the

Creative Learning

EXCHANGE

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Musings on Social Studies and System Dynamics II: Thinking Systemically

by Jeff Potash and John Heinbokel, Co-Directors of CLE's Educational Modeling Exchange (EME)

In the last issue of the *CLExchange*, we suggested that the purpose of K-12 social studies, to develop active and engaged citizens able and willing to grapple with today's complex and challenging issues (National Council for the Social Studies), was supported by the mind- and tool-sets of system dynamics. We ended by suggesting that a three-sector concept map (Figure 1, below), focused on population, resources, and attitudes would help achieve two related goals:

(1) To help *learn* about the critical dynamic interactions that drive the events and processes that comprise the social studies curriculum, and
(2) To help *apply* the learning from these systemic relationships to leverage complex issues or problems.

In so doing, we enhance the potential for each student to become a "systems citizen," capable and willing "to make informed and reasoned decisions for the public good as citizens of a culturally diverse, democratic society in an interdependent world" (NCSS' "Vision of Powerful Teaching and Learning in the Social Studies," available at: http://www.socialstudies.org/positions/powerful/).

INTRODUCTION TO PART II

This second article poses the question, "How can we effectively use system dynamics to build social studies curricula to meet those two goals?" These ideas have evolved over years of working with students, most recently with Rob Skiff within the middle- and high-school Social Science program of the Vermont Commons School. Use of the collective "we" is intentional; the two of us hope to illustrate here (and then continue in a third article) how WE, as a larger educational community, might use generic system dynamics concepts and tools to enhance social studies instruction. We'll then solicit from you, for a third article, examples of what you've done in the classroom and what you might be interested in doing to contribute to the CLE's collections and to bolster our collective capacity to assist social studies educators.

Where do we start? Any undertaking must begin with a fundamental appreciation for how students learn. A recent publication from the National Research

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Systems Thinking in Teacher Education

by Ruth Fruland

In this article I will present some results from my dissertation research, in which I introduced systems thinking (ST) and system 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

The path that led me to education began as a career in geology. Frustration with the environmental work experience increased over time, but fortunately, so did positive experiences with educational outreach projects.

***Teacher Education** continued on page 8*

THIS ISSUE AT A GLANCE

Editorial

As the snowdrops peep through what is left of our meager snow supply this year, our thoughts are turning toward the events of the spring. Our major concentration is, of course, the Systems Thinking and Dynamic Modeling for K-12 Education Conference (June 24-26). It will be another interesting, stimulating and fun event. So many people give so generously of their time and expertise to make it a success! Take a look at the draft program printed on page 13. You can see why the anticipation is building. Please submit your conference registrations soon.

We also have our yearly student (Grades 2-12) learning exposition, Dynami*QUEST,* being held again at Worcester Polytechnic Institute in Massachusetts, on May 3. See below. We urge all of you in the Northeast (and beyond) to bring students, or, if you wish, just come and enjoy what students can do! We hope to both hear from you and see you this spring.

Take care, Lees Stuntz (stuntzln@clexchange.org)

DynamiQUE*ST* 2006

May 3rd, 9am—3pm

Campus Center, Worcester Polytechnic Institute, Worcester, MA

Come join us for the seventh annual DynamiQUE*ST*!

The what and why…

*Students (and teachers) are at various places along the road to developing proficiency with thinking systemically and employing System Dynamics/Systems Thinking (SD/ST) to address complex issues and increase understanding. We seek to encourage students and teachers to develop an understanding of the use of SD/ST tools. We also know that we need an environment, free from the "winner/loser" constraint, where kids can receive feedback from other kids as well as from teachers and professionals well versed in SD/ST. DynamiQUE**ST** creates a venue for both celebrating what has been done and providing encouragement for all to continue!*

In this spirit, DynamiQUE***ST*** was launched in 2000. DynamiQUE***ST*** 2006 will provide a venue for students in Grades 3-12 to showcase work in which they have employed the tools and method of system dynamics. This effort has several purposes:

- Provide a way for students to meet other students and see what they are doing
- Permit teachers from different schools to see evidence of student work in ST/SD
- Provide a venue for teachers and kids to network
- Have some fun and celebrate with your kids!

The how…

Simple! Have a place where students from around the country can bring their SD/ST work for others to see. Don't pit kids against each other, but hold their work accountable to a set of clearly defined standards (see DynamiQUE***ST*** 2006 Rubrics). Give them (and their teachers) a chance to see "where they are" and "where they can go from here."

But, but… *"My kids are at different stages in learning and understanding the tools and method of SD/ST. Why would we make the trip just to bring our BOTG's?"* Of course they are, and this is precisely why you should make the trip! The use of standards allows kids to see their work as a point in time along a learning continuum and see where they can go next. DynamiQUE***ST*** 2006 provides rubrics for any combination of SD/ST tools from a simple (but powerful) BOTG to a full-blown, dynamic model. The 5th grader's BOTG is as valid as the 11th grader's functional model! Both represent vital stages in the development of a systems thinker/dynamic modeler. Let's take some time to see this work, have kids see each other's work, and celebrate where we are and where we are going.

What now…

Look over the guidelines provided on the CLE website. Begin to plan, with your students, what you will bring to DynamiQUE***ST*** 2006!

Musings on Social Studies and System Dynamics *continued from page 1*

Council, *How Students Learn: History, Mathematics, and Science in the Classroom* (The National Academies Press, 2005), identifies three overarching principles for maximizing student learning:

(1) Preconceptions must be identified and challenged,
(2) Knowledge must be organized conceptually, preferably with the processes and frameworks used by experts, and
(3) Individuals must be able to independently translate concepts and/or insights between relevant areas (metacognition).

Operationally, our experience suggests that such efforts to support students in addressing meaningful real-world problems must be pursued steadily and iteratively in small steps that ultimately build that capacity.

This combination of principles and pragmatism meshes well with some of the ideas that were developed by Barry Richmond in *An Introduction to Systems Thinking* (2001) and which the two of us have further refined in our "Ladder of Engagement" sequence of learning (e.g.: http://www.clexchange.org/conference/cle_2004conference.htm). Building from Barry's observation that "thinking" involves "*constructing* mental models, and then *simulating* them in order to draw conclusions and make decisions" (p.4), our Ladder involves sequencing our use of systems thinking tools to first "filter" (Barry's term) and evaluate our *knowledge* (and preconceptions), then to "represent" the driving feedback dynamics to deepen and strengthen our operational *understanding*, and finally, to rigorously use "simulation" to devise and assess policies and strategies with which to *influence* these systems. By supporting students' development of these thinking skills, deepened learning – challenging preconceptions, conceptually framing knowledge, and metacognitively applying those concepts to novel situations – should emerge.

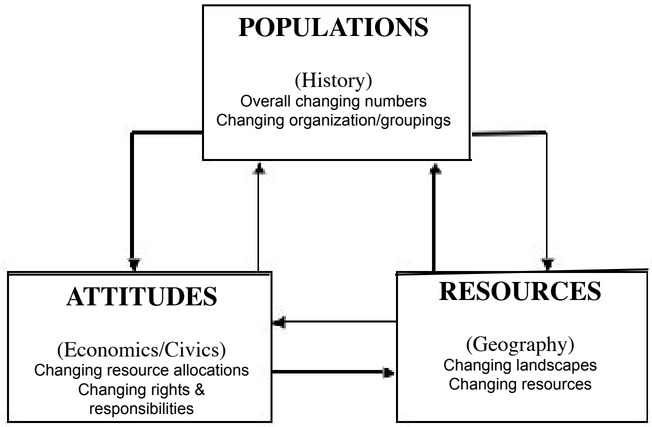

Figure 1. Interactions between three sectors inherent in dynamic social studies scenarios.

But all of this sounds very abstract and unresponsive to our immediate classroom needs. In the remainder of this paper we'll "model" for (and, ideally, with) you this process of engagement using the basic tools of system dynamics. If successful, this process will encourage "better questions," deepen conceptual understanding, challenge preconceptions, and generate transferable insights of value to our present situation. The three-sector structure (Figure 1) developed in the first essay provides an organizing framework for addressing these "real world" problems. While we might begin to consider a given problem from a viewpoint within any one of those sectors, the truly interesting and challenging topics will typically require us, eventually, to draw together insights and perspectives from all three.

Let's begin by recognizing a critically important system dynamics concept that also underlies the social studies: time or, more precisely, "change over time." To appreciate this concept dictates that we jettison a static, "snapshot," perspective of the world around us and begin to "think dynamically." As Barry Richmond observed, we need to "push back" from discrete events "to see the patterns of which they are a part." We need to view the events and conditions that comprise much of our current curricula as components of larger processes of change. That is a fundamental starting point for beginning to think more systemically about the causative loops that extend back in time and whose effects ripple forward from the present. Nurturing this capacity for thinking systemically as a "habit of mind" then connects social studies and the tools of system dynamics in a common quest to build Systems Citizens.

Now permit us to challenge your comfort in working with causal relationships that unfold over a relatively long time line by focusing on a familiar historical episode. Recognizing that system dynamics is all about real-world problem-solving, we'll frame the question as a problem: What exactly were the cause(s) and the effect(s) of the "Irish Potato Famine?" A common response might be:

> The famine was a catastrophic event that occurred between 1846 and 1847, as a result of a potato blight that decimated the food supply. It led to many deaths (estimated at one million) and triggered at least as large an out-migration of Irish seeking new homes in other countries in its immediate aftermath.

Technically, that's correct. But can we develop a richer story, one that provides hooks for looking at our current realities? We've started, almost intuitively,

Social Studies *continued on page 4*

Musings on Social Studies and System Dynamics *continued from page 3*

by focusing on people or, more precisely, on the Irish population that is comprised of discrete entities (people) the aggregate of which is subject to change over time. The "facts" of the scenario are straightforward: many people starved to death and then many more left Ireland in the next seven years. Subsequent, "better," questions come to mind, however, after such a barebones description.

- How did the population become so susceptible to starvation? (We've already hinted at the role of a specific resource, potatoes.)
- Does 1853 really mark the end of the Famine story?

To address these questions, consider a behavior-over-time graph (BOTG) of the Irish population (Figure 2). This focuses on the period between 1791 and 1901, roughly encompassing the half-centuries on either side of the famine, a very deliberately wider time period than our initial story (above) would have suggested. That BOTG shows that, prior to the 1846 Potato Famine, the Irish population grew rapidly (from 4.7 million in 1790 to almost 8.2 million fifty years later).

- What drove that growth?
- Did it make the Irish especially vulnerable to catastrophe such as the Famine?

Furthermore, when the potato crop failed, the resulting famine immediately generated nearly 1 million deaths (illustrated in the first steep drop) and an even greater number of emigrants in the following six years, the bulk of whom set sail for North America. Still, the BOTG shows the population did not rebound after 1854, as the food supply was stabilized, and available data clearly show that births once again exceeded deaths, but continued to decline.

- What was happening? And why?

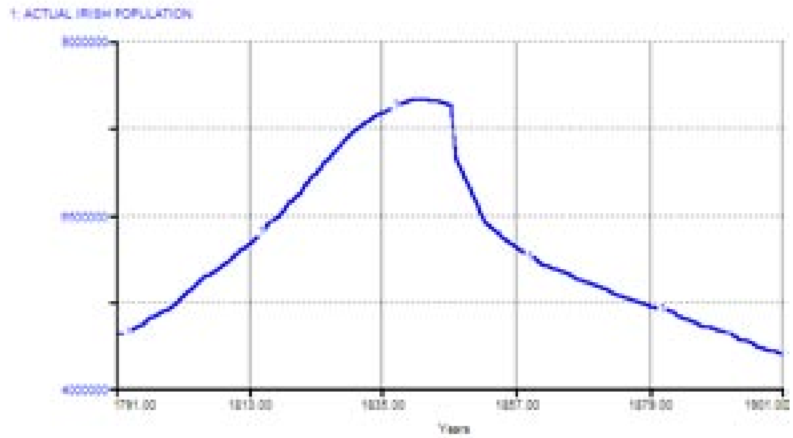

Figure 2. A Behavior-Over-Time Graph (BOTG) of the population of Ireland, 1791-1901

To understand what was driving these dynamics requires that we begin to think in terms of stocks, flows, and feedbacks, the basic "building blocks" of systems. As illustrated in the simple diagram on the top of Figure 3, we start with a conceptual map that includes a single stock (Irish population) and two flows (births and deaths). The stock represents the actual "accumulation" of people present in "the system" at any moment in time. The flows, in turn, identify "rates" or activities that define how the stock changes over time: unlike stocks, flows involve dynamic processes that do not exist at a single moment in time, but rather unfold over time. (Barry Richmond suggested in *An Introduction to Systems Thinking* that stocks may be thought of as the "nouns" in a system, and flows as "verbs.") Thus, our stock/flow diagram reminds us of the critical distinction between an "accumulation" of people at any moment in time and the ongoing processes of births and deaths that continually "flow" in and out to alter the size of the stock

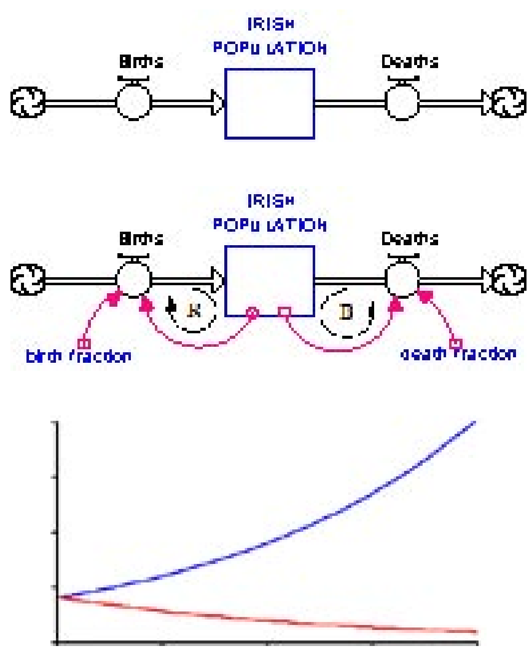

Figure 3. Stock/Flow Feedback Maps with projected behaviors over time that result from the structure of the bottom Stock/Flow Map.

But stocks and flows are only a part of the system: feedback loops comprise the other. In system dynamics, circular feedback involves one of two self-generating (or what system dynamicists' call "endogenous") structures, typically referred to as "reinforcing" and "balancing" loops. In the case of "reinforcing" feedback, a change in one factor will lead to a cycle (or causal loop) of activity that eventually leads to that same factor being pushed further in the original direction; in contrast, a "balancing" (or "counter-acting," as it is sometimes described) feedback loop will set into motion a sequence of events that ultimately leads to the original factor being pulled back toward the position where it started. [Note: For a more detailed explanation, download "Tips for Using System Dynamics Tools" at http://www.clexchange.org/ftp/documents/Implementation/IM2003-12TipsUsingSDTools.pdf]

Both feedbacks are present in our Irish population model as illustrated in the bottom stock/flow map in Figure 3. Both "Births" and "Deaths" flows are parts of a larger integrated "system" incorporating dynamic feedback loops, one reinforcing and the other balancing. In both cases, the size of the population stock is an essential factor affecting those flows. In addition, each of the flows is influenced by the fraction of the population that gives birth or dies each year; those fractions are also included in the lower stock/flow map of Figure 3. These two feedbacks, if operating with constant birth and death fractions, generate one of two behaviors (illustrated in the BOTG on the right side of Figure 3): exponential growth or "goal-seeking" decay. Both behaviors are readily observable, historically or currently, at local, regional, national, and global levels (note, for instance, what is actually happening to some European populations that are falling).

Typically, we talk about annual "birth" and "death" fractions (or rates) within populations as so many (births/deaths) per thousand individuals in the population; that is, during each year some fraction of the population gives birth and some fraction dies. In cases where births outnumber deaths, we would expect to see a pattern of exponential growth because the positive loop is dominant; where deaths outnumber births, exponential decline because the negative or balancing loop is dominant.

Let's do more than simply hypothesize how these loops work. Let's actually convert this stock/flow feedback map into a very simple running computer model and incorporate historical Irish data to test our mental model of population change over time by simulating a portion of the Irish past. We know from research undertaken using available records that there were, in the half century prior to the famine, an annual average of 41 births per 1000 individuals but only 29 deaths.

How accurate is our model in tracking change over time? Figure 4 captures the powerful process of a half-century of net exponential growth prior to the Famine, comparing the actual census data (line 1) with the projection of a simple model (line 2) utilizing constant birth and death fractions equal to the 50-year average values. While, at one level, the cultural "norms" (family size) defining the "birth fraction" were largely unchanging over the half-century, the continual growth in the number of women having children fueled this accelerating growth.

The modeled population seems to track the population size reasonably well for more than 40 years into the model run, until close to the 1830s. For the next 10 years, however, our projection fails to track the reality: while the model continues to project exponential growth (to more than 9.2 million), the real population grows much more slowly, and indeed, appears to show a stagnant or even slightly declining trajectory. What can we learn through those discrepancies?

Ideally, our stock/flow feedback map can help us understand these dynamics. The BOTG displays a classic S-shaped growth pattern, with growth beginning to slow as early as the early 1820's. System dynamicists would recognize this as "shifting dominance" in the system, where the stabilizing feedback exercised by the death side of the system became progressively more important, relative to the reinforcing feedback of births. If we're beginning to engage in "three-sector thinking," we can seek the cause

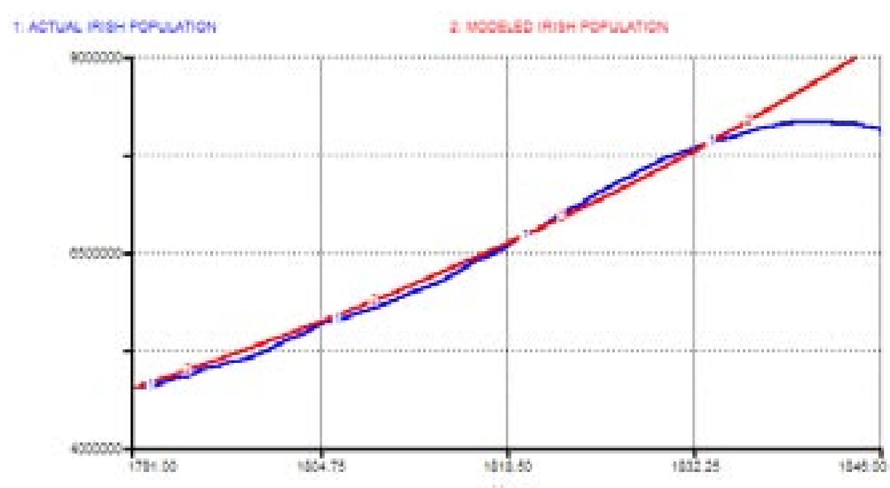

Figure 4. A Behavior Over Time Graph plotting the actual Irish population (Line 1) *vs.* modeled output (Line 2).

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Musings on Social Studies and System Dynamics *continued from page 5*

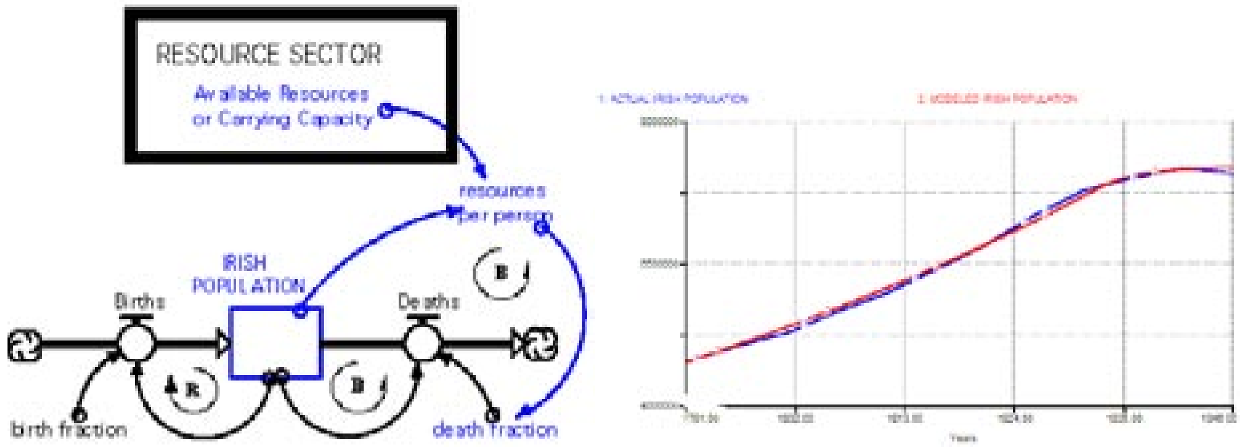

Figure 5. A revised S/F Feedback Map incorporating the concept of a resource-based "carrying capacity" (left) and the resultant Behavior Over Time Graph (right).

of that shift in one of the other sectors. Since our evidence suggests no major change in Irish attitudes relative to family size (that would affect the birth fraction) or migration (more on this shortly) in that period, we are left with the probability of a growing death fraction, likely driven by the resource sector. Whether due to limits on available land or diminishing productivity, we can reasonably hypothesize that the Irish population had run up against the land's "carrying capacity." That suggests that, as the population approached that carrying capacity, food (especially for the less well-off fraction of the population) was reduced and the death fraction increased. We can incorporate that idea into our feedback thinking, operationalize it in our model, and use it to simulate a more accurate and insightful picture of what was happening (Figure 5).

With "causes" now clearer in terms of long-term developments and the shorter-term problems presenting themselves prior to the famine itself (this pattern of declining population growth, incidentally, was also true in the events leading up to the Black Death in the 1340s – an "early warning signal," as it were), we can move our focus to the famine's "effects."

We'll begin by taking the model developed in Figure 3 and running it out to 1901 with the following modifications: we'll incorporate the deaths of 800,000 people between 1846 and 1847 and we'll further add the powerful wave of about 1.4 million émigrés between 1847 and 1853. [Note that we selected these particular numbers to match the two-staged population fall that actually occurred.]

The output from that model (Figure 6, Line 2), however, does not accurately track what happened over the half-century beginning in 1854. That model projects that, even with the reduced birth fraction observed after the famine, the Irish population should have rebounded by 1901 to a population approaching 8 million.

What really happened? Clearly population decline continued to exceed growth. If births exceeded deaths, then the only explanation is that Ireland continued to experience significant emigration, long after the immediate effects of the famine had passed. Indeed, if we dig into the historical data, we find clear indications that folks continued to leave their homeland for decades after conditions returned to "normal." So emigration clearly persisted throughout the next half century. Figure 7 illustrates the modeled timeline after we have recognized the need for such continued emigration.

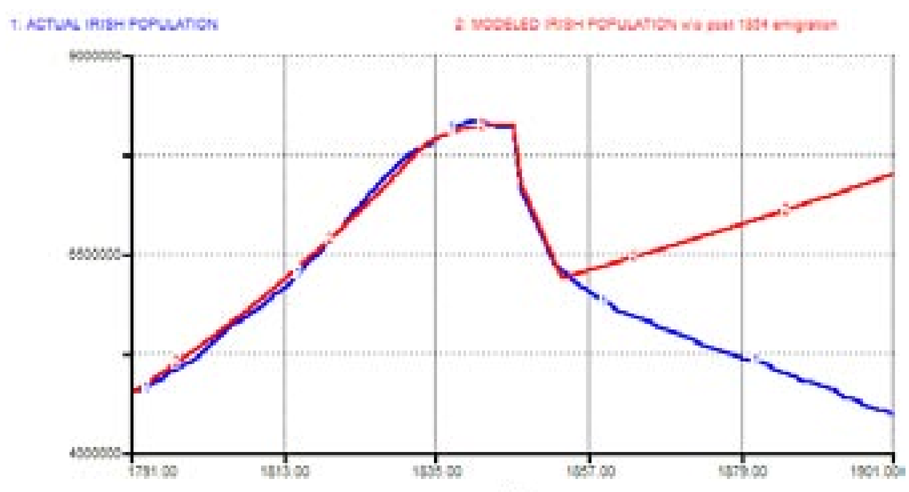

Figure 6. Behavior Over Time Graph of the actual (Line 1) *versus* modeled (Line 2) Irish population

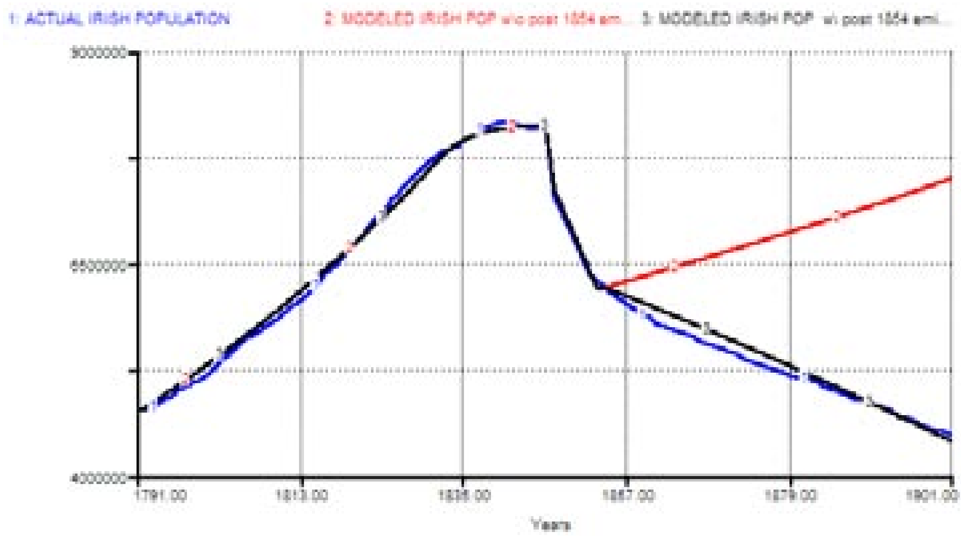

Figure 7. Behavior Over Time Graphs of the Irish Population. Lines 1 and 2 are the same as those presented in Figure 6. Line 3 is the modeled population with an annual emigration of 60,000 per year after 1854.
[Note: Emigration is added as an exogenous (defined from outside the model) variable in order to run this version of the model and to show the imp
(defined by factors internal to the model) variable.]

But why did people continue to leave Ireland so long after the immediate crisis had subsided? Here, let us suggest that we contemplate the third and final sector of "the system": attitudes. And, in the spirit of generating "better questions," let me suggest two very powerful attitudes that probably were functioning during that half-century. The first, we'll call "memory." Traumatic events, we know, can often leave long-term "scars." To the extent that people remained in Ireland who could tell powerful stories, particularly to younger generations, the image of despair and misery could readily invoke concern or fears that inspired emigration. Essentially, the numbers in the Irish population with first-hand memories, combined with the strength of their memories, continued to 'push' the Irish from their homeland.

A second attitude, not altogether unrelated, involved emigrants writing back to relatives and neighbors, advising them of "streets paved with gold" and greater opportunities to be found elsewhere, not least because the earlier emigrants provide resources and support for new arrivals. Here the idea of "expectations" of a life better than that currently available in Ireland would act as a 'pull' to new destinations. This idea of "relative attractiveness" has been powerfully developed by system dynamicists in a variety of contexts.

Each of these hypothesized attitudes can be precisely modeled, if questions such as 'push' *vs*. 'pull' dominance were of interest and were necessary to move the conversation (and the learning) along. These are not particularly easy tasks, however, and often much of the benefit of such modeling can, in this context, be obtained through the conceptual and conversational exploration of the ideas. We would argue that those conversations will be more focused and objective if the underlying stock/flow logic is kept clearly in mind.

So, to sum up: what have we learned? Population dynamics are frequently central in shaping long-term patterns of events and they are often wonderful starting points for exploring such patterns. They are not the "whole" story, however, but act together with resources and attitudes to drive the social dynamics. Here, for instance, we can ascribe the rapid pre-Famine population growth to a combination of resources (the availability of a relatively new and plentiful food resource, the potato) and attitudes that saw high value in children as an important source of farm labor. (We could have attached the Attitude Sector to the birth fraction, if we had cared to, but it seemed an undue complexity for that stage of the story, so it slid by.) Potatoes provided sustenance, allowing larger numbers and higher densities to live on the same land. The Famine illustrated in the harshest terms, however, the vulnerability of a population pushing its carrying capacity and dependent on a single resource. But, at the other end of the time-line, what of the long-term migration, seemingly lost from the record and from many accounts of the Famine? The answer here also rests with attitudes, memory on the one hand and 'relative attractiveness,' driven by prior emigrants, on the other. Only recently has the population rebounded to roughly 6 million inhabitants.

How does this inform the way we think about current events?

- Is population growth putting any of us at risk to overshoot available critical resources?

Social Studies *continued on page 14*

Systems Thinking in Teacher Education *continued from page 1*

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 of 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 systems 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, which is 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 I designed 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.

An interdisciplinary methods course provided an authentic setting for the study. The unit featured "Contemporary Controversies" as one of twelve approaches that teachers could choose for their final project. It was based on genetically modified food (GMF), and framed as a "systems inquiry.". I chose a science-based controversy because many serious social and economic problems emerge from the unexpected consequences of human 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. All of the teachers in the project were asked 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. She also considered that, to be useful, models should include everything. 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]

<u>Metaphors and Representations</u>. 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

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Systems Thinking in Teacher Education *continued from page 9*

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 and way of thinking, as well as with her teaching goals 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, like Deek, believed that models were useful 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 happen 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:

<u>Collaboration</u>. 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"* (their goal) while 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 *"if using one discipline [*to bring subjects together*], systems studies seems like it."* For Karla, this project was the first time she felt she had an authentic need for other subject matter knowledge, and that she would depend 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 for its ease, considering the short duration of the instruction, and for the contributions 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 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 the students were 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.

For the next part of the project, 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 represented 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 pattern could differ 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.

<u>Metaphors</u>. 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. Metaphors are needed to bridge the humanities-science divide, because systems thinking can be a useful way to explore story, and vice versa.

<u>Collaboration</u>. 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).

<u>Thinking differently</u>. When a dynamic, nonlinear system is being studied, a systems paradigm provides a logical framework by functioning as an advanced organizer (Ausubel, 1968). Could a useful pedagogic approach be as simple as applying a standard set of questions?

Teacher Education *continued on page 12*

Systems Thinking in Teacher Education continued from page 11

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 role(s) does the external environment play?

What if these questions were asked from kindergarten to 12th grade?

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 System 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.

[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.

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This article is available on the CLE website catalogued under Why Use System Dynamics in K-12 Education. The whole dissertation can be found on the CLE website.

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Draft program

Friday, June 23 7-9pm Registration for early arrivals

Saturday, June 24
8:30-9:30 Registration/ Continental Breakfast
9:30-11:30 Introductions/Welcome/John Sterman Keynote
11:30-1:00 Lunch
1:00-5:15 Session IA (continued in Session IB)

- Introductory Systems Thinking (first 6 hours of Level I course)
- Systems Thinking for a Sustainable Future
- Utilization of Systems Thinking in Organizations
- Integration of Systems Thinking and Dynamic Modeling into the Curriculum (knowledge of basic ST/DM necessary)
- System Dynamics Modeling (familiarity with SD modeling a necessity)

6:00-7:30 Dinner
7:30-9:00 Systems Games

Sunday, June 25
7:00 -8:30 Breakfast
8:30-10:45 Session IB (same list as IA)
11:15-12:15- Leadership in Schools: Integration of the Work of Michael Fullan and Peter Senge
12:15-1:30- Lunch
1:30-3:00 Session II

- Sustainability and Systems Thinking Tools
- Asian Bird Flu—Murdoch Middle School Takes on the Challenge
- An Exploration of Systems-based Wisdom Using Proverbs, Fables, Myths and Stories
- Teaching Modeling
- Exploring Archetypes
- System Dynamics and Communication
- A Neuroscience Causal Loop Diagram to Facilitate Creativity, Memory and Learning in K-12 and Beyond
- Role of Schools in the Context of Community Development

3:30-5:00 Session III

- Sustainability and Systems Thinking Tools, continued
- *The Shape of Change* in the Classroom
- Helping Students Comprehend Fiction and Non-Fiction Text
- Teaching about the Environment Using System Dynamics
- Constructing Big Ideas with Small Children
- A Strategy to Help Students Internalize the Habits of a Systems Thinker
- Purposeful Integration of the Concepts of Systems, Models and Feedback Loops in Daily Life

6-7:30 Dinner
7:30 -9:00 Interest groups

Monday, June 26
8:30-11:30- Café session with Peter Senge

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Musings on Social Studies and System Dynamics *continued from page 7*

- Do we depend on single, potentially vulnerable, sources of any critical resources?
- Do fears, hopes, or desires drive our resource use?
- If history is to be truly valuable, it should inform the present. Does it?

Concluding Thoughts

In this piece we've tried to "model" an illustration for how we might use the tools of system dynamics and a framework of "three-sector thinking" to develop social studies curricula that challenge our students' knowledge of familiar events, stimulate them to think more dynamically and systemically about causes and effects underlying real world issues, and plant an interest and motivation for them to apply those tools and the insights in addressing the current challenges that face them.

Have we generated any reactions?

- Do you have particular pieces of curricula that address social studies standards and incorporate system dynamics tools that you'd be willing to share in our third and final newsletter piece?
- Equally useful, do you have a particular "problem" or "problems" for which you'd like to see system dynamics-based curricula developed?

The title for the next piece is "Where do we go from here?" We hope it will be a collaborative piece that helps guide us to contemplate new and better ways to make a difference in the future. Send us (jpotash@clexchange.org or jheinbokel@clexchange.org) your thoughts, please!

This article is available on the CLE website catalogued under Social Studies.

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