generality, a **discovery** approach is being used. Application that involves performance of the criterion behavior is **practice** and should be accompanied by feedback.

It is important to note that the two types of examples, **observation** and **exploration**, also differ based on learner participation or lack thereof. Unlike an example that is purely observational, an exploration-type example can be manipulated by the learner through the keyboard or some other input device.

The general instructional model and variations that follow prescribe the optimum features and approach for each kind of simulation.

Table 1. Feature-Function Map.

	No Participation	Participation
Acquisition	by expository approach: Generality with a Prototypical Example	by discovery approach: Prototypical Example to Figure Out the Generality
Application	without criterion performance: Examples	by criterion performance: Practice with Feedback
Example	without manipulation: Observation	by manipulation: Exploration

A General Model for Simulations

The prescriptive theory we have constructed originates with the three phases of learning described above. We have organized and adapted the features of simulations to provide the learner with the most effective and efficient presentations for successful acquisition, application, and assessment. A general model describes five aspects of simulations and provides prescriptions for the implementation of each. It applies to all simulations for teaching principles or procedures. Specific conditions require their own characteristic prescriptions (or types of simulations) that are described as variations on the general model.

Before proceeding with the "how to" of simulation design, some consideration should be given to the question of "when to" use simulations. We have found that simulations can be an extremely efficient and effective form of instruction for content involving changes. Therefore, we propose that they should be used to teach principles and procedures whenever the audience is large enough for computer-based simulations to be cost effective.

Select the Appropriate Complexity

The design of the instructional overlay for any simulation begins with making sure not to overload the learner. This requires selection of the appropriate complexity for the content or behavior that is to be learned. The real situation is usually quite complex, with many variables to consider for successful performance. For such situations, to begin with so many variables in the underlying model will clearly impede learning and motivation. The best design is usually one which begins with only one or two variables in the model and progresses by levels to include all important variables in the simulation at the end of the instruction.

- First determine the complexity of the most realistic underlying model you will use.
- If it is comprised of only a few variables, select an integral approach; that is, do not break it down into simpler levels.
- Otherwise plan on simplifying the model using one of the approaches described under "Variations on the General Model" below.

Introduction

The simulation is preceded by an introduction that describes the scenario, identifies goals and objectives, and presents directions and rules that will govern the simulation.

- Set the stage in the depiction of the **scenario** by identifying the setting, the form of learner participation, and the major characters and objects. Indicate how the simulation will proceed, what kinds of things will happen, and under what circumstances. This should be done by example with simultaneous description.

- Present the **goals and objectives** whenever possible as part of the depiction of the scenario. This will provide a concrete example that will enhance meaningful understanding and motivational appeal.
- Present **directions and rules** to describe how to use the program, including such things as key functions, use of learner control, and other options. Present the directions as text with graphic or video support that requires minimal dependence on documentation. Present the rules via demonstration within the scenario whenever possible.

Acquisition

During the acquisition stage the learner develops a meaningful understanding of a principle or knowledge of the steps in a procedure. The acquisition function may be achieved by means of an expository or a discovery approach and may require either exploration or observation by the learner. In an **expository** approach the generality is presented; in a **discovery** approach the learner is require to "figure-out" the generality. The preferred approach and form of learner participation depends on the nature of the content and criterion behavior and is discussed later under "Variations."

- If an expository approach is used, provide the generality along with a prototypical example for the learner to explore or observe (see "Variations"). The order of the generality and example may be varied to create either an inductive or deductive expository approach (see "Variations" below).
- For a discovery approach, require the learner to "figure out" the generality by exploring or observing a prototypical example. Provide help in the form of hints and prompts to assist the learner with the discovery process.
- Provide help to direct attention, relate the generality to the example, or facilitate encoding by presenting a second representation as needed during acquisition. Use more help and use it more frequently depending on the difficulty of the content in relation to learner ability and experience.

Application

During the application stage the learner develops the ability to use the principles or procedures that have been introduced in the acquisition stage. The primary element of the application stage is divergent practice composed of a stimulus, a learner response, help, and feedback. The following prescriptions are based primarily on the theories and attendant research bases of Gropper (1983) and Merrill (1983).

- Provide cases which have a variety of **stimulus** conditions that include the full range of divergence existing in the real world.
- It may be necessary to create a mechanism for randomly producing cases that include all possible **varieties** of stimulus conditions.
- Use an easy-to-hard progression of difficulty for presentation of cases.
- If different levels of difficulty are used, require the learner to reach **criterion** on one level before going on to the next level.
- Use a **representation form** as close as possible to that of the real world situation unless some form of simplification in terms of time span or complexity is helpful or required by cost considerations.
- Provide **pre-response help** (prompts and hints) when the difficulty of the task makes it necessary to direct attention or relate the practice case to the generality. This form of help should **fade** as practice progresses.
- Require a learner **response** which is consistent with the terminal objectives (criterion behavior) for the content.

An essential component of practice is the **feedback** which follows the learner response. The following prescriptions provide guidance for the design of effective feedback (Alessi & Trollip, 1985; Merrill, 1983).

- Use **natural** feedback to maximize the reality of the simulation. The underlying model (discussed earlier) should produce the appropriate natural feedback for the responses given.
- For simulations that require greater frequency in the feedback schedule and/or greater information than is provided by natural feedback, use **artificial** feedback as well as natural feedback, but gradually **fade** the artificial feedback as the learner masters the task.
- Provide **help** as needed (depending on the difficulty of the content) at first, then gradually **fade** it.

Assessment

After completing the instructional phases of the simulation, a **criterion test** should be administered to determine if the learner has mastered the content.

- Present **new cases** as test items, and include the full range of **difficulty** and **divergence**. These cases should be interchangeable with practice cases.
- Use a scoring mechanism and establish a **criterion score** that must be achieved for mastery.
- Display the score as the learner progresses through the test unless such a **running score** is inconsistent with the nature of the real-world task or provides prompting of some kind.

- A test may be done as **part of the practice**, provided the items are new, but a penalty should be registered for any help provided (both pre- and post-response help).
- If criterion is not met, immediately follow the test with a thorough **debriefing**. It should provide artificial feedback for all mistakes made.

Control

The issue of control influences all components of a simulation. The literature indicates that the learner should be allowed to exercise control over some aspects of the simulation, while the system should exercise control over others (Merrill, 1980, 1984). To some extent user or system control will be determined by the instructional objectives, but in general the following prescriptions apply to all simulations.

- Use system control of the **level of complexity** for each learner, based either on pretest data or on teacher input.
- Use system control of the **learner's progress** from one level to the next to ensure that mastery is achieved at each level before allowing the learner to go on to the next level.
- Use system control of **routine features** (generality, examples, practice, feedback) of the initial presentation for a new principle or procedure. Then permit the learner to choose to see additional cases in example form or to go back to a generality or example at any time during a practice case.
- Use system and learner control of **help**. Provide some help to all learners on early examples and practice, then fade it while allowing the learner to select it back in.
- Use system control to require the learner to see the **introduction** the first time the simulation is used. From then on, access to the introduction should be optional and under learner control.
- Provide the option for either system (including teacher input) or learner control of the **test criterion** to provide maximum flexibility of use. Learner control may be implemented by allowing the learner to select a test of a particular difficulty level or to specify the number or percent of correct answers required (e.g., from a menu). In some situations this becomes highly motivational in that the learner attempts to better his or her score, much like a game, each time he or she uses the simulation. In many cases the teacher may select the difficulty and criterion levels for mastery by setting specific variables made available in a learner management section. This is especially useful for individualization of learner assessment.

Variations on the General Model

While it appears that all simulations should include the prescriptions described in the general model, there are certainly many aspects of a simulation that should vary from one situation to another, depending on such conditions as the nature of the content to be learned, the form of the changes that occur, and the motivational requirements. The following prescriptions for variations on the general model describe when to use each variation and what it should be like.

Nature of the Content

The nature of the content being simulated will determine the nature of the acquisition and application stages of the simulation, including the mode (expository or discovery) and form of manipulation (observation or exploration). Hence, type of content is the single most important basis for prescribing variations in a simulation.

We have identified one major variation of the general model for each of three types of content: procedures, process principles, and causal principles. Table 2 presents prescriptions to guide the design of the acquisition and application stages for each.

As previously discussed, the generality can be presented using an expository or a discovery approach, both of which require the presentation of a prototypical example. The learner may be required to observe only, or to manipulate the example, and then to observe the result.

Table 2. Variations: Features for Functions for Each Type of Content.

VARIATIONS ON THE GENERAL MODEL

	Acquisition	Application
Procedure	Expository by observation: Generality + Prototypical Example	Divergent Examples + Performance Practice (accuracy) + Drill Practice (speed)
Process Principle	Expository: Generality + Prototypical Example	Divergent Examples + Performance Practice (accuracy)
Causal Principle	Discovery (of principle) by exploration: Prototypical Example of the principle	Divergent Examples of the principle + Discovery (of routine) by observation (via Divergent Examples of the routine) + Divergent Performance Practice (accuracy)

Acquisition may, therefore, be accomplished by a discovery or expository approach, either of which may present the prototypical example by observation or exploration. The following prescriptions are tentative hypotheses based on our review of simulations and related literature. We offer them in hopes that they will stimulate research to test their optimality.

For the acquisition stage of **procedural** simulations:

- Use an *expository* approach because it is not feasible or useful for the learner to "figure out" the generality. This is best done by presenting the generality simultaneously with a prototypical example of the procedure.
- Require the learner to *observe* rather than explore the example.

For acquisition of **process principles**:

- Use an *expository* approach because, as with procedures, it is neither efficient nor effective for the learner to engage in a trial-and-error search to discover the generality. This is usually best done by presenting the generality simultaneously with a prototypical example of the process.
- Require the learner to *explore* the example, if possible. Exploration requires that the learner turn the process on and off in the example and then observe the results.

Causal principles are quite different in nature from procedures and processes, because not only must the principle be learned, but the routine for applying it must be learned as well. For acquisition of **causal principles**:

- Use a *discovery* approach. The change relationships should be clearly presented in a prototypical example, and with help, the learner can be lead to "figure out" the principle, resulting in enhanced understanding.
- Require *exploration* of the example by the learner.

After the learner has acquired the generality, the general model calls for the simulation to proceed with the application stage to teach the learner to apply the generality in any situation that might be encountered in the post-instructional environment. For application of all three types of content, if the task is fairly **difficult** to master:

- Precede the practice (a component of the general model) with *divergent examples* of the procedure, process or causal principle.
- Use *divergent practice* to provide the breadth of experience needed to achieve accuracy in applying the generality to different cases.
- Use a larger number of example and practice cases.

Procedures differ from principles in that automatization is usually necessary to ensure sufficient speed of performance and to reduce conscious cognitive processing requirements during performance (Lesgold, 1983; Logan, 1985; Salisbury, 1985). Therefore, in addition to the prescriptions above:

- Provide drill practice to a speed criterion after the accuracy criterion has been reached on performance practice.

For **causal principles**, we have found that the application phase should teach a routine for utilizing the principle, and how to use that routine. Therefore:

- Require the learner to observe a *demonstration* of the routine (as it is utilized to apply the principle), accompanied by *help* to clarify and emphasize the steps in the routine (the generality).
- Then provide divergent *examples* and performance *practice* using the routine to apply the causal principle.

To design the example and practice cases, it is important to analyze the kinds of cognitive behaviors that are learned for each type of content. For a **procedure** the learner is expected to execute a sequence of steps and/or decisions to achieve a particular goal. For a **process principle** the learner is only expected, in the simulations we have analyzed, to describe a sequence of naturally occurring events. For a **causal principle**, however, we have identified three different types of behaviors: prediction, explanation, and solution.

In terms of causes and effects, the **prediction** behavior is expected when the objective requires the learner to predict the likely effect(s), given a set of causes. A simulation requires prediction behavior when it presents a variety of lens shapes and asks the learner to predict the effect of each on light rays. **Explanation** behavior is expected when the objective asks the learner to identify the likely cause(s), given an effect. An explanation simulation might require the learner to identify the causes of pollution in a lake, the physical traits of parents of a particular fruit fly, or the reason for an increase in air pressure under specified conditions. **Solution** behavior is expected when the objective requires the learner to select and implement the necessary causes to bring about a desired effect (i.e., to engage in problem solving). "Lemonade" is a solution simulation that requires the learner to maximize his or her profits using knowledge of the law of supply and demand.

Hence, there are five types of behaviors for procedures and principles: execution, description, prediction, explanation, and solution. Table 3 prescribes the nature of the stimulus and response for the practice cases for each of the five types of behaviors. Often, the learning objectives for content composed of causal principles do not require a specific form of response, rather the general ability to use the principle in any way. If this is the case, use a variety of prediction, explanation, and solution cases in the simulation to provide the learner with greater divergence of behaviors. For complex content, require prediction and explanation behavior for individual principles first, then solution behavior for integrated practice of a number of related principles.

Table 3. Prescriptions for the Nature of the Stimulus and Response for Practice Cases in Five Types of Simulations.

Type of Simulation		Nature of Practice	
Behavior	**Example**	**Response**	**Stimulus**
Execution (Procedure)	Add fractions or Select math operation	Use a sequence of steps and decisions	Goal, inputs
Description (Processes)	Plant Life Cycle	Describe a sequence of effects	Situation
Prediction*	Predict effect of increased price	Predict the likely effects	Causes
Explanation*	Identify cause of increased demand	Identify the likely causes	Actual effects
Solution*	Maximize profits	Select and implement the necessary causes	Desired effect & inputs

* Cause-effect Principles

Complexity of the Content

Before the actual design process begins, the complexity of the desired content and/or behavior must be analyzed to determine if it can be presented as an integral whole or if it must be broken down or simplified. This will determine the kind of macrolevel sequencing for the domain-specific content.

- If the content is relatively simple and involves a limited number of principles or procedures, teach it as an **integral** whole (Gropper, 1983; Landa, 1983).
- If the content is difficult, simplify it using an **elaboration** approach (Reigeluth & Stein, 1983).

If the content is procedural, the elaboration theory describes a methodology for simplifying the procedure until it is simple enough to learn as an integral whole (Reigeluth & Rodgers, 1980; Reigeluth, 1986). Then that "epitome" is gradually elaborated upon, one level at a time, until the complete procedure (as called for by the objectives) is mastered. Although the basics of that methodology also apply to solution tasks, some extensions of that methodology are useful. Space limitations make it impractical to include these prescriptions in this paper.

If the content is primarily principles, the elaboration theory describes a methodology for simplifying the task by requiring use of only the one or two most important and most broadly applicable principles for making the prediction, explanation, or solution (Reigeluth, 1987). Once that principle (or two) has been taught in an "epitome" simulation, more detailed and precise principles are then taught as "elaborations" until the complete domain of principles (as called for by the objectives) is mastered. Such simple-to-complex sequencing within a simulation is extremely important to the instructional quality of the simulation.

Learner Participation

The type of learner participation also varies depending on the nature of the content or behavior being simulated. We have therefore characterized the type of learner participation required for each of the three types of content described above: procedure, process principle, and causal principle. We suspect that the learner's role in the acquisition stage should be different from that in the application stage. Alessi and Trollip (1985) have identified three types of learner behavior: observing, playing a role, and controlling.

Table 4 summarizes the learner role which, based on our analysis of simulations and related literature, appears to be best for each type of content during the acquisition and application stages.

- For procedures, you should require the learner to **observe** the simulated performance of the procedure and then to perform the procedure by **playing a role** during the application stage.

Table 4. Variations: Role of the Learner.

KIND OF SIMULATION	ACQUISITION	APPLICATION
Procedure	Observe a role	Play a role
Process Principle	Observe	Control
Causal Principle	Control and Observe (for exploration)	Observe (routine) Play a role (practice)

- For process principles, you should require the learner to **observe** the naturally occurring events during acquisition and then to describe the sequence of events by **controlling** the simulation (for example, placing the events in the appropriate sequence) during application.
- For causal principles, you should require the learner to manipulate (**control**) examples, **observe** causes or effects, and "figure out" the principle during acquisition. Then, for application, require the learner **to play a role** in which the principle is applied. For example, if the principle is the law of supply and demand, the role may be that of an economist predicting effects of changes in price or a businessman or woman trying to maximize his or her profits.

Simulations are often the only means of instruction in which the learner can actually perform the procedure or apply the principle under realistic conditions.

Form of Changes

Alessi and Trollip (1985) have categorized simulations on the basis of the physical or non-physical form of the changes being taught. A procedure is physical when physical movement is to be learned, as in a flight simulation. A principle is physical when physical changes are to be observed by the learner, as is the case in a simulation of volcanic action. All other procedures and principles are non-physical. The physical or non-physical nature of the behavior being simulated is the major factor in determining the representation form of choice. In general physical changes require greater realism of presentation than non-physical changes. Based on our analysis of simulations and related literature, we offer the following prescriptions for representation forms in order of preference for each simulation category:

- Physical procedure: enactive (3-dimensional simulation), iconic (video or graphics).
- Physical principles: iconic (for enhanced transfer and motivational appeal).
- Non-physical procedures: iconic (if possible), symbolic.
- Non-physical principles: iconic (if possible), visual symbolic (diagrams, graphic art, graphs), verbal symbolic (text, numerals).

Motivational Requirements

If the anticipated attitude of the learners towards the task requires highly motivational instruction, a game-type simulation should be used. Some literature exists prescribing components of simulation games (Priestley, 1984; Carson, 1987). The specific prescriptions that follow provide a brief summary.

- **Establish rapport** between player and computer at the outset by providing the computer with a name, by using the player's name in computer responses, and by using the first person in computer responses to the player.
- Present the **rules** of the game, usually in the form of text accompanied by an example.
- Use a **non-zero based scoring system**. Maintain records of scores, timed responses, number of attempts (correct and incorrect), and levels of difficulty attempted.
- Create a **competitive situation** in which the player wins by beating the computer, another player, or his or her own score.
- Provide **player control** over some aspects of the simulation, such as: number of players, entry level of difficulty, choice of opponent (may include computer or another player), response time, and length of play.

Conclusion

We have provided some prescriptions for the design of computer-based simulations in the form of a general model and variations on the general model based on the nature of the content and learner. These prescriptions are just the first step in an attempt to construct a validated prescriptive theory for the design of computer-based simulations. Considerable research and extensive field tests are needed to provide the information necessary for both confirmation and revision of the various aspects of the theory.

It is our hope that this theory will provide a useful framework for conceptualizing future research studies and that revisions and enhancements of the theory will be proposed from such research. Meanwhile, although caution should be exercised regarding the validity and optimality of the theory, it is our hope that it will serve as a useful guide to designers of computer-based simulations and that its usefulness will grow as the cycle of research and revision continues.

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