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USING SYSTEMS THINKING TO IMPROVE INTERDISCIPLINARY LEARNING OUTCOMES:

Reflections on a Pilot Study in Land Economics

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Abstract: Systems thinking is an inquiry-based method of learning that uses the technique of perspective-taking, fosters holistic thinking, and engages in belief-testing. This paper describes a pilot study in an undergraduate Land Economics course that investigated how systems thinking could be used to facilitate the process of interdisciplinary integration. Results suggest that systems thinking is well suited for this purpose.

Introduction

Systems thinking is a methodology for visualizing interrelationships within a complex system. Given that the focus of interdisciplinary inquiry is "to understand the portion of the world modeled by…[a] complex system" (Newell, 2001, p. 2), it is not surprising that the interdisciplinary studies literature has identified the usefulness of systems theory. Newell (2001) notes that "…applications of systems theory offer us a way to conceptualize the interdisciplinary process in general and integration in particular" (p. 22). Repko (2008b) says that a systems map is "a highly useful analytical tool that can help one visualize the system or problem as a complex whole" (p. 164). Beyond these brief discussions by Newell and Repko, the interdisciplinary studies literature has not yet adequately studied how systems thinking can facilitate interdisciplinary learning and problem solving. The literature has tended to emphasize how to integrate divergent insights within a complex system but not how to first map the complex system of linkages itself.[1] The purpose of this paper is to show how systems thinking can add a new dimension to interdisciplinary learning and facilitate the process of integration. Notably, the use of systems thinking as a pedagogical strategy also served to deepen students' understanding of land use problems in an undergraduate course, Land Economics.

Land Economics: The Study of Land and People (Econ 245) is an elective sophomore-level course in the Department of Economics at the University of North Carolina Asheville. A primary student learning outcome of the course is to improve student knowledge of the complex land-people-place system by using an interdisciplinary approach. We hypothesized that using systems thinking could augment students' interdisciplinary understanding of the land-people-place system. Interdisciplinary understanding is "the capacity to integrate knowledge and modes of thinking in two or more disciplines to produce a cognitive advancement….in ways that would have been unlikely through single disciplinary means" (Boix Mansilla, 2005, p. 14). So in 2003 we designed and implemented a pilot study of the land-people-place system in the Land Economics course.[2]

Newell (2001) contends that, "an interdisciplinary approach is justified only by a complex system" (p. 1). The complex system studied by faculty and students in Land Economics is the system of land use change. Land use change describes the modifications in land use over time, such as the conversion of open space to residential property, or from agricultural acreage to forested land. This course draws upon the disciplines of economics, political science, and sociology and the interdisciplines of land use planning and environmental studies in order to fully understand the dynamics of the land-people-place system and formulate creative approaches to resolving the problems associated with land use change. The Land Economics course used an instrumental interdisciplinarity that "seeks to solve real-world problems or to illuminate and critique the assumptions of the perspectives (disciplinary, ideological, etc.) on which interdisciplinarity draws" (Repko, 2008b, p. 18).

We anticipated that using systems thinking would provide additional benefits to students. These include the liberal education of our students, social and economic problem solving around the issue of land use change, and the production of new knowledge to address the problems associated with land use change.[3] Problems that typically arise from land use change include water quality degradation created from developed landscapes, rising property values that lead to a lack of affordable housing, loss of rural character and aesthetic beauty from the conversion of open space to developed areas, and uncertainty associated with new people, jobs, and ways of life moving into an area. Thus, the focus of the course—the system of land use change—is appropriate to interdisciplinary inquiry because it is a complex problem that requires insights from multiple disciplines to fully understand. An interdisciplinary approach, says Klein (1996), requires the triangulation of disciplinary depth, disciplinary breadth and synthesis or integration (p. 212).[4] Land Economics had historically provided disciplinary breadth through the introduction of content from multiple disciplines, and disciplinary depth through repeated exposure to disciplinary content. However, it was not until the pilot study that the course had provided students with a *process* for the active synthesis or integration.

This process—systems thinking—is the focus of our pilot study. While the steps involved in systems thinking do not conform in every way to the model of the interdisciplinary process that Repko (2008b) offers, it does parallel certain aspects of the process such as breaking complex problems into their constituent parts, identifying which parts different disciplines address, evaluating the relative importance of different causal linkages, and recognizing that a system of linkages is much more than the sum of its parts.

Systems Thinking

What is Systems Thinking?

Systems theory identifies and analyzes the linkages among various elements in a system. For those new to systems theory, it is important to note that "systems" is plural. Systems theory does not presume that there is one grand system to be studied.[5] An early systems model made famous in 1972 in *Limits to Growth* (Meadows et al., 1972) emphasized the linkages between the economy and the environment. Other models examine urban areas, product development, global climate change, and terrorism as systems (Sterman, 2000).

One intellectual thread of systems theory is the field of systems thinking. Systems thinking is a methodology for understanding and managing complex feedback systems such as the ones at work in business and other social systems. Systems thinking is derived from the simulation modeling field of system dynamics (Forrester, 1961; Sterman, 2000).[6] Systems thinking uses mapping of inter-relationships as a means to improve decision-maker understanding of how to intervene and improve system performance. Systems thinking is a heuristic, a tool of analysis that encourages discovery rather than behavioral predictions. Thus, systems thinkers do not produce deterministic models but rather models that facilitate an understanding of the interworkings of systems through visualizations of the behavior occurring within the system.

Understanding the interworkings of a system, or the relationships between the various actors of a system, is useful because it improves understanding of the outcomes of the system. For example, to understand why communities experience traffic congestion in a road system despite extensive road building requires an understanding of the relationships between the actors in the system. Students must understand how governments decide where to build or expand roads and how individuals select driving routes. If a government widens a congested road, it is likely to become congested again even if the destinations of current drivers, employment patterns, location of entertainment and service venues, and other determinants of driving patterns have not changed. Current drivers will use the additional lanes resulting in reduced travel time. However, the improved road tends to quickly attract new drivers who contribute to congestion. Thus, decision makers must know the relationships between road expansion and driver destination in order to formulate effective policy.

The systems thinking approach builds theories for how the system works and uses them to develop insights about the behavior of the system over time, with the goal of improving system performance. The skill of theory building is developed by investigating what is referred to as the *causal feedback structure* of a system, meaning how a change in one part of the system affects other parts of the system. For example, understanding the link between forest management and timber markets requires the development of a feedback theory. This theory seeks to explain how the price of timber influences the number of trees that are harvested, and how, in turn, the harvest rate influences price. Once the feedback theory is developed, it can be used to cultivate insights about the behavior over time of the forest-market

system. The goal of the theory is to improve forest management. Disciplines often ignore feedback effects, especially the effects of the causal linkages they study on the variables studied by other disciplines.

The primary tools of systems thinking include system mapping and experimentation with formal mathematical models. Systems mapping is most frequently used in the Land Economics course because its visual aids—causal loop diagrams and stock and flow diagrams, described below—are useful for students seeking to identify linkages among content areas. There are two different types of systems maps: causal loop diagrams and stock and flow diagrams. Figure 1 provides a causal loop diagram that illustrates how systems thinking helps students visualize the behavior of a system. Specifically, it shows how population affects vehicle traffic in a region which in turn affects air quality (negatively). The subscripts *s* and *o* on the relationship arrows in a causal loop diagram show whether the two phenomena are moving in the *same* or *opposite* direction. Reduced air quality tends to negatively impact public perceptions of a region's livability, which, in turn, has the effect of reducing or even reversing population growth. This type of offsetting relationship is said to be a "balancing loop," and is labeled with a B (for balancing). There are other factors that serve to reinforce the population trend simultaneously which are labeled with an R (for reinforcing) in the causal loop diagram. As population grows, positive word of mouth can also grow as people express enthusiasm about the region to their friends and relatives. The "positive buzz" can lead to "in-migration" which reinforces population growth.

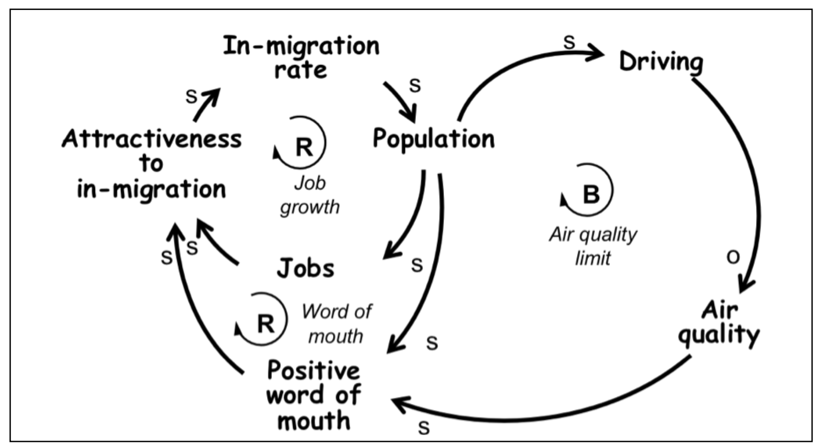

Figure 1: Causal Loop Diagram showing the relationships between population, driving, air quality, and word of mouth.

Part of systems thinking and mapping involves identifying the various actors and relationships in the system and creating causal loop diagrams that model these relationships. This promotes two skills appropriate to interdisciplinary learning: the cognitive ability of perspective taking, and thinking more comprehensively about a complex problem. Perspective taking in interdisciplinary work involves "examining a problem from the standpoint of interested disciplines…and identifying the differences between them" (Repko, 2008b, p. 120). Perspective taking is essential in systems thinking to understand how the various actors in a system interrelate. We asked students in the Land Economics course to engage in perspective taking in order to identify the disciplines most relevant to a particular land use problem. To understand the impact of air quality on population, students needed to assume the role of an individual experiencing poor air quality and theorize how that individual would relay information about their experience when asked, "Would you have any positive or negative things to say?" The response determines the relationship between air quality and positive word of mouth, as indicated in Figure 1.

More comprehensive thinking is required because students must not only identify a problem, but also the causal factors that are important contributors to the problem as well as the relationships among those factors. The causal loop diagram allows students to visualize the complexity of the system. This helps them to understand "how the disciplinary parts of the problem relate to each other and to the problem as a whole" (Repko, 2008b, p. 163). Once students understand the dynamics of the system, they can identify and test hypotheses about where and when to intervene in the system. This will enable them to later propose solutions to the problem.

Figure 2 provides a stock and flow diagram which helps students better visualize the flows and accumulations (stocks) in the complex system of diabetes incidence. The utility of this diagram is that it makes distinctions between people's physiological condition relative to Type 2 diabetes within a given population. Each of the boxes represents stocks or accumulations of numbers of people with various diabetic conditions. The arrows represent flows or relationships between the stocks. The flow mapped in Figure 2 shows the flow of people through various stages of diabetes. For example, a fraction of *People with Normal Glycemic Levels* will experience prediabetes onset and become part of the population of *People with Diabetes*. Some of these individuals will recover and return to the category of *People with Normal Glycemic Levels*. There is a reverse flow depicted between these two stocks. However, some *People with Prediabetes* will experience diabetes

onset and become part of the accumulation of *People with Uncomplicated Diabetes*.

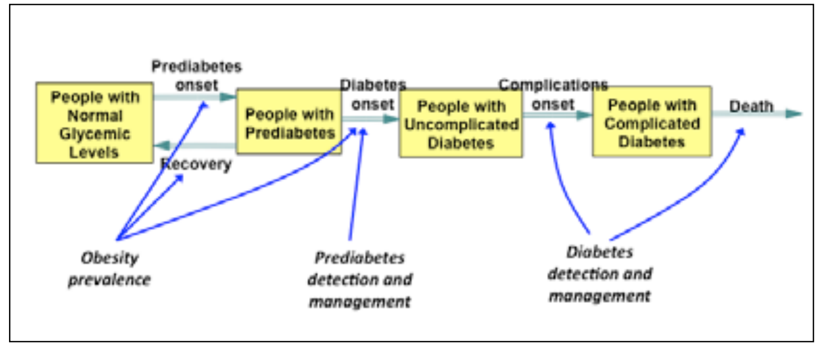

Figure 2: Stock and Flow Diagram showing the population-level flows of people through stages of diabetes, with the public health interventions.

After students have created causal loop and stock and flow diagrams of the land use system under study, the next step in teaching systems thinking is to use data to test the model systems. The use of data and mathematical relationships between the actors allows one to determine if the systems maps (i.e., models) are realistic. This "belief testing" step is used to determine whether or not one's beliefs about the relationships in the system are correct. Not surprisingly, a student's first attempt to model a system is not perfect. Using data to test whether relationships are modeled correctly is part of the continuous learning orientation of systems thinking that helps facilitate interdisciplinary integration, as explained later in the paper. Typically, several attempts at modeling the system's interrelationships are required before settling on one that accurately represents the system. In this process, students are also testing the relative importance of different causal arguments that emanate from different disciplines.

Once students have determined that the relationships they have modeled in the system are realistic, they can identify potential interventions to the system that may improve the system's performance. In Figure 2, these interventions include both "upstream" interventions in prevention (such as detection and management of obesity and prediabetes), and "downstream" interventions (diabetes detection and management). Identifying what these interventions are, along with determining where in the system these interventions will be the most fruitful in preventing populations from progressing to advanced stages of diabetes (as depicted in Figure 2), is an essential element of systems thinking.

Much of the systems thinking work has been done in the quantitatively oriented fields of engineering, operations management, computer science, and environmental science. However, the model conceptualization and experimentation of systems thinking are gaining attention in less quantitative applications. For example, the tools of systems thinking have been applied to a wide range of complex problems such as the motivation of Shakespeare's Hamlet to avenge the death of his father (Hopkins, 1992), Alice's behaviors during her adventures in Wonderland (Horiuchi, 2003) and the actions of emergency workers at the World Trade Center on September 11, 2001.

The scaffolding strategy of systems thinking, summarized in Figure 3, is very similar to that used in problem-based and inquiry-based learning.[7] Disciplinary knowledge is essential for the first three steps in the systems thinking process: defining the problem, identifying the factors that influence the problem, and describing the pattern of system behavior over time. The fourth step, building a systems map, requires the disciplinary skills of systems thinking as well as the interdisciplinary skill of making connections across and between disciplinary knowledge domains. This step may help students identify cases in which different disciplinary experts appear to be saying different things only because they are talking about different linkages. Step 5 requires the student to identify leverage points, or places where "a small shift in one thing can produce big changes in everything" (Meadows, 1999, p. 1). Step 6 involves testing and improving theory by seeking feedback from others, testing the model with data, acting and observing real-world results, and reflection. Steps 5 and 6 require students to integrate knowledge from multiple disciplines to produce a more comprehensive understanding of the system.[8] This scaffolded approach helps structure complex tasks to reduce the cognitive load for students while also making disciplinary thinking and strategies explicit.

In sum, systems thinking is a student-centered, inquiry-based approach that includes perspective-taking, holistic thinking, and belief-testing. Systems thinking is thus well-suited to facilitate the process of interdisciplinary integration. Systems thinking also promotes critical thinking since it requires students to examine assumptions and base conclusions on evidence. While critical thinking is an important method of inquiry across disciplines, the form that critical thinking takes will vary by discipline (Donald, 2002, p. 24). In this paper, the focus is on the critical thinking processes that emphasize the testing of assumptions to build confidence in conclusions. Like the critical thinking frequently experienced as a by-product of interdisciplinary learning, the critical thinking in systems thinking requires students to examine assumptions from multiple disciplines and to evaluate and reconcile their conflicting claims.

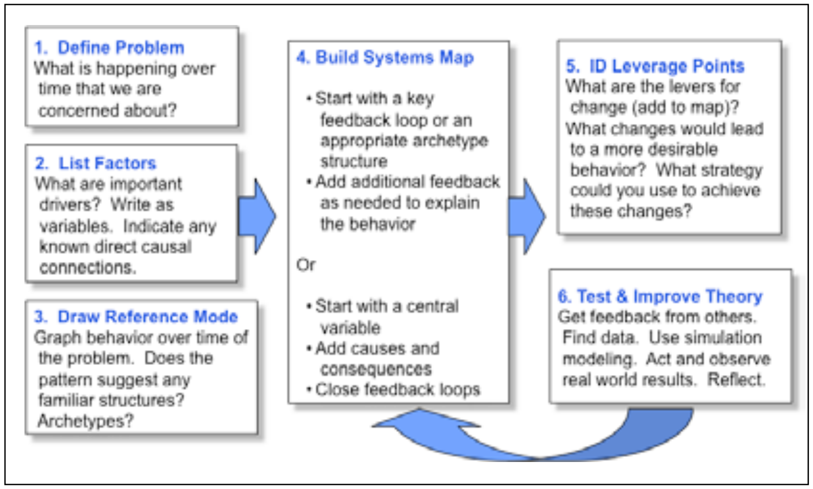

Figure 3: Systems Thinking Methodology (Sustainability Institute, 2005)

Studies of Incorporating Systems Thinking in the Classroom

Several studies describe instances where systems thinking was incorporated into high school and college classrooms with mixed results. In the late 1980s the Educational Testing Service conducted a multi-year study, the *Systems Thinking and Curriculum Innovation* (STACI) project, which examined the effects of using systems thinking to teach general physical science, biology, chemistry, physics and history content and general problem-solving skills in senior high school classrooms (Mandinach et al., 1988). The study found that the four teachers using systems thinking faced a learning curve when it came to teaching systems content. The study also found there were qualitative but not quantitative differences in student learning in these courses; specifically, the systems students approached problems differently from traditional students. However, systems students did not perform better in the courses than students in the traditional (non-systems) courses. Although systems students noted that they could successfully use systems thinking to solve problems in their other classes, this spillover impact was not measured. Ossimitz (2000) summarizes four empirical studies on teaching systems thinking to high school students in Austria and Germany. They found that students enjoyed learning about systems thinking, but teachers found that systems thinking required considerable work and that it was difficult to measure student development of this skill.

Studies on teaching systems thinking at the university level show similarly inconclusive impacts on student learning. Felder and Soloman (1988) report on their experience teaching an interdisciplinary freshman course, The Systems Approach to the Universe, at North Carolina State University.[9] They concluded that a single three-credit course was inadequate for freshmen to learn the formal abstract reasoning required to engage in systems thinking. As a result, they modified the course to emphasize critical questioning and evaluation. Kahne (1980) argues that all university students should be introduced to systems thinking because it involves students crossing disciplinary boundaries and can be used to understand the complex, interconnected systems that students are expected to operate in. Each of the aforementioned studies provides useful information for those incorporating systems thinking in the classroom, but fails to provide clear evidence of improved learning outcomes. Our study addresses this void.

A common theme of the literature is that learning how to become a systems thinker is a gradual process, something that is not accomplished in one semester. In our study, we incorporated systems thinking into an existing interdisciplinary course taken primarily by junior- and senior-level college students. We recognized that students would not master systems thinking in our course, but rather hypothesized that the inclusion of systems thinking could improve their interdisciplinary understanding of the land-people-place system studied in Land Economics. That is, we wanted our students to develop "the capacity to integrate knowledge and modes of thinking in two or more disciplines to produce a cognitive advancement…in ways that would have been unlikely through single disciplinary means" (Boix Mansilla, 2005, p. 14).

The Pilot Study

Description of the Course and Motivation for the Project

A major student learning outcome of the Land Economics course is to improve student understanding of the complex system that links humans and a particular natural resource—land—by utilizing insights (and their assumptions, theories, and concepts) from disciplines relevant to the land-people-place system, find common ground among them, integrate them, and produce a more comprehensive understanding of the problem. Course readings are drawn from history, environmental studies, economics, policy and planning studies. The course content includes issues surrounding land pricing and valuation, land use planning, the links between government land policy and environmental quality, property rights issues associated with land, affordable housing policy, and food production. During the pilot study, the course analyzed the various content areas through the lens of a specific core theme: the dynamics of local land use patterns.

There were several student outcomes that are characteristic of interdisciplinary learning:

- Explain the dynamics of local land use patterns using knowledge and methods from several disciplines, including economics, political science, history, environmental studies, and systems thinking.
- Identify the commonalities between different disciplinary understandings of the dynamics of local land use patterns.
- Integrate diverse disciplinary perspectives on land use patterns,[10] and
- Produce an interdisciplinary understanding of the dynamics of local land use patterns.

In addition to these explicitly interdisciplinary learning outcomes, students were asked to

- Demonstrate understanding of the basic tools and methods of systems thinking.

The interdisciplinary character of the course was enhanced by the diversity of disciplinary majors. Students came from economics, management, environmental studies, history, and literature and language. Since the course is only offered once annually and is quick to reach capacity, the course frequently enrolls upper-division (junior- and senior-level) students who have priority in the registration queue. In fall 2003 when this pilot study took place, the course enrolled 27 students. Most students were environmental studies majors (n=16), all had taken Principles of Microeconomics, and all were either juniors or seniors even though the course is a sophomore-level course.[11] The course met once a week during the evening for two-and-a-half hours in order to allow for more uninterrupted interaction with the material.

The course has historically relied on the extensive use of case studies grounded in real-world situations to identify linkages across disciplines.[12] For example, case studies examining how to provide affordable housing in a region with rising property values are assigned and discussed in class. The discussion of a case typically begins by asking students to identify its core elements such as the trends that are driving property values up, the impact of affordable housing policy on housing prices, and which individuals will have access to affordable housing under a given policy. Once the basic elements of the case are identified, students are asked during the case discussion or in an associated writing assignment to consider the case through relevant disciplinary lenses for the purposes of identifying the connections (and disconnects) between disciplines. For example, affordable housing policy may be economically efficient but politically infeasible. Asking students to identify and discuss the origins of these differences, and explore possible scenarios where the political and economic objectives may be more closely aligned, helps students to contextualize their disciplinary knowledge while simultaneously offering a chance to draw linkages between disciplines.

The use of the case method has been largely successful in assisting students to utilize and connect content from multiple disciplines. However, the use of case studies depends largely on classroom discussion in order to draw these linkages. Not all students are auditory learners, and some students have struggled to make the links when the only "tool" to make linkages is class discussion. This is evidenced by the difficulty that some students have in working through the concepts in class discussion, and in applying the concepts from class in their writing assignments.

We hypothesized that using systems thinking would increase the analytical rigor of our discussion of land systems. Specifically, we hypothesized that systems thinking could move students from merely identifying the multidisciplinary connections that can be made for any given land economics topic to achieving a more intentional interdisciplinary understanding of the issues underlying land systems. In addition, systems thinking could provide visual as well as auditory tools for students to use in the form of causal loop diagrams. For example, in a land use planning case, instead of merely discussing the links between developers, policy makers, residents, and the environment, systems theory allows us to model the specific relationships between these agents, map the causal linkages and direction of linkages, and thus improve our understanding of how policy affects the environment. We hypothesized that the visual tools of systems thinking, causal loop diagrams and stock/flow diagrams, would assist the more visual learners in the class in developing their understanding of the material.

Objectives of the Pilot Study

In addition to the student learning outcomes for the course described above, the faculty had three objectives for the pilot study: (1) learn how to teach systems thinking, (2) determine if the addition of systems thinking improves student comprehension of the course material, and (3) investigate if systems thinking could facilitate students' ability to perform integration. We hoped that systems thinking would lead students to demonstrate an increased understanding of the complex relationship among the actors in land economics (individual property owners, local, state, and federal government, commercial entities, and other institutions).

Description of the Project: Modifications Used to Accommodate Systems Thinking in the Course

This project purposefully integrated systems thinking into an existing course, Land Economics, with the primary aim of improving interdisciplinary learning outcomes. To accomplish this, the structure and content of the course was modified in four ways. First, a collaborating instructor, Jones, a systems dynamics modeler, was added to assist in teaching the course that Mathews had previously taught individually. Second, systems thinking content was added to the course. Third, case study discussions were modified to incorporate systems thinking theory, tools, and practices. Fourth, the course project was modified to include a systems analysis of local land use. Each of these changes is discussed in greater detail below.

Collaborating Instructor: While Mathews considers herself an interdisciplinarian and is learning systems skills incrementally, she did not have the ability to effectively *teach* systems thinking prior to this pilot study. Thus, the most significant change to the course was the addition of an instructor who could provide students with the appropriate background in systems thinking and who could simultaneously teach Mathews how to teach systems thinking. Jones, an expert in systems thinking and modeling from the Sustainability Institute, regularly teaches systems thinking to lay audiences.[13] Jones and Mathews team-taught the course so that students could benefit from learning systems theory from an expert (Jones). An additional benefit was that learning was multi-directional since both the instructors and the students were learning from each other. This invigorated the classroom dynamic as students were encouraged to view Mathews and Jones as co-learners of the course material. In addition, as Nowacek (2009) states, "the simultaneous presence of multiple instructors heightens the opportunities to be immersed in and discuss the rhetorical dimensions of disciplinary expectations" (p. 496).

Integrating Systems Thinking Content: The course content was modified to include an introduction to the basic tools of systems thinking, systems thinking exercises, experimentation with a systems thinking computer simulation, and opportunities for students to "practice" with causal mapping and other systems thinking tools. Altogether the systems content comprised 25 percent of the course content. Since we wanted students to understand basic land economic principles before introducing them to systems thinking, the systems content was introduced about a month into the course. Jones was the exclusive presenter of this component of the course. The first week introduced systems thinking and causal mapping. The second week introduced stock and flow mapping and included discussion of a local scenario where systems thinking has been used to understand the interplay of population, economic forces, environmental indicators, and quality of life at the regional scale (Carlson et al., 2003). The third week focused on the case of human extinction on Easter Island that drew on the work of Diamond (1995) and included experimentation with a computer model of the system in order to demonstrate the ways in which data can be used in systems dynamics models to predict outcomes. The fourth week focused on group project debriefing. The project, more fully described below, was the demonstration of students' ability to apply systems thinking to develop an improved understanding of the dynamics of local land use change. Each group presented their model of local land use change, and the rest of the class and the instructors provided questions and comments on the draft projects.

Pedagogy: A third significant change to the course was the addition of *systems thinking exercises.* In a typical semester, case studies are used to present content and foster class discussion. The case studies have accompanying questions that are used to guide the discussion. During the pilot study, two *systems thinking exercises* which augmented a traditional case were added to the course. During the two systems exercises, Jones used verbal questioning to guide students through the process of what was happening in the exercise using a system dynamics framework. These questions included: *What are the forces influencing the actors in the system described in the reading? What happens to each of the actors when a change occurs in the system? How does this affect the other actors in the system? How do these interactions explain the outcome of the system? What kinds of policies or actions could result in positive changes to the system?* These questions were designed to more deeply probe the dynamics of the system than a typical case study. The systems exercises allowed students to practice building theories for the causal feedback structure of the system, use those theories to develop insights about how the system behaves over time, and explore actions that may improve the performance of the system.

Interdisciplinary Course Project: The course project asked students to apply systems thinking in order to explain patterns of local land use change. It was designed to (1) provide students with a hands-on experience using systems thinking to analyze an issue and develop recommendations for improving system performance and (2) help students understand the dynamics of local land use patterns. Students were required to work in self-selected teams of three or four students to complete the project. To foster interdisciplinarity collaboration, at least two majors had to be represented in each group. Teams were asked to examine population and economic growth trends over time in the local area using the systems thinking methodology as outlined in Figure 3. This began with defining the problem and listing factors that influence the problem (including all relevant actors), gathering relevant data, and sketching several potential futures for local growth using knowledge and methods acquired from the study of various disciplines. Students were asked to engage in perspective taking to identify the disciplines most relevant to the issue of growth. Each team was to select a desired future and appropriate time horizon and then use their knowledge of systems thinking to present a theory of systemic structure that explained local growth trends using causal mapping. Groups were asked to perform "policy tests" where students explained how the policy impacted the dynamics of growth in the region, and then integrate policies to produce a new and more comprehensive policy that they thought would best achieve their desired future. Each group presented a draft of their project to gain feedback on their causal mapping and policy tests; both students and instructors provided oral feedback during the debriefing presentation while instructors provided written feedback. The final group project output included a class presentation and a written report, both done collectively by all members of the group.

Assessment of the Pilot Study

We used two methods to assess the pilot study: a student perception survey, and faculty observations. The survey assessed student perceptions of the systems thinking component and the course project. Faculty observations included exam responses, class participation, the paper, and student presentations related to the interdisciplinary course project.

Student Perceptions

Student Reflections on Systems Thinking

At the end of the course, students were asked directly in a reflection exercise several questions about the use of systems thinking in the course. The first question asked if they believed their learning of land economics was helped or hindered by using systems thinking, and invited them to provide specific examples of how this helped or hindered their learning of the content. Twenty-one of 23 students who completed the survey indicated that including systems thinking in the course (in general) improved their understanding of land economics. The comment of one student summarizes their experience:

> The use of systems thinking significantly enhanced my understanding of land economics. There are many different factors involved in land use and land policy that must be recognized in order to have a basic understanding. While all of these various factors were addressed without systems thinking, systems thinking helps by placing them in a more comprehensive picture.

Other students thought that causal mapping aided their understanding by allowing them to visualize connections, while still others commented on how they applied systems thinking to other subject areas:

> For me, the use of systems thinking in this course not only helped me understand land economics, but also helped me understand many of the other subjects that I was learning about in other courses, such as mathematics and environmental science.

Not surprisingly, the same majority of students (n=21) recommended that future offerings of Land Economics include a systems thinking component. Most of these were strong recommendations, such as *YES! YES! YES!* and *I feel like the course would not be as complete without the systems thinking component*. This representative comment shows that the student had developed the cognitive ability to view the complex land-people-place systems from multiple disciplinary perspectives.

Students also said that learning would be enhanced in other UNCA courses by the inclusion of systems thinking. Some students recommended that *most UNCA classes should integrate some component of systems thinking into their course material.* One student (who was indifferent as to whether systems thinking should be included in Land Economics) suggested that a separate course in systems thinking be taught which would cover case studies from all of the liberal arts.

Student Reflections on Course Projects

We also asked students to reflect on whether the group project helped their understanding of land economics. The same patterns emerged as with the first two items: the same majority of students (21 of 23, or 91%) felt the project improved their understanding of land economics. One student wrote:

> The group project helped in my understanding of land economics by exemplifying how difficult it is as policy-makers to agree upon and implement effective policies. It is extremely hard to find an effective point of leverage that is ethical, that everyone can agree upon, that is politically feasible, that does not have unintended negative side-effects, etc., … I think all policy makers should be trained in systems thinking as a prerequisite to their jobs.

Some student comments focused on the active components of the exercise, such as:

> This group project did help me understand land economics, because it was a "hands on" experience. Instead of just learning from case studies or other experiences, we were able to create our own solutions to a problem and see how land economics played into it.

When asked what specifically they learned as a result of the group project, students indicated they had a better understanding of the tradeoffs that policy makers face when making decisions. In particular, students learned that land use policies, which on the surface appear similar, may have conflicting outcomes, and that the beneficiaries of such policies may not be similar. This deeper and more comprehensive understanding of the tradeoffs associated with various policies was summed up by one student when he said, "it's *hard* to be a policy maker."

In addition to having a much deeper understanding of the role of policy makers, other student learning outcomes from the course project included an enhanced ability to identify conflicting perspectives. The systems thinking tools utilized in the course project required students to name the multiple agents involved in the local land use system (home buyers and sellers, governments, businesses, and so on) and then place themselves in the position of these various agents to gain understanding of how each agent would respond to changes in the system. This develops students' cognitive ability to more fully comprehend the various perspectives of these agents and understand why they conflict. The ability to engage in perspective taking is a prerequisite to the ability to perform integration, a key student learning outcome in the Land Economics course.

In addition, students gained practice in seeing "the big picture" from their course project. The assignment required that students identify the causes and potential solutions for local land use patterns. Analyzing the key elements of a complex system and how those elements interact with each other produces a more comprehensive understanding of the way the system works, and allows for creative solutions to emerge to resolve the problems of the system.

Faculty Observations

Did Students Understand and Use Systems Thinking?

We used multiple modes of observation to assess student ability to apply systems thinking.[14] First, we evaluated student understanding of the tools of systems thinking through their responses on exams and their participation in class. Most students appeared able to identify and use the tools of systems thinking. They showed proficiency in reading and (in small teams) in creating causal loop and stock and flow diagrams. At least two students appeared to struggle with the basic tools such as the construction of causal loop diagrams and identifying stock and flow variables, as evidenced by their frustration during in-class exercises. Interestingly, because of the group nature of the final projects, and the fact that the individual exam questions specifically related to their projects or other applications of the tools of systems thinking, students' perceived difficulty with this material did not necessarily translate into lower course grades for them.

Did Systems Thinking Promote Higher-Order Thinking?

Anderson and Krathwohl (2001) provide a learning taxonomy that includes both the kind of knowledge to be learned (factual, conceptual, procedural, or meta-cognitive knowledge) and the cognitive process used to learn (to remember, understand, apply, analyze, evaluate, or create knowledge). The higher-order dimensions of the learning process—analysis, evaluation, and creation—are hypothesized to be promoted by systems thinking (Richmond, 1993). The four hallmark abilities of interdisciplinary learning identified by Repko (2008a)—perspective-taking, structural knowledge of problems, integration of conflicting insights from multiple disciplines, and the production of an interdisciplinary understanding of the problem—similarly involve higher-order thinking (p. 172).

We were interested in assessing students' ability to perform integration and to use higher-order cognitive processes. We evaluated classroom discussion, final course project reports and presentations, and exam responses to determine whether there was evidence of integration and other higher order cognitive processes. Mathews' observations were relied upon for this assessment since she had a benchmark from previous years of the level of higher order thinking that was demonstrated in the class. She also had taught several of the students in previous semesters and thus had prior knowledge of their individual levels of higher order thinking ability.

Prior to the pilot study, the connections that students made between agents in land-people-place relationships were an important learning outcome of the course. However, these have historically been linear, cause-effect relationships. Mathews' perception was that the year of the pilot study, students demonstrated more complex, intertwined—i.e., *realistic*—understandings of land-people-place systems. For example, many students could readily identify multiple possible sources of outcomes in addition to those that had been previously offered in the class through readings.

During the final group presentations, students were performing integration. They were making connections between seemingly unrelated policies, identifying multiple effects as a result of forcing themselves to think through problems, and thinking more globally than in previous semesters. Students were demonstrating their ability to use knowledge from multiple disciplines to perform integration by producing a model. This model embodied their enhanced understanding of the local land-people-place system, including the factors that caused problems in the system, and analyzed their hypothesized solutions to the problems associated with growth in the system. Effectively, the presentations showcased integrative thinking: Students produced a model that embodied their broadened understanding of the complex local land use system, tested solutions to the problems in the system via their policy tests, and dissected the effects of those solutions by analyzing their distributional consequences.

An example of the integration performed by one group demonstrates this outcome. The group demonstrated an interdisciplinary understanding of the factors that influence population growth in the region by integrating the following disciplinary factors: economic factors such as income and education as well as age and other demographic trends (demography), the relative cost of living across the United States (economic geography), preferences for outdoor recreation and respite (environmental psychology), and others. The group described how population trends in the United States influence local population growth by explaining the dynamic interactions (feedback loops) between the micro and macro phenomena. They determined that the problems associated with these trends were an increased cost of living and increased environmental disturbance from land use change. This group first proposed a land transfer tax to resolve the problems. The land transfer tax would effectively raise the cost of new housing developments in the region, which would reduce the demand for this kind of development. Their hypothesis was that the reduction in housing demand would reduce housing prices and thus ease the pressure on cost of living, since housing costs in this region are largely demand-driven. The group concluded, based on their model, that the tax itself would likely not resolve the problem because it is the relative (not absolute) cost of living that brings newcomers to the area. Since the land transfer tax would not significantly change the relative cost of living, it would not likely reduce the demand by newcomers for housing in the area. It would, however, increase the price of housing in the area, thus making housing less affordable to those with lower incomes. Thus students demonstrated their ability to draw upon knowledge from various disciplines in order to generate a more comprehensive understanding of land use change.

The process of not only articulating but also conceptually depicting directional cause-effect flows between actors and outcomes helped students with the challenging task of performing integration. As one student said, *by using the loop diagrams we were able to see flaws in our policies that we otherwise probably wouldn't have seen. Specifically, we needed to draw out loop diagrams in order to see how policies were feeding the population.* Another group reported,

> In systems thinking, we learned how one action leads to a separate action and can be traced through a system to find the resulting actions…these methods require one to step back and critically look at what they are doing. Systems thinking is a type of formal introspection for the policy maker.

A third group stated their understanding and evaluation this way:

> We felt that systems thinking is a tool that everyone should have access to and everyone should learn. Most important, we enjoyed the ability to tangibly, visually create a model of a seemingly non-tangible systemic structure. This allowed us to find gaps and uncover bad logic in our understanding of these structures as well as manipulate data. We saw that slightly changing one variable could, like a set of dominoes, affect all parts of the system dramatically. This tool allowed us to clarify our assumptions and beliefs, as well as make realistic changes to the system. Our world moves fast and systems thinking allowed us to understand it and break down the complexities within which we live.

Overall, students were clearly able to use the tools of systems thinking in a way that enhanced their ability to think critically about land-people-place systems, which promoted the higher-order learning dimensions of analysis, evaluation and creation during discussions, in written reports, and on exams.

General Observations: What We Like about Using Systems Thinking in Our Classroom

Students noticeably enjoyed playing the role of policy maker as noted in their comments above. One of our goals was to have students assume the role of policy maker and experience the joys and pitfalls of the real world. Mathews was particularly concerned that students increase their economic literacy by seeing how the discipline can be applied to real-life situations. Systems thinking provided a framework for students to see how economics fits in with land use change in western North Carolina. Students were able to see the failure or success of their theories about what was driving land use change in the region and what could modify the amount of land use change. This process allowed them to see economic theory come to life by visualizing the options available and testing the outcomes of different responses.

As a result of the real-world emphasis of the course, students also had the opportunity in their class project to see that their ideas are sometimes ethically problematic.[15] Several individual students and groups of students identified important challenges with ethics during their projects.

> Ethics was our largest hurdle when dealing with our project. It seems that every positive action we wanted to take had negative repercussions. It seemed that every action had the potential to be unjust and unfair for some community members.

While many economics courses frequently deal with the distributional effects of policy, or how various groups are impacted by a policy action, the tools of systems thinking require that students identify and name the affected parties and the specific ways in which they are affected. For example, rent control policy may benefit renters who are able to find housing since prices are cheaper, but other parties are impacted as well: Landlords are less willing to rent housing at the lower prices, which may lead to a housing shortage, increased homelessness, and overcrowding. The distributional effects of this policy may thus exacerbate existing housing inequities (rather than resolve them) by making it more difficult for low-income households to find affordable housing. Systems thinking requires students to identify and name all affected parties for a given policy, which makes the distributional consequences of policy actions more visible to them. Once the impacts on various parties are visible, students are obligated to integrate these impacts in their analysis of the system under study. As a result, students acquire and use knowledge about these impacts to create integrated solutions to complex policy problems.

Many college students mistakenly assume that research is about supporting one's beliefs, rather than asking questions. To correct this errant notion, we encourage the testing of our beliefs to evaluate whether or not they lead to the outcomes that we desire. Systems thinking teaches students to ask questions—to develop a policy based on an idea before developing a full-blown model—rather than picking (policy) answers that they like, which is a temptation that some students (and policy makers) cannot resist. This process of thinking before doing is extremely helpful for students when they are struggling with the *how* and *why* of decision-making processes. Students are encouraged to test policy options they might think useful and identify the likely effects—both positive and negative—that this policy might have. They may thus reject policies or alternatively gain confidence in a policy and their ability to argue for it. This type of iterative critical thinking appears to be an excellent way to develop students' skills of analysis, evaluation, and creation.

Another element of systems thinking we find advantageous is its continuous learning orientation. There is no one correct answer to a systems question, but rather an opportunity to improve our understanding of the dynamics of the system. This, in turn, implies that our understanding of the system can only improve with additional effort to understand the system, which may involve adding yet more variables and linkages to study. While not as neat and tidy as many students would like, this continuous learning orientation is a useful skill for the real world.

A major contribution that systems thinking brings to interdisciplinarity is that it creates connections between and across disciplines. One cannot build a model of a system of land use drawing on only economics; for example, an understanding of politics, environmental studies, planning studies, history, and sociology are also necessary. After acquiring disciplinary knowledge to improve understanding of a system, systems thinking requires that one ask how each relevant discipline contributes to our understanding of the system as a whole. When similarities in method or content of study are identified as part of this process, learners make connections across disciplines. Making these disciplinary connections are not sufficient for interdisciplinarity, but they are a necessary precondition (Repko, 2008b, p. 15).

For these reasons, students find systems thinking empowering. They are asked, indeed *required*, to identify the outcomes they desire to see in the world, generate hypotheses about how to achieve those outcomes and then test and refine them. The student voice is particularly strong. This is challenging to some students who have not yet become comfortable with the notion of being responsible for their own learning. Many seniors in this class were invigorated by the opportunities that this course provided them to direct their learning. The inquiry-based and self-directed learning that is characteristic of systems thinking is not likely to be appreciated by all students. This could explain why high school students or college freshmen may not benefit from systems thinking in the same way as upper-division students (Ossimitz, 2000; Felder & Soloman, 1988).

Lessons Learned: Reflections on the Pilot Study

First, we learned about *how* students *learn* systems thinking, which has implications for how systems thinking is taught to students. As we know, students have different abilities to visualize data and concepts. Some students in our class (though a distinct minority) wanted more math and computer modeling of systems to help improve their understanding of how systems work. Somewhat predictably, these students tended to be economics majors and/or had a significant background in math or computer science. Mathews had anticipated (correctly) that most of the students who would enroll in the course would not fall into these categories, and thus had decided with Jones early on that the mathematical component in this course would be minimized. However, this decision may have constrained the opportunities for some students to develop an even deeper understanding of the systems they were studying. Additional modeling would be important for learning systems thinking in courses that are oriented toward students who are interested in mathematical modeling, quantitative analysis, and rigorous science.

Second, we discovered the importance of paying attention to the pace of student learning. The course project was started in October, but in retrospect it is clear that students would have benefited from an earlier start time so that they could engage in additional rounds of feedback on their systems maps and policy ideas. As it was, students were able to present and receive feedback on only one draft of their project's maps and policy proposals. However, there was not adequate time for significant changes to be made to the policies proposed in their model or to engage in deeper analysis of the policies they were testing. All groups could have benefited from another iteration in which to thoughtfully examine their hypotheses, check them against real-world data, and refine their ideas.

One strategy that we used and will continue to use in this course is to require that each group be composed of students from different majors. In our class, most students were environmental studies majors while a minority were from economics, political science, or interdisciplinary studies. We required that each group contain at least one student who was not a major in environmental studies. We found that this was an effective way to form groups of diverse skills and perspectives. We believe this improved each group's ability to evaluate the region's growth dynamics. Blending majors also fostered interdisciplinary collaboration and aided perspective-taking.

From a curricular perspective, we also learned many things. Those of us who majored in disciplines tend to approach a complex problem from the narrow perspective of that discipline. As a result, learning to be a systems thinker, which requires both disciplinary depth and interdisciplinary breadth, is not natural for many students. Interdisciplinary thinking and integrative skills cannot be mastered in one course or during just one semester but must be honed over time. It may thus be useful to consider teaching systems thinking in a two-course sequence such as that suggested by Kahne (1980). An introductory course could have as its aim to help students acquire the basic tools of systems thinking, along the lines of the Felder and Soloman (1988) course, while a second more intense course could be a semester-long opportunity to focus on more advanced systems thinking skills as well as the interdisciplinary process. This could function as an upper-division undergraduate research seminar, either in the major or an interdisciplinary capstone experience. A common theme of the studies cited earlier in the paper on teaching systems thinking is that learning how to become a systems thinker is a gradual process. Thus it seems to follow that repeated exposure to systems thinking will be necessary for a meaningful impact on students' ability to make connections between issues and events in their personal and professional lives, as well as in other courses. Many of the students in our pilot study concur with this idea—11 of 24 students indicated they thought a separate course in systems thinking would be ideal.

As with any team-teaching endeavor, there are additional costs involved for faculty. They have to jointly decide upon and coordinate readings and assignments. Ongoing communication is essential. In this class, the arrangement was somewhat unique in that Jones was essentially responsible for four weeks of the class instructional material but none of the grading or day-to-day communication with students (though he regularly worked with students on their projects). Mathews was the only one responsible for assigning course grades so no additional time was necessary for coordinating grading activities. However, this approach clearly had its drawbacks. One student reported that she "felt as if I was taking two separate classes" due to the discrete teaching styles and content in the course. While this did not appear to be a widely held view, future efforts will benefit from greater integration of content and style so that both faculty and students have a greater sense of integration within the course operation itself.

Implications

In our pilot study, we found that systems thinking fosters the development of the four cognitive abilities noted earlier by Repko (2008a): (1) perspective-taking, (2) structuring, (3) integrating, and (4) producing a cognitive advancement or interdisciplinary understanding (p. 172). First, systems thinking requires that learners engage in perspective taking. In the study of land use change, for example, students must assume the perspective of individual landowners, local government officials, citizens who perceive the impacts of private land use decisions, and the like. Second, systems thinking promotes the understanding of the structure of the system under study, including how local government representatives respond to the actions of individual property owners and concerned citizens, how citizens engage with government, and how both government and citizens alike respond to changes in market prices. This level of structural understanding of the interworkings of the system is essential in systems thinking, and became visualized in the causal loop and stock and flow diagrams that our students used as systems thinkers. Third, systems thinking asks learners to "test" various hypotheses about how to resolve the problems of a system, which requires that learners integrate views from multiple disciplines. In Land Economics, insights into the problems associated with land use change were frequently provided by economists, land use planners, and sociologists. These had to be integrated in order for students to "test" their ideas for improving the performance of the land use system.

In the end, the process of learning about land use change with systems thinking enabled students to produce an *interdisciplinary understanding* of land use change of the sort described by Boix Mansilla (2005). Since systems thinking develops the cognitive abilities necessary for fostering integration, it is not surprising that the use of systems thinking can enhance interdisciplinary understanding.

This discovery should be of interest to teachers of interdisciplinary studies. Given that the steps associated with systems thinking are similar to those required of interdisciplinary work, the adoption of systems thinking by interdisciplinarians will likely be straightforward. The largest hurdle may be mastering the conventions of the causal loop and stock and flow diagrams of systems thinking. An excellent starting point for those wishing to learn systems thinking in order to teach it is Richmond (1993), whose article aims to "eradicate the distinction" (p. 114) between systems thinkers and educators. Anderson and Johnson (1997), Richmond (2000), and Sterman (2000) are other key references for those wishing to learn systems thinking. Once the basic skills of systems thinking are acquired, it is most helpful to practice the skills regularly. Subscribing to a newsletter such as *The Systems Thinker* (www.thesystemsthinker.com) will allow one to do just that, as it provides short articles and applications of systems thinking. The System Dynamics Society (www.systemdynamics.org) sponsors an annual conference and provides other resources for those interested in learning about system dynamics and systems thinking.

Since systems thinking improves student understanding of the limits of and links among individual disciplines, it could be useful to faculty who teach general education courses. Our campus recently adopted a new general education curriculum that clusters courses by topic.[16] This is an exciting prospect, but it also comes with challenges about how to best connect

the content from our traditional discipline-based courses. Systems thinking offers one tool that may facilitate the bridging and integrating that must occur if this new framework is to serve students well. Student comments supported this notion by identifying the crucial role systems thinking can play in integrating disciplines for application in the real world and in one's personal life:

> ...systems thinking is not only valuable in the academic setting but in the personal setting as well. By understanding yourself and how your "personal" system works, you can better understand how the world around you operates. It's not the behavior, but the motives behind the behavior that are important—systems thinking helps you discover that.

One student summed up the need for systems thinking in the undergraduate curriculum this way:

> …as time continues to pass, the world we live in gets increasingly more complex. If today's students are to be tomorrow's policymakers, problem solvers, educators, etc., then we must empower them to possess a set of skills that enables them to think about and analyze complex systems. They may then be able to more effectively and efficiently create solutions to the complex issues that we are increasingly faced with—systems thinking should be implemented into all majors like writing and speaking proficiencies.

Future research on the teaching of systems thinking will benefit from a deliberate monitoring and critical examination of the potential and type of student resistance to the use of systems thinking in college classrooms. In our pilot study, only two of 23 students expressed resistance. However, we believe that resistance can be reduced by taking into account differences in learning styles as well as student preferences for more certain processes and outcomes than systems thinking provides. While we perceive the heuristic nature of systems thinking to be a real benefit to student learning, students may resist if they perceive that learning about systems is "more work" than learning more concrete concepts because there is no set right or wrong answer. This can yield uncertainty for students because it is an unfamiliar pedagogy, one that requires a significant level of abstract thinking about big picture issues. Students may also be concerned about how these less certain outcomes will be translated into grades, especially if they are accustomed to being evaluated on outputs as opposed to process. Additional research is needed to determine what types of resistance may be encountered when teaching systems thinking and if they are significantly impacting student learning outcomes.

Conclusion

Our study investigating whether systems thinking could improve interdisciplinary learning outcomes was, by our criteria, a success. Students enjoyed being able to learn how to wrestle with the dynamic interworkings of systems while faculty reveled in the higher-order thinking that students demonstrated in class discussions and course projects. While this could be a random experience—the luck of the draw with the dynamic interaction of the particular group of students—our sense is that there is something to be acknowledged about the excitement that both teachers and students felt about the course.

For faculty interested in fostering integrative thinking in their classrooms, systems thinking is a pedagogical option which has tools and methods to foster integration *built in* as part of the methodology. However, since most academics are trained in one discipline, the desire to teach and use the tools of systems thinking to improve student learning in our courses is complicated by the fact that most of us have been trained to *not* use a systems approach. Richmond (1993) points to an additional problem that arises: Systems thinking requires a learning-directed educational process, which is not yet standard in our higher education system.

Future research on the use of systems thinking in higher education classrooms should address the potential for student resistance to the tools of systems thinking, and whether or not it is feasible to measure any learning improvement from the adoption of systems thinking. Another question raised by the pilot study is whether the use of systems thinking advantages visual learners to the disadvantage of students with more auditory learning styles. We will be interested in learning the answers to all of these questions, and more, as the tools of systems thinking are adopted by other professors and additional evidence is gathered on its benefits and risks. In the meantime, we will continue to use systems thinking in our classrooms because we think it can help students better understand the world—and that is our ultimate motivation for teaching.

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Notes

[1] Szostak (2000) is an exception, in that he constructs a schema "which consists of a hierarchical list of the phenomena of interest to human scientists, and the causal links (influences) among these phenomena."

[2] Our pilot study was facilitated by a 2003 grant from UNC Asheville's University Teaching Council. The grant was used to add Jones as a second instructor to Land Economics, regularly taught by Mathews, during the fall semester.

[3] Klein and Newell (1997, p. 394) list seven motivations for interdisciplinary study. These include the promotion of general and liberal education; social, economic and technological problem solving; the production of new knowledge; professional training; social, political and epistemological critique; and financial exigency.

[4] Klein (1996, p. 212) prefers the term "synthesis" because it "connotes creation of an interdisciplinary outcome through a series of integrative actions."

[5] Systems thinking does not presume an infinite web of relationships in a system either. One of the steps of the scaffolded strategy of systems thinking, described later in this section, include identification of the relevant factors that influence a problem. Much like the process described by Repko (2008b, p. 166), it is important to identify potentially relevant factors and then determine which are the most relevant factors to incorporate into a systems map.

[6] Systems thinking is a very broad topic. Richmond (2000) describes the seven types of systems thinking as dynamic, systems-as-cause, forest, operational, closed-loop, quantitative, and scientific. Useful general references on systems thinking include Sterman (2000), Richmond (1993, 2000), and Anderson and Johnson (1997).

[7] Hmelo-Silver, Duncan, and Chinn (2007, p. 100) assert that "there are no clear-cut distinguishing features" of problem-based and inquiry learning. The

authors provide an excellent overview of the use of scaffolding in problem-based and inquiry learning.

[8] The scaffolded strategy of systems thinking is quite similar to the steps for conducting interdisciplinary research as outlined in Repko (2008b). The first and final steps in both systems thinking and interdisciplinary research as defined by Repko are virtually identical: Define the problem (step 1) and produce an interdisciplinary understanding of the problem and test it (step 10). The intermediate steps vary between the two methods, but they aim to produce a similar outcome, an integrated understanding of the system or problem under study. In systems thinking, steps 2-5 are designed to assist students understand the interworkings of the system and are thus geared toward improving the systems map. Repko's intermediate steps 2-5 (justify an interdisciplinary approach, identify relevant disciplines and choose the most relevant to the problem, conduct a literature search, and develop adequacy in each relevant discipline) more thoroughly assist students with the process of explicitly recognizing the disciplinary contributions to the problem. Repko's steps 6 through 8 (analyze the problem and evaluate insights into it, identify conflicts between insights and locate their sources, and create or discover common ground) mirror step 4 in systems thinking (build systems map). In order to build the systems map, students must have analyzed the problem, evaluated the insights into it, identified conflicts between insights, and discovered common ground. Systems thinking can thus aid students in performing some of the steps in the interdisciplinary research process, but not all. In particular, systems thinking can help students map the set of linkages between and among disciplines, but will not necessarily be sufficient for performing integration.

[9] Felder and Solomon use the term interdisciplinary to describe their course in which systems thinking was applied to examples from multiple disciplines. The Interdisciplinary Studies course description reads, "Systems approaches to problems in physical, social, and behavioral sciences and technology. Concepts of general systems (interactions between systems functioning). Emphasis in interdisciplinary problem-solving methods and critical questioning."

[10] Repko (2008b, chap. 11) identifies creating or discovering common ground as a precondition to performing integration.

[11] Several students were in their last semester at UNCA when they took the course (n=8) which may have impacted their abilities and interests in the course content and systems thinking pedagogy.

[12] The case method used in Land Economics is similar to problem-based learning which is popular in interdisciplinary contexts.

[13] The Sustainability Institute is a "think-do tank" dedicated to sustainable resource use, economics, and community. It provides information and consulting services related to sustainability issues for governments, businesses, and educational institutions. More information about the Institute can be found on its website, www.sustainer.org.

[14] Repko (2008a, p. 175) indicates, "Student performance on the comprehensive assignment at the end of the course constitutes a valid assessment of overall student success in developing the four hallmark abilities." The cognitive abilities referred to are perspective-taking, structural knowledge of problems, integration of conflicting insights from multiple disciplines, and the production of an interdisciplinary understanding of the problem (p. 172).

[15] Newell (1990) indicated a greater sensitivity to ethical issues is an outcome of interdisciplinarity.

[16] More information about UNC Asheville's Integrative Liberal Studies program may be found at http://www.unca.edu/ils.

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