Systems Thinking in Teacher Education

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In this article I will present some results from my dissertation research, in which I introduced systems thinking (ST) and systems dynamics (SD) to preservice teachers in an interdisciplinary methods course. I wanted to understand how preservice (student) teachers would respond to the paradigm of systems thinking, including specific components, and SD modeling methods, to guide future work in teacher education. The whole dissertation can be found on the CLE website.

Background

It might be instructive to begin with describing the path that led me to this point. Initially, I was a geologist by profession. Frustration with my work experience increased over time, but fortunately, so did positive experiences with educational outreach projects.

My participation in several teacher-scientist collaborations, designing project-based units, enabled me to witness first hand, high levels of student engagement and learning. Those experiences stood in sharp contrast with my own children's boredom and difficulty learning isolated content, subject, by subject, by subject. Providing a framework that connected content, rather than expecting students to figure it all out on their own (Orr, 1994)[1] contributed to the difference. I began to connect the compartmentalization of traditional education with roadblocks to problem solving at work and learning at school.

Eventually, fascination with teaching and learning, combined with frustration at work, catapulted me back to school. From the beginning I wanted to work with student teachers, because my classroom experiences had demonstrated the pivotal role that teachers play in designing and implementing instruction. To affect student learning, I reasoned, would require both designing instruction that made natural connections among different content areas, and supporting teachers in doing so.

My first inkling that there could be a principled approach came when I read Alan Kay's "Powerful Ideas Need Love, Too!"[2] in which he presented three different ways of thinking: *story*, *logic*, and *systems*. The *systems* mode was intriguing, but became clearer when I read Donella Meadows' "Whole Earth Models and Systems" article[3] describing how "systems" can be used to make connections on a global scale, triggering my memory about the *Limits to Growth* (1972). The *System Dynamics Review* issue (1993) featuring system thinking in K-12 education, introduced me to Jay Forrester and compelling arguments for using systems dynamics as a framework for education. It seemed clear that the systems paradigm provides a different way to think about persistent problems, essential because, as Einstein's dictum states, *"Problems cannot be solved within the mindset that created them."*[4]

Eventually the path led to the Creative Learning Exchange and all the important work and collaborations among K-12 educators and the SD community. If I were going to introduce systems thinking and modeling to student teachers, this was the place to start. Phone interviews (Tracy Benson, Mary Scheetz, Tim Joy), responses to a survey I submitted on the K-12 listserv, and a visit to Portland where I talked with Scott Guthrie, Diana Fisher, and Ron Zaraza, all informed my research, and I thank all who shared their insights and experiences.

The Study

Overview. The study combined instructional design and case-based methods to learn how secondary preservice teachers[5] would respond to systems thinking and contemporary controversies as teaching tools. The instructional unit represented a "complex intervention," and its implementation became one of the study results. Data collection strategies included questionnaires, classroom observations, student notebooks, and interviews. Grounded theory, which can be described as a systems framework for qualitative research, was used to analyze the data and interpret the results.

The instructional unit used a systems perspective to frame inquiry based on a contemporary controversy related to genetically modified food. Its design was coordinated with the course instructors, because it was to be implemented in a teacher education course on interdisciplinary methods. Interviews with participating teachers were conducted after the course ended.

The interdisciplinary methods course provided an authentic setting for the study. I offered "Contemporary Controversies" as a general approach that teachers could choose for their final project, and based it specifically on genetically modified food (GMF). I used a science-based controversy because many serious social and economic problems emerge from the unexpected consequences of our interactions with the natural world.

Twelve student teachers agreed to participate in the instructional design part of the study, and use systems thinking to approach the GMF controversy. Among the 12, were 2 language arts (LA), 2 math, 2 science, and 6 social studies (SS) teachers. Five agreed to be interviewed after the course (2 LA and 3 SS). The instructional unit was implemented over a 2-week period in 4 classes, each 2 hours and 20 minutes long. All of the teachers had prior exposure to controversy as a teaching strategy. None had heard of systems thinking before. The systems thinking and system dynamics design elements that were incorporated into the study are summarized in Table 1.

Table 1. Summary of Systems Thinking and Modeling Design Elements

ST/SD Design Elements	Introduced by	Prior Knowledge Questionnaire
Mental Models Ladder of Inference	Story: *The Shadow of the Neanderthals*[6]	World Views[7]
Flow Accumulation Feedback	Demonstration: Pouring water into a pitcher, blindfolded[8]	Systems Thinking[9] Dynamic Thinking[10]
Hidden Connections Lag Times	Story: *Tip of the Iceberg,*[11] *How not to parachute more cats*[12]	Nature of Scientific Models[13]
Model diagramming	Story: *Tip of the Iceberg* Stock and flow diagrams[14]	
Behavior Over Time Graphs	Graphing examples	
System Dynamics Model	Demonstration: Easter Island[15]	

Instructional Design. The course assignment for the final course project was to collaboratively create a set of curriculum materials and demonstrate one of the activities. The teachers in my study used the question, "Is genetically modified food necessary to help solve the persistent problems of world hunger, malnutrition, and famine?" to accomplish both tasks. I provided examples of materials related to language arts, science, math, and social studies to encourage the teachers to focus on collaborative processes and design elements.

In brief, the first day, I presented a unit overview and the teachers brainstormed about the causes of hunger, famine, and malnutrition. During the next two classes, student teachers completed questionnaires, were introduced to the design elements, and interacted with each other, the researcher (as participant-observer), and various forms of content. On the last day they collaboratively decided what materials to include in their curriculum packets and their demonstration activity.

The responses to ST/SD of those LA and SS teachers who participated in the interviews are presented below, followed by some of the implications of this research with respect to systems thinking in teacher education programs.[16]

Language Arts (LA): Karla and Deek

Both LA teachers personally resonated with the holistic nature of systems thinking as a *paradigm*, and not surprisingly, were intimidated by the technical nature of system dynamics. Metaphors and humanistic values were key to their responses. Karla and Deek valued critical thinking and believed that LA fostered it through literary analysis, persuasive writing, rhetoric, and journalism. However, they had very different perceptions of whether or not systems thinking was appropriate for LA.

Karla thought that systems thinking made a "huge" difference in helping to understand the genetically modified food (GMF) controversy, because "*trying to just do 'cause and effect' left out most of the actual issues surrounding this topic*."

Deek initially resonated with the concept of systems thinking, because she perceived it as representing another holistic way of thinking. When the basic components of SD models (accumulations, flows, and feedback) were introduced in class, Deek immediately associated the model diagram with the "web of life," a metaphor more familiar to her. By the end of the unit, her response to systems thinking was: “*Language Arts is all about humanity, and for me, systems thinking seems to mechanize everything to a point that takes away from the holistic way that I think. I do not think that way*.” In other words, Deek came down on the “humanities side” of the “two cultures” (Snow, 1959).[17]

Metaphors and Representations. Karla pointed out that even though “graphic organizers” are being used more in language arts, many teachers are not experienced or comfortable with them, herself included. Her feedback during the interview was that metaphors familiar to LA teachers, such as the “*web of life*,” or “*how everything is woven together like a tapestry*,” would have provided a better bridge to systems thinking rather than beginning with the more scientific “accumulation and flow” diagrams. It is interesting that BOTGs did not elicit the same objections that the simple model diagrams did, perhaps because graphs are such a ubiquitous and familiar form of representation.

Social Studies: Angi, Reba, and Susi

The social studies teachers’ responses to systems thinking reflect a more natural alignment with their subject matter. Angi’s focus was on how systems thinking would be useful for understanding present-day processes with an eye on future impacts, compared to the historical orientation of Reba and Susi, who would use systems thinking *“to show connections between things that happened in the past and things that happen today.”*

With respect to problem-based learning and curriculum integration, Angi said, *“systems thinking is the way I would like to have people tackle problems.”* Reba provided the most enthusiastic response to systems thinking, because it aligned with her feelings, thinking, and teaching goals for her students and subject (history). She wanted her students *“to learn to think, not just know what happened in some war* [and] *to tie history to the now so they can own the information and relate it to themselves.”* She thought that systems thinking would result in better decisions if it helped you “*see how your decisions are going to effect your environment in the broadest sense.”*

Reba thought that systems thinking offered a much better way to approach history than *“traditional teaching* [that] *splits up history into eras or on a timeline, so that facts are not interrelated.”* She thought, *“The feedback aspect was very important* [because] *you’re factoring in different variables and seeing the interrelatedness between different decisions, actions, and reactions.”* Reba thought that models were useful, but, like Deek, only if they included everything.

Reba thought that a systems approach helped you to *“think and reflect…weigh more information to make better decisions rather than impulsive and selfish ones.”* During the interview she declared, *“If you’re not thinking in terms of systems, you’re thinking in a selfish way.”*

Susi shared Reba’s preference for using systems thinking to show students the *“connections between things that happened in the past and things that happy today.”* In her mind, she *“summed up”* systems thinking as *“making connection.”* From the perspective of Social Studies, she liked *“the idea of change over time, and also the idea of looking at the parts and then putting them together…or looking for evidence that helps you connect parts to the whole.”*

Susi was the only other teacher besides Deek, to resonate with the importance of mental models. However, Deek’s concept of her students’ mental models was related to their cultural and social worldviews, not something that she necessarily wanted to change with her teaching. Susi, on the other hand, was more concerned with mental models students had that she did want to change:

Collaboration. The LA and SS teachers believed that their subjects were interrelated, and would benefit from each other’s content, such as the political and economic forces at the time of a historical novel. They also voiced similar teaching commitments, like actively looking for multiple causes and effects, and considering a problem from multiple perspectives. Because of these prior teaching beliefs, they saw benefits to incorporating system ideas such as “hidden connections,” and “feedback loops,” as well as the general concept of mental models, at least conceptually. Although they did not feel comfortable with the modeling elements, they were open to collaborations that involved system dynamics, if the science and math teachers were able to provide that expertise.

Angi believed that “the collaboration worked well because we had a common thread tying us together (our goal) and each person had his own expertise to contribute (and own sense of responsibility/ownership).” Susi also felt that as long as science or math teachers understood and knew how to model, then *“the idea of…using one discipline [to bring subjects together] systems studies seems like it.”* Karla felt that this project was the first time she felt like she had an authentic need for other subject matter knowledge, and would be dependent on teachers in math and science if she were to do an integrated unit that required graphic organizers and modeling methods.

The last day

The actual planning process on the last day, integrating instructional materials and designing a demonstration activity, was remarkable, considering the short duration of the instruction. During it, you will finally hear the voices of the math (Joy) and science (Mark) teachers.

Karla wanted to use "systems" instead of Genetically Modified Food as the central organizer for her contribution to the curriculum packet, so that she could include material about hidden connections. When they turned their attention to integrating their content, one of the science teachers, Mark, drew a concept map with the GMF question in the middle, and lines leading to different topics, such as geography, language arts, and science. Another social studies teacher pointed out "if a country has to [import] food, it's not going to be free," so Mark added "economics."

Mark then began to list what he believed were the relevant issues for science—the productive life span of the land, soil type, soil fertility losses—which prompted Angi to point out that loss of soil productivity would also be part of the economic piece (a connection that formally-trained economists fail to make). Joy volunteered to do a BOTG related to fertility losses, and other ideas were discussed, such as the relationship between food supply and population growth.

Joy, being a goal-oriented person, asked what the end product was supposed to be, what were the students supposed to learn? Very quickly the teachers realized that they could not possibly know everything they "needed to," and the anxiety level began to increase until Mark said, *"I guess we'll have to let go of having to have all the answers…we'll have to be co-learners."* This had an amazing calming affect.

Shifting from the curriculum materials, they decided to do a social studies activity called "Take a Stand," where 'pro' and 'con' evidence is given about a controversy, after which students decide "where they stand." They decided to provide their "evidence" playing different "roles:" American farmer (pro), Monsanto scientist (pro), reporter (con), Somalia refugee (con), demographer (pro), and third world farmer (con). Mark and Joy started discussing how people might change their mind during the process, which gave Joy the idea of graphing the changes. She actually got excited about *"tracking how the whole system changes."*

At the end of the planning, the teachers talked about how much easier it was than they imagined it would be: *"…it just happened without any conflict or problems!"*

Limitations

The controlled laboratory and designed classroom "world views" of research in education have parallels in the Newtonian and Darwinian "world views" of research in science. In Newtonian physics, the traditional goal is to gain predictive power through simplification, control of variables, and generalization; in ecological studies, the goal is to describe and explain complexities and interrelationships of specific times and places.[18]

From the Newtonian research perspective, the results are qualitative and not generalizable. From a Darwinian perspective, the results were contingent on the local ecology and not transferable. The most severe limitation was the short time (2 weeks) for the complexity of the intervention.

Summary

This design study simulated a system in which 12 subject matter experts, the preservice teachers, interacted together to function as a whole. They related to each other as peers (same cohort), but with different "properties" based on subject matter expertise, world views, teaching goals, interests, and personalities. The context for their interactions was an assignment (goal), and the process was team-based collaboration.

As the researcher, I was a different part of the same system, and functioned as instructor during the intervention, and researcher during the interviews. Flow of information occurred among all of the parts in circular loops, and also with the environment (other teachers in the same course). The teachers' experiences were contingent on the conditions of the study (time, duration, setting) and interactions among all of the elements (people, materials, information), i.e., the whole learning ecology.

Their responses to systems thinking appeared to be related to how well it matched their teaching preferences, rather than the content area itself, although this could change with a larger number of teachers. Generally, teachers who were holistic thinkers appreciated systems thinking.

Suggestions for Future Work

In spite of the study's limitations (e.g., too much material in too little time), there were several outcomes that can inform future work with student teachers.

Metaphors. Earlier I mentioned "stories" as one mode of thinking, which is shared by people across all cultures. We also think in smaller "units" called metaphors. George Lakoff has made the claim that metaphors are central to our thinking, and as we move to more abstract concepts, we need more layers of metaphor.[19]

Karla's recommendation to introduce LA teachers to system dynamics concepts through more familiar metaphors, such as the "web of life," or "weaving a tapestry," is a type of "scaffolding." This is an educational metaphor referring to a "temporary mental structure" for students to use as they build more accurate or complete conceptual understanding. What metaphors would be useful to bridge the humanities-science divide, desirable because systems thinking can be a useful way to explore story, and vice versa?

Collaboration. The collaborative processes were productive because some key conditions were met. The teachers shared a common goal that was clear (class assignment). They participated in the same process (team-based collaboration). They were interdependent (needed each other to be successful), and yet each had unique contributions to offer (subject matter expertise).

Thinking differently. When a dynamic, nonlinear system is being studied, a systems paradigm provides a logical framework by functioning as an advanced organizer (Ausubel, 1968). It could take the form of questions, such the following:

1. What are the parts of the system?
2. What are their properties independent of each other?
3. How are they connected? What are their relationships? Are there feedback structures?
4. How do they interact? What are the processes? What are the results of their interactions? Are there feedback effects? Are there lag times?
5. What are the conditions? What are the interactions contingent on?
6. What is the context? What roles does the external environment play?

Endnotes

[1] David Orr contends that students fail to learn an integrated sense of the world from an educational system that has "fragmented it to bits and pieces called disciplines," with serious "consequences for their personhood and for the planet at large." In 10th Anniversary Edition, *Earth in Mind* (Orr, 2004, p. 11).

[2] Remarks presented to the US House of Representatives Joint Hearing on Educational Technology in the 21st Century (1995).

[3] In, *The CoEvolution Quarterly* (1982, p. 98-108)

[4] In *Natural Capital* (Hawkins, Lovins, & Lovins, 1999, p.6)

[5] The "preservice teachers" will be referred to as simply "teachers" from here on in the article.

[6] Hutchens, D. (1999). *Shadows of the Neanderthal*. Waltham, MA: Pegasus Communications, Inc.

[7] The "World Views" (e.g., mental models) questionnaire was a forced-choice instrument based on Donella Meadows' four world views as described by Paul Hawken, Amory Lovins, and L. Hunter Lovins in *Natural Capitalism (*1999, p. 310-312). In a nutshell, it distinguished among peoples' preferences for problem solving based on either economic, social justice, environmental/scientific, and local/democratic values.

[8] Water-pouring exercise described in "System Dynamics/Systems Thinking: Let's Just Get On With It," by Barry Richmond (1994). Delivered at the 1994 International Systems Dynamics Conference in Sterling, Scotland.

[9] Adapted from Donella Meadows (1991), "System Dynamics Meets the Press," an excerpt from *The Global Citizen.*

[10] Adapted from L. B. Sweeney & J. D. Sterman (2000), Bathtub dynamics: initial results of a systems thinking inventory, in *System Dynamics Review*, 16(4), 246-286, and D. Kainz & G. Ossimitz (2002), Can Students Learn Stock-Flow Thinking? An Empirical Investigation, in a paper presented at *The 2002 System Dynamics Conference, Palermo, Italy*.

[11] Hutchens, D. (2001). *The Tip of the Iceberg*. Waltham, MA: Pegasus Communications, Inc.

[12] Lovins, A. B., & Lovins, H. L. (1996). *How Not to Parachute More Cats* (G96-01). Snowmass, CO: Rocky Mountain Institute.

[13] Adapted from Schwarz, C. V. (1998). Developing Student's Understanding of Scientific Modeling. Unpublished Dissertation, University of California, Berkeley, Berkeley.

[14] Adapted from Road Maps 2, A Guide to Learning System Dynamics (2001), Beginner Modeling Exercises (D-4347-7) by Leslie A. Martin.

[15] Easter Island SD model from http://www.iseesystems.com/.

[16] A copy of my dissertation can be found on line at the CLE website.

[17] Snow, C. P. (1959). The two cultures and the scientific revolution. Cambridge: University Press.

[18] Harte (2002). In Physics Today.

[19] Lakoff, G. & M. Johnson (1980). Metaphors We Live By.