Chapter XXIV
Complex Systems Concepts in Simulations

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ABSTRACT
This chapter discusses how a teaching simulation can embody core characteristics of a complex system. It employs examples of specific frameworks and strategies used in simSchool, a research and development project supported by two programs of the U.S. Department of Education: Preparing Tomorrow’s Teachers to Use Technology (2004-2006), and currently, the Fund for the Improvement of Postsecondary Education (2006-2009). The chapter assumes that a complex system simulation engine and representation is needed in teaching simulations because teaching and learning are complex phenomena. The chapter’s two goals are to introduce core ideas of complex systems and to illustrate with examples from simSchool, a simulation of teaching and learning.

INTRODUCTION
One of the most challenging problems facing new teachers is to figure out how to maximize learning for each child in the classroom, an admittedly complex task. For example, one child may learn best if taught simple content via a lecture and assessed using an interview. But another child may dislike those approaches so much that when assessed, the student will perform far below their level of ability or knowledge. Some students come to class with social problems, others with deeply rooted psychological ones, and still others are just having a temporary bad day. The number of choices and complexity of options in each moment of class is daunting. The challenge is to find a set of strategies that allow the most learning by all students. In other words, preservice teachers need to seek ways to connect student learning with their teaching and make the changes necessary to aid student achievement while working in a complex environment.
Core ideas about complex systems arise in many branches of science, each of which adds a unique perspective to the definition. For example, from mathematics and physics come concepts such as chaos, transition states, and dynamics. From ecology come notions of system evolution, diversity, and genetic crossover. Because of this diversity of perspectives, a single formal definition of complex systems that would satisfy all disciplines is problematic.

In addition, some confusion exists between defining systems that are complicated versus those that are complex. Complex systems are more than complicated; they are unpredictable in their details, even though they may operate within well-defined boundaries, while systems that are merely complicated are highly predictable and have parts that are connected in stable, unchanging relationships. For example, a mechanical watch is complicated, but not complex. It is complicated because there are a great many moving parts (e.g. gears, wheels and hour and minute hands) with highly detailed relationships. But a watch is not complex because it is highly predictable and if we take out one or two gears, it would stop working. A biological clock that regulates aging, on the other hand, is both complicated and complex. It has a great number of elements in various relationships, but if one or two of those elements are removed, the clock will adapt and keep going.

However, in spite of these differences in perspective and difficulties in defining a complex system, an informal definition can help point out some main characteristics:

\textbf{A complex system is one whose evolution is very sensitive to initial conditions or to small perturbations, one in which the number of independent interacting components is large, or one in which there are multiple pathways by which the system can evolve.} (Whitesides and Ismagilov 1999)

Applying this definition to what we know about teaching and learning, it is relatively straightforward to describe how initial conditions matter a great deal. A teacher’s background knowledge and years of experience or a learner’s socioeconomic status and early learning experience have large effects on performance. Likewise, the number of variables involved in learning (e.g. the clusters of interacting variables in psychological, social, intellectual, and physical domains) is certainly large. Also, the number of interacting clusters of variables involved in planning, communicating, monitoring, and applying differentiated instructional strategies is large for teaching. In addition, there are a multiplicity of pathways in which a teacher or learner grows and matures over time; people from similar backgrounds with similar life experiences can diverge widely in their strengths, interests and aspirations. Similar things can be said about the social complexities of classrooms and society at large. It is safe to assert that teaching and learning involve complex behavior embedded in and arising from complex systems. Thus, it is useful to understand some of the basic ideas of complex systems as part of the foundation for developing and using teaching simulations.

Several core characteristics of complex systems—nonlinearity, feedback loops, openness, memory, nested relationships and emergent properties—expand the informal definition and provide a starting point for describing features that a simulation needs in order to embody complex system behavior (Table 1). The system of teaching and learning relationships that are modeled by simSchool utilize these concepts and provide specific examples.

The plan of the chapter is to briefly define and discuss the core ideas of complex systems, calling attention to how teaching simulations can embody them, then describe the specific way that simSchool serves as an example of an application inspired by complex systems concepts.
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