Building the Wrong Simulation: Matching Instructional Intent in Teaching Problem Solving to Simulation Architecture

Summary Paper[1]

Wellesley R. Foshay[2]
PLATO Learning, Inc.

There is now a rich history in the literature of case reports on instructional simulations, educational games, microworlds, goal-based scenarios, and related open-ended software environments for teaching problem-solving.[3] A quick scan of a sample leaves the impression that a few of them include clear statements of learning outcomes attained by learners; still fewer report in measurable detail on the learning outcomes originally intended by the designers and whether they were attained; and almost none of them include any kind of detailed account of an instructional design rationale robust enough to have led the developers from the original intent through to an effective finished product. The reader is left to wonder if there *was* a systematic design rationale, or if design judgments were simply made on an ad-hoc basis by the development team according to some general theoretical framework. This situation has led to calls for research using a design experiment model, articulated by Merrill a generation ago (1996) and more recently by Collins (Collins 1990).

Upon reflection, one is left to wonder if any of these products represent, in any sense, an optimum design for the intended learning purpose, or if they simply represent the creative preferences of the team who built them, given whatever deadline and budgetary constraints the team had. From the stakeholder's perspective, it is a critical point: is there any sense in which we can legitimately show that a $600,000 educational simulation or game will really be ten times better than a $60,000 one with the same instructional intent? Is there any way for the design team to systematically choose, for instance, to spend proportionately more of its budget on increasing the number of decision nodes in the problem space, but with the tradeoff of using still photos with text or audio, instead of video? It seems likely that without a framework to relate design attributes to instructional intent and effect, in most cases the design tradeoffs made by the team will be less than optimum, by whatever metric one might choose. Stated differently, it is probably much easier for a development team to build the wrong simulation, than to build an optimum one for a defined purpose.

---

[1] Presented to the American Educational Research Association, Montreal, April 14, 2005.

[2] VP Instructional Design & Research, PLATO Learning, Inc.
rfoshay@plato.com www.plato.com www.foshay.org

[3] Following the lead of Rieber (1996), an underlying assumption of the current paper is that the design dimensions needed for any of these types of open-ended learning environments is the same, so the proposed conceptual framework is intended to be applicable to them all.

We are a long way from developing a coherent design theory or design technology for any of the open-ended learning environments. Given the state of the art, each design we see now probably represents more craft than design technology. But it is not too early to begin speculating about what the most important dimensions should be for design tradeoffs in open-ended learning environments of all sorts. We also should wonder if the basic tradeoffs are the same for each type of open-ended software, or if there are important differences. The discussion which below uses instructional simulation as the frame of reference, but it is likely that the argument presented can easily be generalized to other types of open-ended learning environments.

What are the dimensions of design?

Very little has been written on generalizable dimensions of design for instructional simulations, nor have I been able to find a taxonomy of types or genres which appears to reflect design rationale. Helfesrieder and Shankararaman (1999) proposed that the design framework for intelligent tutoring simulations should include:

- Modeling methodology
- Simulator integration
- Model visualization and inspection
- Model fidelity
- Support for diagnostic and troubleshooting training
- Degree of object-orientedness
- Model authoring tool used

This framework led the authors to a very interesting taxonomy of intelligent tutoring system (ITS) types, and a number of thought-provoking observations about how to advance the state of the art in designing and building ITS. But the limitations of their framework should be fairly clear: it is based on accounts of ITS which teach operation and troubleshooting of physical systems; its generalizability is not obvious to the broad range of procedural, abstract and ill-structured problem solving which are also the focus of many instructional simulations. Furthermore, the parameters chosen appear to be mostly system-driven, rather than learner-driven, so it is not clear how we might use them to match simulation features and functions to the features of the learner experience which most powerfully affect learning.

Reflecting a constructivist view, Hawley and Duffy (1998) proposed six primary design criteria for instructional simulation:

- The problem needs to be authentic
- The cognitive demands in learning are authentic
- Scaffolding supports a focused effort relevant to the learning goals
- Coaching promotes learning rather than directing or correcting performance
- Reflection supports abstracting, synthesizing, and extending the learning
- The environment should be engaging

The contrast with the Helfesrieder and Shankararaman criteria is obvious. Clearly, the former criteria are focused primarily on the act of simulation creation, while the latter are focused primarily on the learner's experience of the simulation. The intended scope of

Hawley and Duffy clearly is the broader of the two: it could apply to nearly any problem-centered environment, whether online or not. By contrast, Helfesrieder and Shankararaman are drawing from their experience with system simulators for teaching operation and troubleshooting. While both sets of criteria appear to be potentially useful guides to design, it is not clear how to use either of them to make tradeoffs in design.

Addressing the related issue of simulation evaluation, Feinstein and Cannon (2002) proposed a 3-way distinction to characterize simulation designs:

- Representational validity
- Algorithmic validity
- External educational validity (issues related to learning outcomes and far transfer)

This distinction is helpful, because it provides a structure which accommodates both the Helfesrieder and Shankararaman framework, and the Hawley and Duffy one. The former appears to address primarily representational and algorithmic validity, while the latter appears to be concerned primarily with external educational validity.

But we are not much closer to some way of defining the learning outcome and using it systematically to drive design of the learning environment. Logically, we probably should reason from intended learning outcome to learner experience (including scenario, interactions, feedback and the like), and from learner experience to software structure. Furthermore, the schemes presented so far do not adequately address the complex issues of intrinsic motivation which are clearly an important consideration in any design. Garris, Ahlers and Driskell (2002) propose an input-process-output model for understanding the design of learning games. Their schema includes the following game dimensions:

- Fantasy
- Rules/Goals
- Sensory Stimuli
- Challenge
- Mystery
- Control

They also address user judgments as a set of considerations for game design:

- Interest
- Enjoyment
- Task Involvement
- Confidence

And finally, they address learning outcomes:

- Skill based
- Cognitive – Declarative
- Cognitive – Procedural
- Cognitive – Strategic
- Affective

With a few wording changes, most of the game design terms could be applied to design of instructional simulations (or microworlds and other open-ended learning environments). For example, where Hawley and Duffy explicitly mentioned cognitive demands, Garris, Ahlers and Driskell take into account a number of design variables which probably affect cognitive load, including sensory stimuli, challenge, and control (though any of the game dimensions could affect cognitive load). The user judgments and learning outcomes could apply equally to any learning environment. Thus, the whole framework of Garris, Ahlers and Driskell might be a good way to expand the Hawley and Duffy model into a set of design criteria for the learner experience. With the addition of the software design criteria of Helfesrieder and Shankararaman, we may have a start on a set of dimensions which are most important to design of instructional simulations. But it is a start, not a coherent framework for design tradeoffs which most affect cost and effectiveness.

Critical Design Dimensions for Instructional Simulations (and other open-ended learning environments)

We are left with this challenge: using as our starting point the work summarized so far, we need to decide what design dimensions most affect the cost and effectiveness of instructional simulations (with an eye to generalization to other types of open-ended learning environments). Following the three-layered design rationale proposed above (from learning outcome to learner experience to software design), one can imagine a very large number of attributes related to each design layer. But perhaps it is not premature to speculate on the design attributes for the learner experience and the software design layers which are most likely to affect learning outcomes and cost. In this spirit, I propose the following list of design attributes as most important to the ultimate value of instructional simulations.

Fidelity and Complexity vs. Cognitive Load. In all three layers of design, fidelity to the system being simulated is a major external validity consideration. In addition, there is a relationship between sheer size and complexity of the system being simulated and the size of the simulation: the more system components, and the more behaviors of each component, the larger and more complex the simulation, and the more costly it will be to develop. But other things being equal, larger, more complex simulations also are likely to increase cognitive load, which may not be desirable for novice-level learners. Thus there appears to be a tradeoff between fidelity's demand for size and complexity and optimum cognitive load, which directly affects cost and effectiveness of the simulation. It may well be that if we need to reduce cognitive load (for novices), then the optimum simulation design could be lower in fidelity (smaller or simpler) than the real system, and thus of lower cost than a more fully realistic one. On the other hand, if the cognitive load needs to vary according to the proficiency of the learner, the optimum simulation design could be more complex than one which only seeks maximum fidelity.

Rules/Goals vs. Size/Complexity. Simulations result from a four-level modeling process (Widman and Loparo 1990):

1. The real system is observed
2. Experiential frames are selected within which the model must operate with fidelity
3. A lumped model is designed, which maps the logical states of the model.

4. A quantitative computer model is constructed which behaves according to the specifications of the lumped model.

The number of experiential frames is a crucial limit on size and complexity of the simulation. There is no requirement to accommodate everything that might happen in reality. Instructionally valuable and effective environments may be considerably simpler than reality, if the intended learning outcomes are narrowly defined. Simplicity leads to lower cost, often with acceptable effectiveness.

Representation Complexity. A major advantage of simulations is that they can represent processes and component behaviors which are normally obscured, or are invisible because of size or time. However, visualizations of such phenomena add complexity and cost, so it is clearly important to use them only when they are critical to understanding of the causal mechanisms or components under study. Furthermore, simply adding displays to a screen can needlessly (and unrealistically) increase cognitive load, so it makes sense to design the learner screen displays based on the cognitive demands of the tasks at hand. Varying complexity depending on the learner's level of expertise may well make sense. So, representation complexity is a true optimization task for the designer: too little may hinder comprehension by the learner; too much may increase cognitive load as well as cost. For every simulation there is some optimum "sweet spot" of representation complexity which strikes the right balance of effectiveness and cost.

Media Production Values: Complexity of media design is one of the biggest costs in any instructional software project. Live video, spectacular multi-channel audio, and virtual reality, are most realistic (authentic), and often are most attractive to the learners. But they are easily the most expensive media to build and to deliver. If we are to believe Clark (1994), the choice has little to do with cognitive learning outcomes unless critical information can only be represented in a particular medium. Lower-cost media technologies and styles may well be instructionally effective and acceptably appealing to the learners, depending on their level of media sophistication. Optimization thus should be based on dual considerations of information representation requirements and appeal, versus cost of development and delivery.

Coaching, Scaffolding and Feedback. Simulations vary widely in the type and amount of feedback they provide to the learner. At one extreme, only the system behavior is represented, as in an equipment operation simulator. If the learner violates a rule, the simulation may simply terminate (with some kind of "game over" message but no other information). In the middle of the continuum of feedback complexity are simulators which maintain a dialog with the learner about the behavior of the learner in acting on the system, as well as the behavior of the system. A simple example is a simulator with a "show me how" demonstrator, or games which vary difficulty with learner proficiency. More complex are simulators which signal to the learner when a given behavior violates a rule, skips a step, is out of limits or is otherwise "fatal." At the extreme of complexity are systems which maintain a strategy-level dialog with the learner by pointing out actions which are logically impossible or unwise, soliciting goal and strategy statements, or soliciting and judging argumentation about goals, conclusions or strategies.

We often talk in terms of a “student model” (internal representation of the student’s behavior) as a driver for feedback. Underlying the design decisions for the student model are the rules which determine what range of learner behaviors must be accommodated (and what behaviors will simply be dismissed as “illegal”), and what the limits are of the problem space (which are defined by the simulation’s goals).

Note that a four-step process similar to Widman and Loparo’s can be used to structure design of the student model, coaching and feedback attributes of the simulation. The process parallels that used to design the simulation of the system itself, described above. Combining both design processes leads to the observation that an instructional simulation which has to accommodate a very wide range of problems or goals and learner behaviors is much larger and more complex, and therefore costly, than one which must accommodate only one. Clearly, the complexity of the learner model within the system varies substantially along this continuum, as does the number and complexity of messages or other representations to the learner (as an example, a system which simply terminates with a “game over” message is much simpler than one which can watch learner actions and jump in with a dialog such as “are you sure you want to do that now?”). For this design tradeoff, we can presume that, other things being equal, more or better feedback, coaching and scaffolding is more effective than less, up to some saturation point. We can also assume that greater complexity adds to the cost. But we are far from developing design optimization principles to help guide the cost-effectiveness tradeoffs for coaching, scaffolding and feedback to the learner.

Scale. Some simulations are premised on a multi-user environment, which is needed to adequately model the target system or problem space. Even when this is not the case, a multiplayer simulation strategy may be justified to facilitate collaborative learning – and avoid the high end of the feedback complexity continuum. Other things being equal, multi-player simulations and games are more costly to develop than single-player ones, so scale becomes an important cost-benefit tradeoff to consider.

Conclusion

This paper proposes that the design dimensions of *fidelity/size, rules/goals, representation complexity, media production values, coaching/scaffolding/feedback,* and *scale* are the design dimensions which most directly affect the cost-effectiveness tradeoffs in instructional simulation design. By extension, they probably can be generalized to other types of open-ended learning environments including games, microworlds, goal-based scenarios, and the like. Each of these dimensions represents a continuum of complexity which directly affects cost of development. Some of them appear to have a linear relationship with cost and effectiveness, but others probably do not, so it is not universally true that “more is better.”

The paper also proposes that Widman and Loparo’s four-level modeling process for simulations can be generalized to instructional simulations, and probably to design of other types of open-ended learning environments. On the other hand, there is no claim that the design dimensions proposed above encompass all design decisions, or that the proposed dimensions include all of those discussed by the other authors discussed above. Instead, this paper proposes that the dimensions proposed here are the ones which have the greatest effect on effectiveness and cost, and thus are the ones which should be used to cast the basic structure of an instructional simulation.

To test and validate this argument, a great deal of design science investigation is needed. Ultimately, we should validate these dimensions by comparing the learning outcomes and user experience in a range of instructional simulations with the design decisions made along these dimensions, across as wide a range as possible of applications and contexts. As a first step, however, it might be a good test to use these design dimensions as attributes to generate a taxonomy of types of instructional simulations (and other open-ended learning environments).

References

Clark, R. E. (1994). "Media Will Never Influence Learning." Educational Technology, Research and Development **42**(2): 21-29.

> Discusses different points of view about the impact of media on learning, motivation, and efficiency gains from instruction. The author's arguments about research and theory of media effects are summarized; reactions to the claim that media do not influence learning are characterized; and responses are given to Robert Kozma's specific criticisms (IR 529 138). (Contains 23 references.) (KRN)

Collins, A. (1990). Toward a design science of education. B. Bolt and Newman, Center For Technology in Education.

Feinstein, A. H. and H. M. Cannon (2002). "Constructs of simulation evaluation." Simulation & gaming **33**(4): 16.

Garris, R., R. Ahlers, et al. (2002). "Games, motivation, and learning: A research and practice model." Simulation & gaming **33**(4): 29.

Hawley, C. L. and T. M. Duffy (1998). Design Model for Learner-Centered, Computer-Based Simulations. Association for Educational Communications and Technology, St. Louis, MO, AECT.

Helfesrieder, B. and V. Shankararaman (1999). "Design approaches to model-based simulation in intelligent computer assisted instruction." The Knowledge engineering review **14**(Part 3): 221-256.

Merrill, M. D. and et al. (1996). "Reclaiming Instructional Design." Educational Technology **36**(5): 5-7.

Rieber, L. P. (1996). "Seriously Considering Play: Designing Interactive Learning Environments Based on the Blending of Microworlds, Simulations and Games." Educational Technology Research and Development Journal **44**(2): 43-58.

Widman, L. E. and K. A. Loparo (1990). "Artificial Intelligence, Simulation, and Modeling." Interfaces **20**(2): 48-71.