Synthesis for the Interdisciplinary Environmental Sciences: Integrating Systems Approaches and Service Learning

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As our understanding of complex environmental issues increases, institutions of higher education are evolving to develop new learning models that emphasize synthesis across disciplines, concepts, data, and methodologies. To this end, we argue for the implementation of environmental science education at the intersection of systems theory and service learning. A tight coupling of systems theory and service learning provides learners with the knowledge and skills required to tackle contemporary social-environmental challenges. The tangible benefits of a systems theory—service learning (STSL) curriculum occur in two principal learning areas: increased knowledge breadth and depth. Systems theory requires a broad assessment of social and environmental changes, whereas service learning promotes a brand of research and teaching resulting in a deepening of knowledge through field immersion. We present the tangible benefits of this deepening and broadening process along three axes: appreciation, research methods, and communication.

Synthesis is increasingly recognized as an effective mode of interdisciplinary research and education for solving complex environmental problems, as it provides a mechanism to link diverse ideas, data, concepts, and methodological approaches (Carpenter et al., 2009; Gober, 2000). According to Callison (1999), synthesis supports comprehension, application, and analysis that are crucial for addressing issues at the human–environment interface where different disciplines are involved. With synthesis, resolving environmental problems entails comprehending fundamental interactions across different levels of scale and complexity. Synthesis therefore raises the possibility for theoreticians, empiricists, modelers, and practitioners from the sciences as well as the humanities to formulate new approaches to existing questions and to integrate environmental science with education (Carpenter et al., 2009; Graybill et al., 2006; Lélé & Norgaard, 2005). In light of these benefits, funding agencies such as the U.S. National Science Foundation (NSF) and European Science Foundation are increasingly setting research agendas to support synthesis (Gutmann, 2011; Simon & Graybill, 2010). This is evidenced, for example, by the NSF's National Socio-Environmental Synthesis Center established in 2011. Government agencies have similarly focused research attention toward synthesis through, for example, the establishment of the U.S. Geological Survey's John Wesley Powell Center for Analysis and Synthesis in 2011.

As our understanding of complex environmental issues increases, institutions of higher education must also evolve to meet these challenges (Fortuin, van Koppen, & Leemans, 2011; Klein, 2005; Rhoten & Parker, 2004; Sung et al., 2005; Tress, Tress, & Fry, 2003). This paper contributes to a reformulation of college teaching and learning in environmental sciences using synthesis. We view synthesis as the essence of interdisciplinary scholarship for its ability to coalesce theories, methods, and worldviews from different disciplines and to enhance our understanding and appreciation of human–environment interactions. Specifically, we argue for the implementation of environmental science education at the intersection of systems theory and service learning. This approach is guided by the notion that attention to individual components often fails to explain the behavior of systems (Werner, 1999) and that comprehending dynamic interactions between components (synthesis) will generate deeper understandings of the world (Patton, 2002). We suggest that a tight coupling of systems theory and service learning in environmental science can provide learners with the knowledge and skills required to tackle increasingly complex environmental challenges.

Systems and systems theory

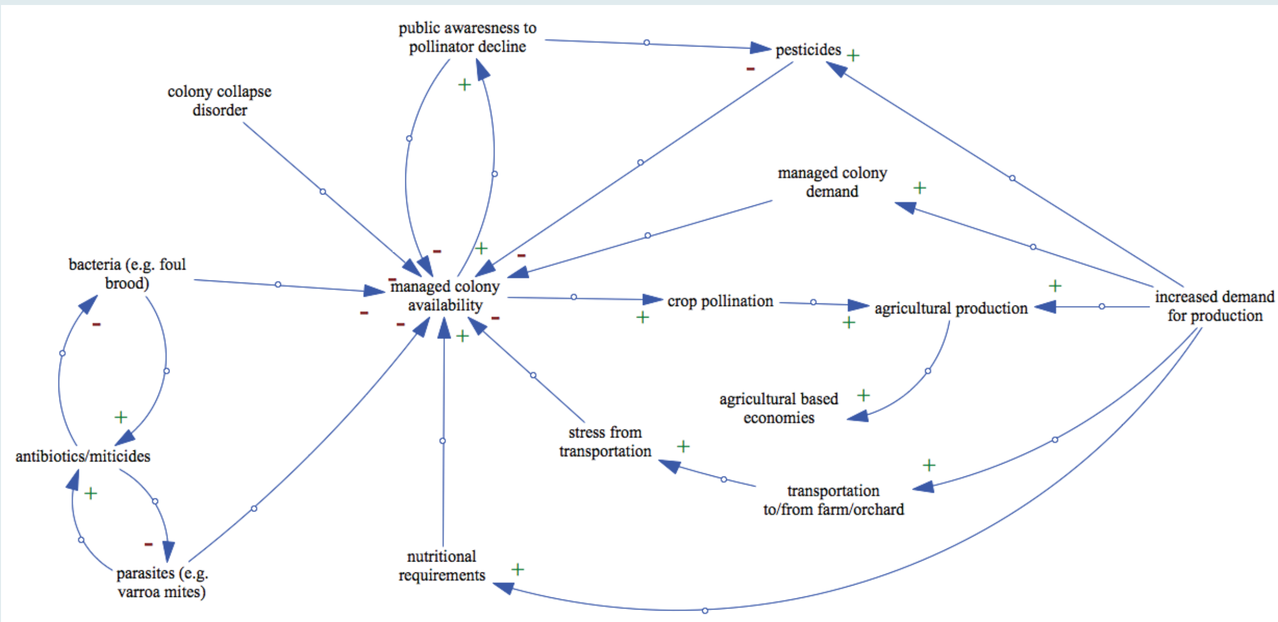
Systems theory has emerged as a unifying theoretical framework that encourages synthetic interdisciplinary solutions to complex environmental problems. Originally developed as general systems theory in the mid-20th century by Bertalanffy (1968), systems theory was initially viewed as a way to unify disciplines in the sciences that had become fragmented and also to increase the efficiency by which scientific principles could be transferred and applied in different fields of study. We use the notion of "system" to connote an ensemble of interacting parts and emerging phenomena that is more than just the sum of its components (Chen & Stroup, 1993). Applied in the environmental sciences, a system is comprised by elements and characteristics of human–environmental landscapes and the dynamic forces and processes that influence it (Chorley & Kennedy, 1971).

The role of systems theory in environmental science research and teaching has expanded over time to facilitate a broader understanding of complex environmental interactions and challenges facing society (Capra, 1996; Meadows, 2008). At its heart, systems theory is useful for identifying the causes and consequences of social-environmental problems as it avoids compartmentalized explanations. Instead, systems theory considers issues of directionality, feedback loops, and other active processes within systems. Explanations of systems theory coalesce around a common and enduring maxim—systems emphasize holism and networks of relationships, not reductionism, where one constituent part is isolated and examined independent from its context. Indeed, early in the conceptual development of systems theory, Laszlo (1972) commented that, "Some knowledge of connected complexity is preferable even to a more detailed knowledge of atomized simplicity, if it is connected complexity with which we are surrounded in nature and of which we ourselves are a part" (p. 10).

It is now widely accepted that an era of interdisciplinary studies is upon us (Harrison, Massey, & Richards, 2008; Ivanitskaya, Clark, Montgomery, & Primeau, 2002; Lélé & Norgaard, 2005; Leshner, 2004; Sung et al., 2003). Scientists across diverse fields agreed that single disciplines are no longer able to offer adequate understandings of multifaceted problems that are comprised by biophysical and human systems (Fortuin et al., 2011; Graybill et al., 2006; National Research Council, 2004; Newell, 1994). For example, understanding and appreciating the significant and wide-ranging impacts of managed European honeybee decline in the United States requires using knowledge in entomology (e.g., species characteristics and behavior), botany (e.g., plant-pollinator dynamics), agricultural economics (e.g., management costs and crop yields), natural resource policy and planning (e.g., land-use decision making) and psychology (e.g., public perceptions), to name but a few relevant areas of study. The practice of managing on-farm honeybee bee populations is itself a system, which is embedded within local systems of interacting laws, social organizations, and biophysical processes. These subsystems are embedded within still larger systems comprised of state and federal policies, scientific research and dissemination networks, and national environmental regulatory structures.

FIGURE 1

Mapping managed European honeybee decline as a system with multiple, interacting feedback loops.



Accordingly, the study of honeybee decline requires more than just aggregating disciplines; it also necessitates synthesizing diverse knowledge domains across multiple scales.

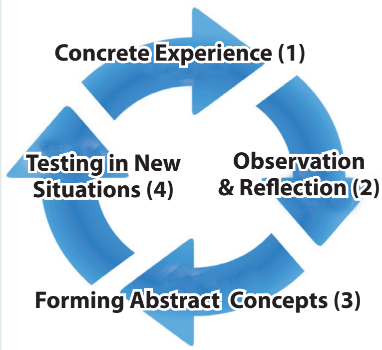
The higher order system influencing honeybee populations is comprised of an array of subsystems driven by a multiplicity of feedback loops and a combination of linear and nonlinear relationships that travel in many different directions simultaneously (Figure 1). Unsolicited responses, or feedbacks, are of particular importance when studying systems. Feedbacks determine how a system will progress and when or where changes and outcomes will materialize. A feedback loop is formed when modifications to a component of a system affect the flows into and out of that component (Meadows, 2008). Positive or reinforcing feedback loops (+) enhance the direction of change that is imposed on a system component. Negative or balancing feedback loops (–) oppose the direction of change in a system to maintain stability. These feedback loops are exemplified in Figure 1, which describes the drivers and consequences of a decline in managed honeybee colonies. There are social drivers in the form of public perception, environmental stewardship, and pesticide application practices; there are political drivers intended to manage rates of pollination, agricultural production and food security; and there are ecological drivers in the form of degraded habitat, nutrition availability and parasite and pest outbreaks—each of which influences transformations across the system.

Service learning

Service learning allows participants to apply knowledge acquired in the classroom to realistic events and situations, often in the form of local environmental problems. As Seifer and Connors (2007) noted, service learning is a "*structured* learning experience that combines community service with preparation and reflection" (p. 5, emphasis in original). Service

FIGURE 2

Kolb's experiential learning model, by McLain (2012).



learning reflects a student-centered and problem-based approach to teaching and learning about environmental science. Specifically, students develop ownership for the problems that they are attempting to understand and resolve (Blumenfeld et al., 1991). Furthermore, the problem is authentic, in so far as student thinking and behavior in learning environments prepares them for real-world situations (Honebein, Duffy, & Fishman, 1993). Finally, students are self-directed in their learning, that is, they are responsible for information gathering and the application of this knowledge in different contexts, such that learning is "not knowledge driven, rather, it is focused on metacognitive processes" (Slavery & Duffy, 1996, p. 146).

Systems learning is theoretically grounded in experiential education, which provides students with direct, first-person experiences in real-world settings in order to move learning beyond content (McLain, 2012). Kolb's (1984) cycle of experiential education (Figure 2) outlines how "knowledge is created through the transformation of experience" (p. 38), where concrete experiences and observations promote reflections that encourage learners "to confront their basic assumptions about the world . . . to integrate new and more complex ways of thinking" (Kezar & Rhoades, 2001, p. 155). It is important that learning can begin at any point in this cycle and is part of a continuous process of constructing and reconstructing individual, group, and collective (interdisciplinary) knowledge (McLain, 2012).

The application of Kolb's learning model to real-world service learning projects can generate profound learning benefits—including an increase in environmental awareness and sense of civic duty among project participants, a strengthening of community ties, an expansion of disciplinary perspectives made possible through real-world experiences, and exposure to both conceptual and experiential learning. Because service learning is collaborative with shared goals that are jointly derived from learners and communities, it is not surprising to find that it has been applied as an instructional tool in environmental science (Brubaker & Ostroff, 2000), health (Seifer & Connors, 2007), and education (Fitzgerald, 2009).

From a pedagogical perspective, service learning is frequently mistaken for community-centered curriculum and instruction (e.g., field-based internships). Although considerable overlap exists, a key difference between service learning and these other approaches lies in the levels of reciprocity between participants. In service learning, both learners and community members have specific needs met as a result of their sustained interactions. Hence, teaching and learning typically occurs over a longer time, nurturing relationships and building trust that is pivotal to the success of service learning projects.

Integrated model of systems theory and service learning to achieve synthesis

Efforts to understand and resolve complex environmental problems require synthesis across different disciplines and will thus benefit from learning environments that encourage collaboration between disciplines, and academic and public/private entities (Tress et al., 2003). We argue in this paper that the benefits of integration are greater than simply the sum of its parts. In other words, new ideas, experiences, and skills emerge out of an integrated systems theory—service learning (STSL) curriculum. These new outcomes together serve to achieve synthesis. By synthesis we mean the complete integration of disciplinary activities within a single stream of research and/or learning. Synthesis thus entails the comprehensive enmeshment of data, methodologies, concepts, theories, and subject matter from diverse fields of inquiry (Figure 3).

The tangible benefits of STSL curriculum occur in two principal learning areas: increased knowledge breadth and depth. Systems theory—through its analytic commitment to dynamic processes, feedback loops, nonlinear systems, and other complex system features—requires a holistic assessment of the drivers, patterns, and outcomes of social and environmental changes (Chen & Stroup, 1993; Gulyaev & Stonyer, 2002). This broadening of knowledge and analysis is a hallmark feature of systems theory.

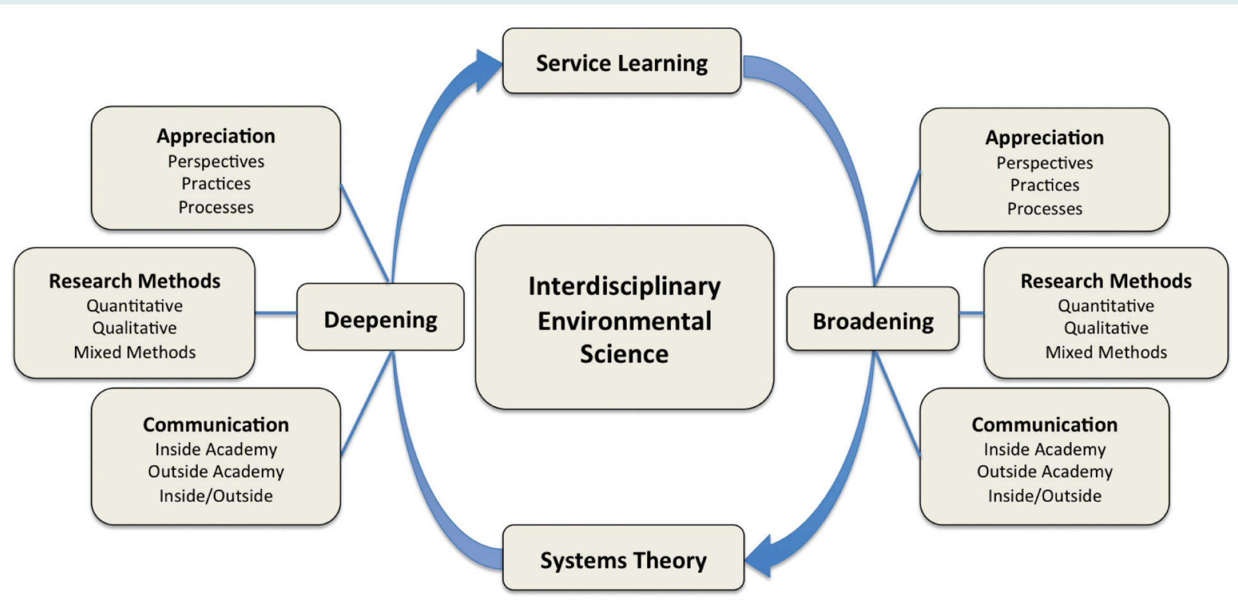
If systems theory encourages working and learning between disciplinary fields, then service learning promotes a brand of research and teaching premised on immersion within a field location or suite of sites. Effective service learning requires close and recurring exposure to human and environmental field subjects (Kezar & Rhoades, 2001; Seifer & Connors, 2007; Ward, 1999; Wiese & Sherman, 2011). These onsite research and learning experiences deepen knowledge through interactive and interpersonal engagement with course materials.

It is important to note that we are not suggesting service learning is inherently void of interdisciplinary thinking or that systems theory necessarily obviates in-depth analysis. What we are suggesting is that each approach to education has its strengths and that, when combined, an integrated STSL framework can significantly improve our ability to teach, understand, and respond to complex social-environmental issues. In short, we suggest that faculty in higher education leverage synthesis in STSL curriculum to generate pedagogical frameworks and methods that encourage both broadening and deepening of knowledge and skills in environmental sciences and therefore advance synthesis. This process occurs along three axes: appreciation, research methods, and communication (Table 1).

Appreciation: In order to be successful, interdisciplinary programs of study will need to cultivate a research and learning environment that promotes appreciation of various academic viewpoints, research questions, cultural norms, geographic contexts, and system processes. Through their involvement in STSL projects, participants will better appreciate the theoretical perspectives, scholarly pursuits, and practical realities of other disciplines and stakeholders. Similarly, group members will develop greater appreciation for the everyday practices and experiences of their peers. Finally, participants involved in such projects will gain deeper appreciation for the many dynamic and interconnected processes comprising human–environmental systems. Broadening one's perspectives and practices will open pathways for collaboration and appreciative enquiry between multiple research participants and subjects. Project members who deepen their appreciation will gain a thorough understanding of system attributes embedded in a specific location or set of activities.

FIGURE 3

Systems Theory—Service Learning (STSL) benefits for interdisciplinary environmental science.



Research methods: To gain detailed understanding of complex social-environmental issues, STSL programs must use quantitative, qualitative, and mixed-method approaches to research, teaching, and learning. Through a process of broadening, interdisciplinary educational programs provide opportunities for participants to learn from a diverse suite of research methods. It is important to note that participants do not learn and apply these methods separately. Rather, the goal of STSL programs is to integrate different research approaches to understanding different environmental processes and questions. Deepening occurs as project members' focus on, and begin to master, a research method that examines a particular location or system process. These methods can apply to data collection and interpretation occurring in classroom, laboratory, and field-based settings. They may involve the use of field equipment, software programs, and survey/interview techniques. The development of research methods in STSL programs thus involves sharpening analytic tools while simultaneously constructing a larger and more diversified research toolkit.

Communication: Interdisciplinary environmental science programs involve defining, examining, and solving complex environmental problems. By moving through these stages of inquiry, collaborators will be exposed to, and thus increase their awareness of, multiple disciplinary and professional discourses. A discourse is a set of values and expectations reflected in a unique language (conversations, writing, and other forms of communication) that generate and reinforce disciplinary ideals and perspectives. Through a process of broadening, participants will increase their ability to effectively communicate within and across disciplinary, public, and professional fields. Through a process of deepening, individuals will improve their ability to communicate effectively between a small number of stakeholders and scientists associated with service learning activities. Generally speaking, group members will increase their capacity to communicate effectively with individuals both inside and outside the academy.

We recognize that interdisciplinary projects will vary across institutions and programs. Projects may differ in their commitment to both systems theory and service learning because of institutional constraints, funding limitations, resource availability, preexisting curriculum, and scholarly commitments. It is thus reasonable to expect that some projects will endeavor to deepen or broaden more than others.

Application of STSL model to University of Colorado Denver Five Fridges Farm

In the following section we describe a proposed application of the STSL model to an interdisciplinary environmental sciences project for both

TABLE 1

Overview of three broadening and deepening axes.

Interdisciplinary STSL environmental science learning model	**Broadening** Systems theory demands holistic assessment of drivers and outcomes of social-environmental changes. Full-spectrum analysis requires paying attention to diverse entities, processes, and feedbacks across temporal and geographical scales.	**Deepening** Service learning is premised on intimate and recurring exposure to human and environmental field subjects. Onsite experiences result in a focusing of knowledge within system subarea through hands-on engagement with material.
Appreciation Programs should cultivate research and learning environments that promote understanding of diverse perspectives, practices, and system processes.	Group members better able to understand diverse elements of system and complex system interactions, thus gaining appreciation for diverse viewpoints and subject materials.	Individuals gain a thorough understanding of the perspectives, practices, and processes embedded within a specific location or node in the social-environmental system.
Research methods Programs should utilize quantitative, qualitative and mixed-method approaches during data collection and interpretation activities in classroom, lab and field settings.	Participants are provided with opportunities to learn a broad array of research methods, including the use of diverse equipment, geo-spatial techniques, statistical software, and survey/interview techniques.	Project members focus in on, and begin to master, a small number of relevant research methods that closely examine a particular geographical location, a localized subsystem, or a specific system process.
Communication Programs should increase ability of group members to communicate effectively inside the academy and outside the academy, and also between those inside and outside.	Participants increase ability to communicate effectively with diverse audiences within and across disciplinary, public, and professional fields.	Individuals improve capacity to communicate effectively between a small group of stakeholders and/or scientists involved in area of research/learning focus.

Note: STSL = systems theory—service learning.

undergraduate and graduate students. Our goal is not to describe the specific impacts, challenges and/or benefits of implementing an STSL model. Several years of implementation at the University of Colorado Denver will ultimately be needed to diagnose the precise implications of our proposed learning model. (Our long-term goal is to report and analyze specific instances, challenges, and benefits of teaching and learning in a subsequent manuscript; after the STSL model is applied through several iterations in a new environmental science / sustainability course scheduled to begin in spring 2013.)

Rather, our objective at this juncture is to leverage scientific and pedagogical theories to articulate and justify the need to bridge traditionally disparate learning models. Indeed, one need not look beyond our own university to see how systems theory and system learning approaches are highly compartmentalized modes of inquiry, neatly delineated between courses and rarely overlapping in their presentation to students. On its own merit, our theoretically informed proposal for curriculum integration represents an innovative and valuable contribution to the field of environmental science education.

In early 2012, the opportunity arose to develop STSL-based projects with the establishment of the Five Fridges Farm as a Field Research Station at the University of Colorado Denver, a

TABLE 2

Illustration of broadening and deepening process using the activity of poultry husbandry at the University of Colorado, Denver, affiliated Five Fridges Farm.

STSL Learning Model at Five Fridges Farm	Broadening and Deepening				
	Ecology	*Soil*	*Water*	*Food*	*Community*
Appreciation Perspectives Practices Processes	Restoration, native planting, exotics eradication Resource-conserving vegetative cover Wildlife habitat and predation Integrated pest management Habitat, shelter, buffer, corridor design	Composting activities Soil cultivation Soil amendments and application Soil chemistry Pest control Conservation and use rotation Riparian zone soil stability	Water laws and rights Regional water supply Water flow and distribution Irrigation ditch management Creek restoration activities Water quality and nutrient loading	Management of farm food waste and manure Poultry husbandry from egg to end of life Multi-nodal food distribution Food security Awareness of connection to food source	Community Supported Agriculture (CSA) management Members of chicken cooperative Farm neighbors Food justice advocates Community meetings
Research Methods Quantitative Qualitative Mixed Methods	Species diversity analysis Vegetative cover area and edge measurements Species identification and population monitoring Ecological buffer, shelter, corridor calculations	Soil core and composite sampling Soil erosion monitoring Sedimentation testing Soil composition/structure testing Soil biodiversity analysis	Site assessment measurements Water quality testing Water metering Precipitation measurements Chemical fate and transport measurements	Food price elasticity and market dynamics Nutrition testing Poultry measurement Cost-benefit analysis Food access gap analysis	Surveys Focus group interviews Observations Knowledge assessments Mapping Journaling and note-taking Agent based modeling
Communication Inside Academy Outside Academy Inside/Outside	Articulate habitat management plans Communicate with Conservation Reserve Program Coordinate findings and generate lesson plans with educators Conflict resolution between farm, community, recreationists	Communication with government agencies and extension offices Communication of results from soil science testing Articulate management priorities to community and stakeholders Coordinate findings and generate lesson plans with educators	Water conservation outreach and communication Communication of results from aquatic testing Articulate management priorities to community and stakeholders Coordinate findings and generate lesson plans with educators Water conflict resolution	Articulate current issues related to husbandry Communicate local food system benefits/challenges Coordinate findings and generate lesson plans with educators Communicate diverse food distribution channels Convey social-ecological impacts of food choices	Formal and informal outreach to public Intercultural communication Conflict resolution/ Mediation Public hearings, stakeholder information

Note: The deepening and broadening occurs along three learning axes: appreciation, research methods, and communication. Deepening takes place as learners engage with recurring, hands-on activities in five system subareas—ecology, soil, water, food, and community. Signified by the horizontal arrows, broadening occurs as project participants connect subareas and link them to wider systems comprised of complex processes, interactions, and feedbacks. The broadening process may be carried out using a wide range of analytic tools such as agent-based modeling, Bayesian data fusion, cellular automata, concept mapping, ethnography, etc. STSL = systems theory—service learning.

medium-size, public university located in downtown Denver. Although privately owned, the farm is administered by the Department of Geography and Environmental Sciences. Consisting of 13 acres in nearby Wheat Ridge, the Five Fridges Farm is ecologically and topographically varied with a stream, irrigation ditch, pond, natural habitats, livestock, and areas under agricultural production. The Five Fridges Farm presents an ideal setting for developing (and ultimately implementing) STSL curriculum, as the farm provides opportunities for students to engage in farm design, land-use decision making, conservation planning, and landscape restoration as well as a full range of tasks associated with produce marketing. Moreover, as the Five Fridges Farm continues to develop, students and faculty will encounter an evolving set of environmental issues and dynamics, which will generate new research questions and learning opportunities. In this way, an STSL curriculum provides the opportunity for a longitudinal study of urban farm development and associated interacting processes, with successive cohorts of students benefiting from and building on the work of previous students.

We use the activity of poultry husbandry—one of many pursuits taking place at Five Fridges Farm—to illustrate how an STSL learning model can potentially unfold in practice and to describe anticipated benefits and challenges of implementing an STSL-based project. Poultry husbandry is a particularly compelling example as it links to many processes and activities that are concurrently internal and external to the farm. Students are thus introduced to systems theory as a method for learning about the diverse and interconnected social and biophysical characteristics that support and influence farm activities (broadening process). Students then identify specific areas of interest where they can gain expertise and acquire new and in-depth knowledge (deepening process). Table 2 describes five subsystem areas—ecology, water, soil, community, and food—that are linked to poultry husbandry and that serve as useful topical areas for in-depth research.

Conclusion

We suggest that systems theory and system learning are not only complementary but that they can operate symbiotically within a single, interdisciplinary learning program. For the STSL model to be effective, educators in higher education need to provide students with opportunities to engage in meaningful learning that broadens and deepens their research and communication skills as well as their appreciation for project subject matter. For example, following Kolb's (1984) learning model (Figure 2), we can see that students investigating processes related to poultry husbandry at Five Fridges Farm have the potential to understand the farm as a system that is itself embedded within other systems. Then, through close and recurring engagement, students get hands-on interactions with topics related to ecology, soil, water, food, and community in the context of the farm system. Following this immersion experience, students are able to reflect on their prior assumptions about environmental actions and consequences (i.e., to recognize social-environmental feedback loops). Students may then apply their newfound knowledge to other activities at the farm or in different environmental settings. We have suggested that actualizing these achievements necessitates the acceptance and application of a learning model—offered here as an STSL model—that nurtures interdisciplinary teaching, learning, and research environments.

Although the STSL model proposed in this paper has not yet been implemented at the Five Fridges Farm, this essay performs an equally important task: articulating the pedagogical and scientific theories that support the integration of formerly distinct learning models (systems theory and service learning) within a single innovative curriculum framework. Given our own experiences, we view the integration of systems theory and service learning as a departure from traditional concepts of scientific objectivity with discrete facts as the building blocks of fundamental laws. Embracing a systems lens to natural/social phenomena while concurrently seeking opportunities to engage in community-based activities involves critically analyzing the networks and connections inherent between parts of a system—local and global, enduring and ephemeral, linear and nonlinear. We contend that the path toward synthesis must begin by accepting that the transformation away from disciplinary knowledge and its rigid applications is both inevitable and beneficial. ■

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