A Paradigm Shift Toward Systems Thinking in Colleges of Agriculture

Katrina R. Alford[1], Nicole L. P. Stedman[2], J. C. Bunch[3], Shirley Baker[4] and T. Grady Roberts[3]

[1]Faculty Instructional Resources and Support Team, University of Florida
[2]Graduate School, University of Florida
[3]Department of Agricultural Education and Communication, University of Florida
[4]School of Forest, Fisheries, and Geomatics Sciences, University of Florida

Author Note
Correspondence regarding this article should be addressed to Grady Roberts, PO Box 110540, Gainesville, FL 32611; Email: groberts@ufl.edu

Abstract

The world of the 21st Century is a world that is constantly changing. New approaches to higher education must be considered so graduates can adapt to an increasingly complex world capable of tackling wicked problems like those abundant in agriculture. In this article, we discuss why and how systems thinking can be developed and utilized in colleges of agriculture. Based on a thorough literature review, we propose two new models to advance systems thinking in colleges of agriculture. The first model demonstrates potential outcomes that may occur when matching a learner's level of conceptualization to the type of problem they are addressing. The second model shows how systems thinking skills should be incorporated into the curriculum via experiential learning to assist individuals in their progression of systems thinking growth. Recommendations for practice and additional research are also provided.

Keywords: problem-solving, systems thinking, models, teaching

The world of the 21st Century is a world that is constantly changing. The current food system must produce 50% more food to meet the projected population growth (Food and Agriculture Organization [FAO], 2018). Yet Mbow et al. (2019) note that the food system is vulnerable to climate change, which contributes to its vulnerability. Mbow et al. (2019) posit that climate and non-climate stressors (i.e., population growth, trade, and governmental policies) must be addressed to achieve worldwide food security. These stressors constantly change and present an unprecedented challenge to those who want to solve them. According to Camillus (2008), social complexity, coupled with the technical difficulties related to various concerns, is characteristic of wicked problems. Agriculturalists are starting to think differently about global food production, embracing a systems perspective using terms like food systems, agroecology, AgTech, and Agriculture 4.0 (Klerkx & Begemann, 2020). The agricultural workforce of today and tomorrow will work within a transforming agrifood sector and face these wicked problems. Colleges of agriculture have a role in developing this human capacity.

The U.S. National Research Council (NRC) was concerned that college graduates in the agricultural sciences were unprepared to operate in an increasingly globalized agricultural industry (NRC, 2009). McKim and McKendree (2020) stated that graduates must conceptualize complex solutions to complex problems within the constantly changing agriculture, food, and natural resource (AFNR) systems. Yet, it appears that graduates struggle with the concepts of ambiguity and change (Crawford & Fink, 2020). The question must be asked: does a new approach to higher education need to be considered if graduates cannot adapt to the increasingly complex world? This article will discuss why and how systems thinking can be developed and utilized in agricultural universities and colleges.

A conflict has emerged regarding the purpose of higher education. Advocates support the view that universities should be academic havens that are divorced from the politicization of knowledge. In contrast, others support the notion that they should be utilized as a means of economic growth by developing human capital through vocational programs (Palmadessa, 2020, Chapter 1). With the rise in concern regarding wicked problems, a third vision has been proposed: higher education should create social transformation by promoting social and environmental justice (Palmadessa, 2020, Chapter 1). The philosophy surrounding the purpose of the universities influences their structure and curriculum, which affects students' knowledge and motivations. Adopting a transformational learning approach to education is in itself a paradigm shift from the purpose and objectives of education. To achieve this new purpose, new philosophies, teaching approaches, and objectives must be considered. Colleges of agriculture in U.S. land grant universities have the resources to make meaningful progress toward solving the pressing issues of societies by preparing students for their future lives, but are their educational practices consistent with what needs to be done to make significant change? Within higher education, sustainability degree programs appear to be among the leaders in embracing systems thinking competencies (Brundiers et al., 2020). There are growing calls in STEM disciplines to embrace systems thinking pedagogy (Baron & Daniel-Allegro, 2020; Lavi et al., 2021). We propose that developing systems thinking capabilities in students is necessary to create the next generation of complex problem solvers in the agricultural workforce.

Purpose

Systems thinking has been well documented in various disciplines; however, a literature review shows a lack of research on teaching to develop systems thinking within the agricultural sciences. The purpose of this paper was to synthesize existing literature on systems thinking theory and develop a model that can be utilized to guide college-level agricultural educators into creating and using a systems thinking paradigm.

Historical Perspectives

Research has repeatedly demonstrated that the human mind likes simple straight lines such as 1 + 1 = 2, or A affects B, which causes C (de Langhe et al., 2017). Linear thinking is the term used to describe this approach to thinking, and Greer (2010) noted that people struggle with nonlinear situations. Ebersbach et al. (2010) concluded that linear reasoning occurs naturally in young children (ex., five years old) even before instructional practices have been developed. Therefore, it can be inferred that linear reasoning is a "natural" inclination of individuals. Secondary school teachers are heavily influenced by linear thought and thus teach their students using linear thinking (Greer, 2010). Greer (2010) noted that students develop thought processes similar to those of their teachers, and, as a result, they may have difficulties grasping nonlinear situations. As such, linear thinking dominates the educational system, along with its corresponding pedagogy of behaviorism. Behaviorism is often the first (and most enduring) learning theory utilized in the classroom, despite many other pedagogical approaches (Jackson & White, 2020).

Ebersbach et al. (2010) argue that since it is common for instructors to overlook the predominance of linear thinking, special attention needs to be paid to not weaken or eliminate nonlinear thinking in early education. This argument can be extended to higher education. Jackson and White (2020) advocate that higher education instructors must move beyond behaviorism and focus on active learning and student-centered pedagogical approaches. For this to occur, instructors must create environments encouraging deeper engagement with complex social subjects. Systems thinking has emerged as a model for thinking differently (Cabrera et al., 2008). Still, despite its wide application in many disciplines, "systems thinking remains marginalized from mainstream science" (Barton & Haslett, 2007, p. 144). Systems thinking has been proposed as a solution to tackling issues of complexity (Plate, 2010). As the agricultural sector faces multiple wicked problems, systems thinking may need to become more prominent in higher education. However, there is a lack of shared understanding about the term, which is critical for developing discourse around the phenomenon for both policymakers and academia (Knight, 2004).

Introduction to Systems Thinking

Systems thinking can be thought of conceptually as looking at interrelationships between parts related to the whole (Trochim et al., 2006). Ison (2008) wrote that many people (but not all) are aware of the interconnected nature of systems. However, it was not until 1954, when the Society for the Advancement of General Systems Theory (now known as the International Society for the Systems Sciences [ISSS]) was founded by von Bertalanffy, Boulding, Gerard, and Rapoport (Hammond, 2002) that systems thinking became a formalized concept. These four individuals are often considered to be the "fathers" of the idea of "systems thinking." Since then, considerable work has been designed to advance systems thinking as an alternative way of thinking (Hammond, 2002).

However, as Hammond (2002) notes, different groups of people ascribe different meanings to systems theory depending on their discipline. A review of the literature shows that there are different definitions of the term systems thinking. Still, many terms have meanings that are either synonymous with or similar to "systems thinking." These terms include but are not limited to systems-oriented thinking, ecological thinking, complex problem solving, and network thinking (Riess & Mischo, 2009). Within the agricultural field, terms such as critical thinking, inter-disciplinary, multi-disciplinary, and boundary-crossing have also been used to describe various methods for approaching problems, which may have roots in systems thinking but should not be used interchangeably with systems thinking.

Critical thinking "is a purposeful, self-regulatory thinking aimed at solving problems, addressing questions, forming judgments, and making decisions" (Baker et al., 2021, p. 42). Inter-disciplinary and multi-disciplinary involve integrating multiple disciplines, often basic and applied sciences (Hu et al., 2023). Boundary crossing involves developing the skills to think across a variety of social and scientific boundaries when solving problems (Bishop & Eklöf, 2022). All these problem-solving approaches differ from systems thinking in that they fail to fully capture the interconnected nature of complex problems.

McGuire (2017) makes the case that having a shared understanding of a concept is essential when the conceptual area has many distinctions that can be confused. Systems thinking was initially conceived "as a set of interacting or interdependent parts forming a complex whole" (Stalter et al., 2016, p. 324). However, the concept has evolved to include other dimensions, including social, technical, and cultural contexts, and with this expansion, the definitions also expanded. Leischow and Milstein (2006) define system thinkers as those seeking patterns and relationships between interdependent components of a system by looking at them from a non-linear and complex perspective. Senge (1990) defined systems thinking as looking at both the whole and using a framework to see interrelationships rather than individual things, and patterns of change rather than static snapshots.

In systems thinking, there are distinctions correlated to other concepts, and it is essential to examine both the similarities and differences of these concepts. Arnold and Wade (2015) make the case that systems thinking has three key elements that determine whether a concept can be called systems thinking: (a) the purpose of systems thinking, (b) the elements (characteristics) of system thinking, and (c) the interconnectedness of how elements feed into each other. This systems test can determine if a definition of a concept can be classified as systems thinking.

Arnold and Wade (2015) define systems thinking as "a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects" (p. 675). Their definition addresses the three elements that they believe encompass systems thinking. For this paper, this definition will be utilized to operationalize systems thinking.

In addition to the complexity of having multiple definitions, the literature also uses other words interchangeably to describe the same concept. Cross-disciplinary, interdisciplinary, and complex problem solving are all used to define a type of thinking that is non-linear and interrelated. However, these terms are not comparable to systems thinking, and it would be incorrect to use them in place of systems thinking. For example, Kereluik et al. (2013) stated that cross-disciplinary knowledge could be defined as taking knowledge and integrating information from across various fields. However, this definition does not address either the purpose of systems thinking or the interconnectedness of elements. As such, the concept of cross-disciplinary knowledge falls short of true systematic thinking since it does not encompass all three components outlined by Arnold and Wade (2015).

Another example would be the definition of complex problem solving (CPS). When Frensch and Funke (1995) asked Beckmann and Guthke (two contributors to their book) to define CPS, they wrote, "CPS represents a class of task demands the cognitive mastery of which calls for the recognition of causal relations among the variables of a system" (p. 34). This concept again falls short of being systematic thinking because it does not mention the characteristics of systems thinking. Interdisciplinary definitions emphasize the integration of disciplinary work (Lattuca, 2003) but do not address the purpose or elements of systems thinking. Therefore, interdisciplinary approaches and perspectives are not a substitute for systems thinking.

With various definitions and meanings ascribed to systems thinking, it is unsurprising that there is a lack of shared understanding of the concept. Therefore, there is value in exploring the history and evolution of systems thinking. It should be noted that, due to the vast array of disciplines conceptualizing their definition of systems, this research may not capture the complete evolution of systems thinking. However, it provides a starting point for discussion about the current level of understanding of systems thinking and how it should be applied to agricultural universities.

General Systems Theory (GST)

Overview of GST

GST provides the historical foundation for contemporary views of systems thinking. Despite the varying definitions of systems thinking, a key element among them is the understanding that the sum is greater than the parts (Bawden et al., 1984). Individuals who are systems thinkers are aware of the interconnections that make up a holistic view, as opposed to systematic individuals who utilize a step-by-step approach (Ison, 2008). Ison (2008) argues that most people naturally have some degree of systems thinking; however, Kali et al. (2003) found "that general awareness of the holistic aspect of a system does not necessarily foster systems thinking" (p. 563). It appears that multiple fields such as biology, engineering, cybernetics, ecology, physics, and sociology, to name a few, have developed general cognitive principles that focused on this concept of whole and parts. These cognitive principles formed the basis for the beginnings of a systems thinking approach (Caulfield & Maj, 2001), which has evolved and become more codified over the decades. However, each discipline chose its course until a biologist named Ludwig von Bertalanffy noted the parallelism between the disciplines and attempted to generalize it into a theory (Caulfield & Maj, 2001).

General Systems Theory (GST) was designed to achieve a cross-disciplinary application. Its roots were strongly connected to the field of mathematics, as von Bertalanffy (1972) noted that mathematics is a language that can permit rigorous confirmation and deductions of the phenomenon under investigation. Although GST was based on a language of mathematics, its objective was to transcend disciplinary boundaries by acting as a bridge between the different sciences (Mulej et al., 2004). Von Bertalanffy looked at technology, science, and philosophy and created a theory that looked at the relationships between the parts and a larger whole within a system (Hammond, 2005). Through his work in theoretical biology, von Bertalanffy conceptualized open systems, which acknowledged the evolution and complexity of living systems and contributed to concepts such as the feedback loop and causality within systems thinking (Hammond, 2005). However, many practitioners found that GST lacked practical methodologies, perhaps because systems thinking can become bound up in modeling, obscuring the context of the situation (Rountree, 1977). Thirty-three years later, Zexian and Xuhui (2010) lodged the same critique of GST in that it was based on abstract mathematical modeling, which did not reflect real-world problems.

Limitations of GST

The limitations of GST resulted not in the failure of systems thinking in general but rather in the refinement and expansion of the concept of systems (Checkland, 2005). The term "Systems" in systems thinking evolved not just to encompass the world but also to focus on the process of dealing with the world (Checkland, 2005). This shift in viewpoint resulted in different underlying epistemologies for defining and interpreting systems thinking (Ison, 2008). Checkland (2005) distinguished between two types of systems thinking: hard and soft. The foundation for hard systems thinking (HST) rests in positivism and functionalism designed to solve well-defined problems (Zexian & Xuhui, 2010). However, as Rittel and Webber (1973) noted, the paradigm of science and engineering (i.e., positivism), which underlies most professions, cannot be applied to open societal problems. As Meadows (2008) wrote in Thinking in Systems: A Primer:

Let's face it, the universe is messy. It is nonlinear, turbulent, and chaotic. It is dynamic. It spends its time in transient behavior on its way to somewhere else, not in mathematically neat equilibria. It self-organizes and evolves. It creates diversity, not uniformity. That's what makes the world interesting, that's what makes it beautiful, and that's what makes it work. (p. 153)

Initially, systems thinking modeling focused on stages used to address problems. The first stages involved evaluating the problem situation and analyzing the problem (Checkland, 2005). Yet this model failed to consider cases in which there was no defined problem situation due to humans interpreting and perceiving different viewpoints (Checkland, 2005). The social reality was not reflective of the testable physical reality, and as such, systems thinking needed to evolve to address this disconnect (Checkland,1981). Therefore, soft systems thinking (SST) was developed to address the interpretive element of human activity (Zexian & Xuhui, 2010). Ison (2008) writes that soft systems thinking involves an epistemological shift in which systems are no longer based on models but rather required to gain a deeper understanding of a phenomenon.

However, Ison (2008) also rejects the dichotomy of HST and SST but instead perceives the two as belonging to a continuum. Randle and Stroink (2018) argue that systems thinking should be viewed as a cognitive paradigm encompassing a holistic worldview, expanding on causation within systems, and acknowledging constant change. Adopting this perspective, they further argue that systems thinking involves individual differences responsive to situational cues (Randle & Stroink, 2018). This contrasts with prevailing research, which looks at the domain-specific systems thinking skills and highlights the idea that systems thinking as a cognitive domain can be developed (Randle & Stroink, 2018). Within the context of agriculture, Bawden (1991) argues that agriculturalists need to build a paradigm appropriate for the magnitude of the problem being studied. He writes:

And in our rethinking, we must learn how to come to terms with complexity and chaos and develop learning strategies that enable us to help others to deal with such dimensions. In sum, we must be prepared to let go the old and embrace the new science and praxis of complexity. (p. 2371)

This call to action can no longer be ignored. The agricultural discipline needs to be more intentional about developing systems thinking through both reflection and action.

Hard and Soft Systems Thinking

There have been various warnings that the traditional method of linear thinking used to solve problems will no longer be sufficient due to the world's complexity (Roberts, 2001). Batie (2008) stated that a linear approach could be appropriate in answering the "what is" and "what if" components of the problem and, as such, science is often guided by a linear model. However, this approach is ill-suited when applied to the science of wicked problems (Batie, 2008). Systems thinking is a unique thinking approach that integrates the parts and the whole and builds on a continuum (Kali et al., 2003). HST is traditionally viewed from a positivistic lens and assumes that systems models reflect the real world. These systems can then be engineered to demonstrate problems and solutions (Ison, 2008). HST focuses on keeping systems as simple as possible and developing models to solve problems, approaches often seen in the natural sciences. SST retains the view that introducing the human element of divergent viewpoints means that systems models can be utilized for learning and understanding, and they can describe issues and accommodations rather than just problems and solutions (Ison, 2008). SST emphasizes understanding the problem and multiple realities that may exist within systems, which is typical in the social sciences. Hung (2008) writes that systems thinking is one of the most complex types of higher-order thinking and is often challenging to master. The introduction of "soft" variables, such as social, emotional, or psychological into systems thinking requires deeper cognitive ability due to the difficulty in quantifying and representing them within the system. This continuum of thinking from linear to hard to soft systems thinking demonstrates an individual's growth in their ability to understand complex cognitive problems, which is necessary considering the types of issues facing the agricultural industry. Table 1 provides a comparison of HST and SST.

Table 1

Comparison of HST and SST

Hard Systems Thinking (HST)	Soft Systems Thinking (SST)
Well-defined problem	Ill-structured problem(s)
[Post]Positivist Epistemology	Constructivist Epistemology
Structured around problems(s) and solutions	Structured around issues
Assumes the world can be structured and modeled	Thinks the world can be explored but not modeled due to human perspectives
Focused on goal-seeking	Focused on understanding and learning

Table 2

Characteristics of Types of Problems

Type of Problem	Characteristics of Problems
Tame	Known problem. Known solution.
Complex	Known problem. Multiple options for solutions.
Wicked	No agreement on the problem. No agreement on solutions. Potential solutions may cause more problems

As noted, HST and SST focus on different types of problems. Rittel and Weber (1973) identified two types of problems, “tame” and “wicked.” Tame problems are those in which there is a clear mission because there is a known problem and known solutions. Examples may include solving a math problem, repairing a broken radiator, or finding the feed-to-weight conversion in salmon. In contrast, the complexity, ambiguity, diversity, and uncertainty of wicked problems mean that divergent views result in various interpretations of problems leading to different opinions of potential solutions (Head & Alford, 2013). In short, wicked problems have no clearly defined problem(s) and no known solution(s) (Batie, 2008).

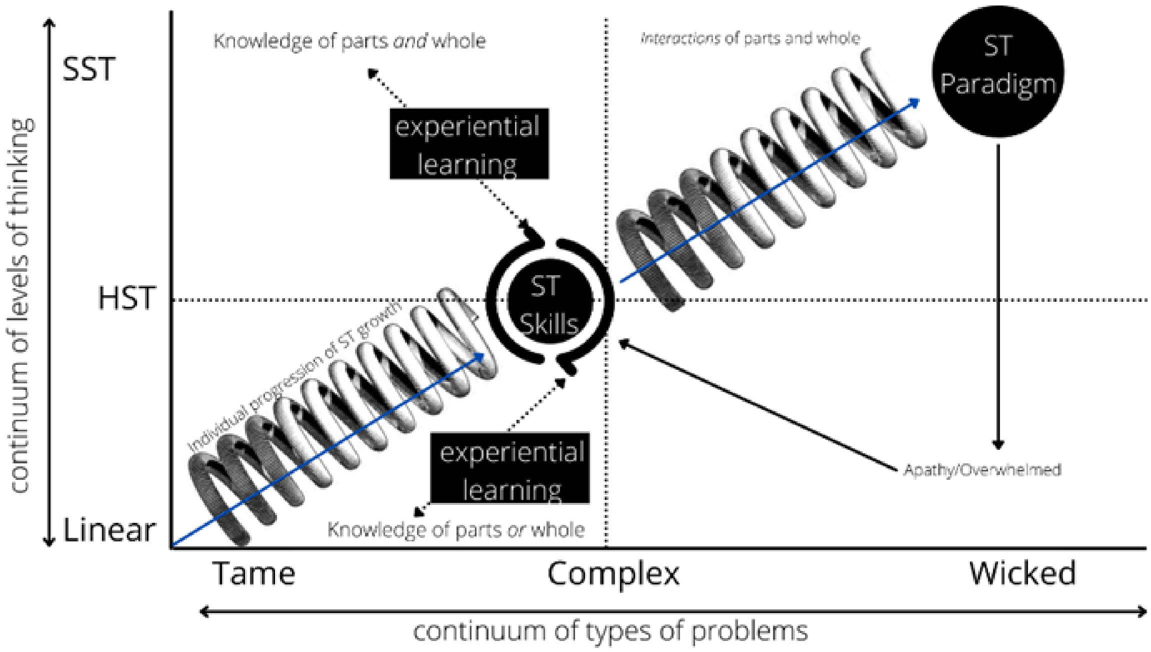
For an agricultural example, consider the problem of food insecurity in a struggling community. Is it because of a lack of infrastructure resulting in a food desert, lack of jobs leading to economic instability, or a lack of education regarding the importance of a balanced diet? Each person looking at food insecurity within the community may choose a different angle to approach the issue, which leads to different proposed solutions, which may impact other problems and solutions (ex. addressing infrastructure issues may unintentionally cause environmental problems). Head and Alford (2013) note that there is no single “best” approach to dealing with problems because there is no longer a “root cause” that can be identified. Roberts (2001) also developed a third category of problem, complex problems, that falls between tame and wicked problems. Complex problems can be described as having a specific problem, but it may have multiple solutions (Batie, 2001). Examples of complex problems may be managing root rot in an oak tree, a doctor deciding the best way to treat diabetes, or how to register high school student to vote. These all contain an identifiable problem, but individuals can develop multiple solutions available to them to address these issues. Although at first glance complex and wicked problems seem similar due to the level of complexity involved, it is worth noting that wicked problems are a step beyond complex problems of the lack of a clear pathway to resolving the issue (Whyte & Thompson, 2011). These three types of problems can represent the level of cognitive ability needed to address issues, with wicked problems requiring the highest order of cognitive ability. Table 2 summarizes the characteristics of each type of problem.

A Model for Developing Systems Thinking

As with the levels of thinking, problems can be interpreted as a continuum, starting with tame problems before moving to complex problems and then on to wicked problems. Combining the type of problems with the level of thinking creates a matrix that can be utilized to assess the growth and development of an individual’s systems thinking paradigm. Figure 1 is a conceptual model created to demonstrate potential outcomes that may occur when matching a learner’s level of conceptualization to the type of problem they are addressing. The grey quadrants represent potential cognitive outcomes that can occur when matching

Figure 1

Conceptual Model of the Development of a S.T. Paradigm through a Progression of Problem Types



the level of thinking to the type of problem. The spiral line intersecting the box represents an individual's progression towards a systems thinking paradigm. Note how linear thinking can lead to systems awareness when matched with a complex problem, allowing for the development of systems thinking competencies.

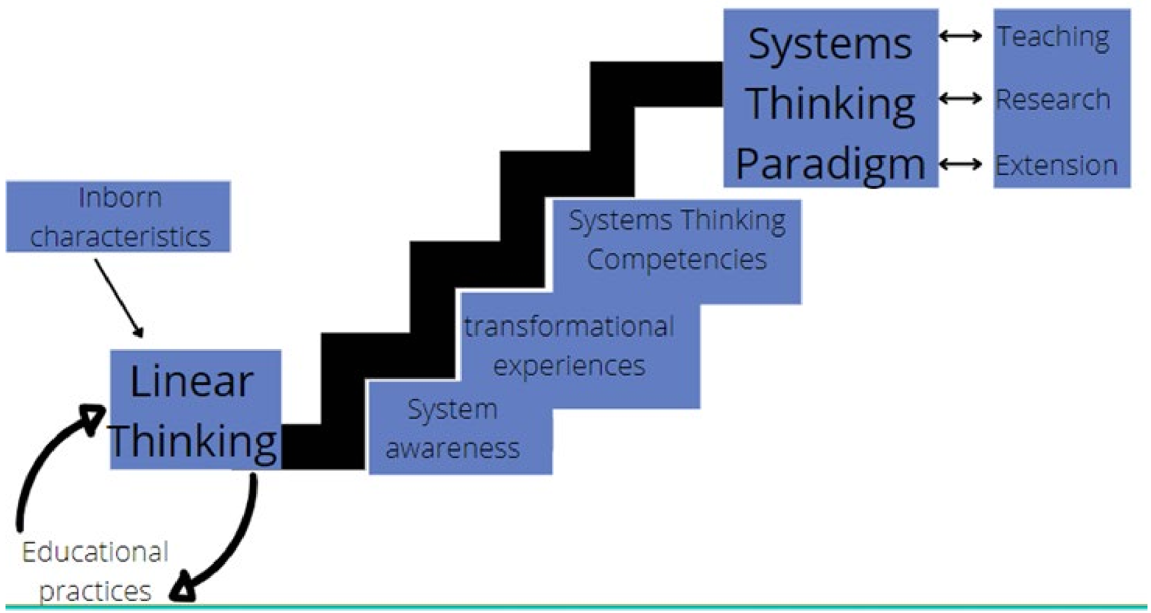
Linear thinking is a default method of thinking (Ebersbach et al., 2010) and marks the lowest level of cognitive thinking. To develop a systems thinking paradigm, Kali et al. (2003) concluded that there needs to be a knowledge-building stage for the parts and whole of the system. To solve a tame problem, individuals will need to know the parts or the whole of the problem to find a solution. As individuals progress along the continuum from linear thinking HST to SST, their comprehension expands to include the parts and the whole. Depending on the type of problem, an individual can adjust their level of thinking by moving along the continuum to find solutions. As problems move from tame to complex, individuals must progress in their thinking through the structured development of systems thinking skills. The base knowledge of parts, wholes, and the sum of the parts and the whole serves as a foundation to develop and build systems thinking competencies.

Experiential learning, a learning theory that includes a cyclical process of experiences and reflections (Kolb, 1984; Roberts, 2006), can help individuals utilize their knowledge to refine their systems thinking skills. Dewey, considered to be the father of experiential learning, argued that the learning process is characterized by individuals experiencing a phenomenon, reflecting on the experience, and then forming concepts based on the experience and pre-existing knowledge (Dewey, 1938). This process is continuous, with each new experience initiating new reflections and new conceptualizations of the world (Dewey, 1938). This cyclical model of learning underpins an individual's progression towards the system's thinking growth. As individuals interact with the knowledge of parts and whole and systems thinking skills, they reflect and incorporate this knowledge into their conceptualization of the world. This continuous cycle of experiencing and reflection allows individuals to deepen their cognitive understanding by relating the content to a systems thinking perspective. Thus, developing a systems thinking paradigm is intimately linked with the experiential learning process and the importance of allowing individuals to experience and reflect on skills and knowledge needed to develop systems thinking competency.

In conjunction with the development of HST and SST levels, developing systems thinking skills and competencies is necessary to shift individuals into the upper right quadrant, where they can utilize their foundational knowledge to examine the interactions of the parts and the whole. Within this area, an individual can conceptualize and adopt a systems thinking paradigm. This systems thinking paradigm involves a worldview that allows an individual to address the complexity of both the social and natural world (Randle & Stroink, 2018). This paradigm is needed to address wicked problems that are abundant in agriculture because they involve both the social and natural world. Should individuals utilize a lower level of thinking, they may feel apathetic or overwhelmed in addressing a wicked problem. Within this situation, if an individual is sufficiently motivated, they may return to acquiring more base knowledge and applying systems thinking skills. This will allow them to further develop their level of thinking and employ the systems thinking paradigm, thus reinforcing key concepts to address the problem under investigation.

Figure 2

Individual's Progression from Linear Thinking to a S.T. Paradigm



Applications of the Model

Within the context of the colleges of agriculture, systems thinking and this developmental model (Figure 1) have applications for both faculty and students. Faculty need to consider the level of thinking that their students can accomplish and provide appropriate types of problems to help them learn the necessary content. Students can utilize this model to self-assess their development and tailor their learning experience based on their quadrant. Applying systems thinking skills should be incorporated into the curriculum via experiential learning to assist individual students in their progression of systems thinking growth. It is important to ensure that experiential learning supports individual student development and is not just focused on the whole-class level. This individual growth towards a systems thinking paradigm can be conceptualized in Figure 2.

Ebersbach et al. (2010) noted that linear thinking is found in young children before entering formal education. Therefore, there is an inborn tendency to utilize linear thinking from an early age. Greer (2010) noted that educational practices, such as behaviorism, within the educational system reinforce linear thinking, making it difficult for students to understand nonlinear situations. However, Ison (2008) notes that most individuals have some systems awareness level. This systems awareness, once realized, can serve as a foundation for transformational experiences designed to promote systems thinking skills. As individuals reflect on these experiences within systems thinking skills, they further develop their systems thinking competencies. Over time, this progression can grow into a systems thinking paradigm. For faculty in colleges of agriculture, a systems thinking paradigm can influence their teaching, research, and outreach/extension activities, further developing their systems thinking paradigm. Faculty and educators can utilize this progression model to intentionally design educational experiences that promote the development of systems thinking competencies, which will develop their level of thinking. The design of these educational opportunities and introduction of problems in the classroom must align with the student's current level of thinking and where they are on the steps of progression towards a systems thinking paradigm. An attempt to jump from linear thinking to a systems thinking paradigm will fail, but careful and deliberate experiences can result in higher levels of thinking.

Discussion and Recommendations

One of the most significant challenges that humanity faces will be supplying enough food for the growing population (West et al., 2014). However, increasing food production can have adverse effects by generating greenhouse gases which contribute to climate change (Mbow, 2019). West et al. (2014) note that a holistic approach is needed to address food security, environmental sustainability, and tradeoffs between each. However, this holistic approach involves complex cognitive abilities, contrary to people's natural inclination to approach problems from a linear perspective (de Langhe et al., 2017). The skills needed to transition beyond linear thinking are not well taught in higher education (Batie, 2008), as behaviorism is still the dominant pedagogical theory utilized in the classroom. A transition to systems thinking is needed. However, Ritchie (2017) noted that systems thinking has not been widely adopted in most U.S. school systems. Given the applied nature of the curricula, colleges of agriculture are positioned to be leaders in changing higher education.

Recommendations for Practice

Systems thinking is viewed as an important higher-order thinking skill needed to solve complex problems (Akcaoglu & Green, 2018). Yet, there has been a lack of progress within the agricultural sector regarding a shift towards systems thinking (Bawden, 1991). Deliberate incorporation of systems thinking into the curriculum in colleges of agriculture will be needed to develop the systems thinking competencies of students. However, this can only be accomplished if educators understand systems thinking and if they are well-trained in developing this ability among their students (Rosenkränzer et al., 2017). This understanding includes starting conversations about how agricultural disciplines define systems thinking and how individual faculty identify their own levels of thinking based on the continuum presented in Figure 1. Educators should be aware of their students' levels of thinking and structure their curriculum to guide them through appropriate types of problems. Using experiential learning activities can assist in the progression toward systems thinking. However, for this to occur, educators must have frank discussions about the feasibility of moving this theory into practice.

A discussion about which systems thinking competencies may be most appropriate to be taught in the classroom should be started. Furthermore, administrators in colleges of agriculture should assess how they are rewarding faculty teaching and what actions can be taken to promote systems thinking and experiential learning in the classrooms. Additionally, researchers should develop instruments to assess levels of thinking and systems thinking competencies that are compatible with classroom instruction so that administrators and faculty can assess current levels and measure changes.

Recommendations for Research

Batie (2008) suggests that further research is needed to understand systems thinking and its role in higher education. There is still little to no research regarding how college educators who self-identify as systems thinkers achieve this paradigm shift. An exploration of what experiences contributed to educators' development of systems awareness, their development of a systems thinking paradigm, and their development of systems thinking competencies. This information could be utilized to structure deliberate professional growth experiences to assist individual educators in moving along the growth model (Figure 1).

Further research should be conducted to determine if Checkland's (2005) delineation of hard and soft systems thinking represents a comprehensive picture of the different types of systems thinking. There should be further exploration of the continuum of levels of thinking (Figure 1) to determine if there are other typologies not captured by this model. Lastly, research should examine how educators' systems thinking typology manifests itself in their teaching and research practices. This information may be helpful in creating a starting point for open dialogue about systems thinking among the various educators within the field of agriculture.

References

Akcaoglu, M., & Green, L. S. (2018). Teaching systems thinking through game design. *Educational Technology Research and Development, 67*(1), 1–19. https://doi.org/10.1007/s11423-018-9596-8

Arnold, R. D., & Wade, J. P. (2015). A definition of systems thinking: A systems approach. *Procedia Computer Science, 44*(2015), 669–678. https://doi.org/10.1016/j.procs.2015.03.050

Baker, M., Lu, P., & Lamm, A. J. (2021). Assessing the dimensional validity and reliability of the University of Florida Critical Thinking Inventory (UFCTI) in Chinese: a confirmatory factor analysis. *Journal of International Agricultural and Extension Education, 28*(3), 41-56. https://doi.org/10.5191/jiaee.2021.28341

Baron, C., & Daniel-Allegro, B. (2020). About adopting a systemic approach to design connected embedded systems: A MOOC promoting systems thinking and systems engineering. *Systems Engineering, 23*(3), 261-280. https://doi.org/10.1002/sys.21513

Barton, J., & Haslett, T. (2007). Analysis, synthesis, systems thinking and the scientific method: Rediscovering the importance of open systems. *Systems Research and Behavioral Science, 24*(2), 143–155. https://doi.org/10.1002/sres.816

Batie, S. (2008). Wicked problems and applied economics. *American Journal of Agricultural Economics, 90*(5), 1176–1191. https://doi.org/10.1111/j.1467-8276.2008.01202.x

Bawden, R. J. (1991). Systems thinking and practice in agriculture. *Journal of Dairy Science, 74*(7), 2362–2373. https://doi.org/10.3168/jds.s0022-0302(91)78410-5

Bawden, R. J., Macadam, R. D., Packham, R. J., & Valentine, I. (1984). Systems thinking and practices in the education of agriculturalists. *Agricultural Systems, 13*(4), 205–225. https://doi.org/10.1016/0308-521x(84)90074-x

Bishop, K., & Eklöf, K. (2022). Boundary-crossing field research marks the way to evidence-based management of mercury in forest landscapes. *Journal of Geophysical Research: Biogeosciences, 127*(8), e2022JG007065. https://doi.org/10.1029/2022JG007065

Brundiers, K., Barth, M., Cebrián, G., Cohen, M., Diaz, L., Doucette-Remington, S., ... & Zint, M. (2021). Key competencies in sustainability in higher education—toward an agreed-upon reference framework. *Sustainability Science, 16*, 13–29. https://doi.org/10.1007/s11625-020-00838-2

Cabrera, D., Colosi, L., & Lobdell, C. (2008). Systems thinking. *Evaluation and Program Planning, 31(*3), 299–310. https://doi.org/10.1016/j.evalprogplan.2007.12.001

Camillus, J. C. (2008). Strategy as a wicked problem. *Harvard Business Review, 86*(5), 1–10. https://hbr.org/2008/05/strategy-as-a-wicked-problem

Caulfield, C. W., & Maj, S. P. (2001, October 7–10). *A case for systems thinking and system dynamics* [Paper presentation]. 2001 IEEE International Conference on Systems, Man and Cybernetics, Tucson, AZ, United States. https://doi.org/10.1109/ICSMC.2001.971932

Checkland P. B. (1981). *System thinking, system practice.* Wiley.

Checkland, P. B. (2005). *Systems thinking, systems practice: Includes a 30-year retrospective.* John Wiley & Sons.

Crawford, P., & Fink, W. (2020). *From academia to the workforce: Navigating persistence, ambiguity, change and conflict in the workplace.* Association of Public and Land-Grant Universities. https://www.aplu.org/library/from-academia-to-the-workforce-navigating-persistence-ambiguity-change-and-conflict-in-the-workplace/file

de Langhe, B., Puntoni, S., & Larrick, R. P. (2017). *Linear thinking in a nonlinear world. Harvard Business Review* (Vol. 2017). https://repub.eur.nl/pub/100448.

Dewey, J. (1938). Experience and education. Simon and Schuster.

Ebersbach, M., Van Dooren, W., Goudriaan, M. N., & Verschaffel, L. (2010). Discriminating non-linearity from linearity: Its cognitive foundations in five-year-olds. *Mathematical Thinking and Learning, 12(*1), 4–19. https://doi.org/10.1080/10986060903465780

Food and Agricultural Organization. (2018). *The future of food and Agriculture: Alternative Pathways to 2050*. https://www.fao.org/3/CA1553EN/ca1553en.pdf

Frensch, P.A., & Funke, J. (1995). *Complex problem solving: The European perspective.* Lawrence Erlbaum Associates Publishers.

Greer, B. (2010). Overview of the papers: Why is linear thinking so dominant?. *Mathematical Thinking and Learning, 12*(1), 109–115, https://doi.org/10.1080/10986060903465996

Hammond, D. (2002). Exploring the genealogy of systems thinking. *Systems Research and Behavioral Science, 19*(5), 429–439. https://doi.org/10.1002/sres.499

Hammond, D. (2005). Philosophical and ethical foundations of systems thinking. *Triple C: Communication, Capitalism & Critique, 3*(2), 20–27. https://doi.org/10.31269/vol3iss2pp20-27

Head, B. W., & Alford, J. (2013). Wicked problems: Implications for public policy and management. *Administration & Society, 47*(6), 711–739. https://doi.org/10.1177/0095399713481601

Hu, Y., Zhao, T., Guo, Y., Wang, M., Brachhold, K., Chu, C., ... & Zhang, Q. (2023). 100 essential questions for the future of agriculture. *Modern Agriculture, 1*(1), 4-12. https://doi.org/10.1002/moda.5

Hung, W. (2008). Enhancing systems-thinking skills with modelling. *British Journal of Educational Technology, 39*(6), 1099–1120. https://doi.org/10.1111/j.1467-8535.2007.00791.x

Ison, R. L. (2008). Systems thinking and practice for action research. In P. Reason & H. Bradbury (Eds.), *The Sage handbook of action research participative inquiry and practice* (2nd ed., pp. 139–158). Sage Publications.

Jackson, J. L., & White, P. (2020). Beyond behaviorism: Engaging students in the age of neoliberalism. In L. Parson & C. C. Ozaki (Eds.), *Teaching and learning for social justice and equity in higher education: Foundations* (pp. 39–52). Springer Nature. https://doi.org/10.1007/978-3-030-44939-1

Kali, Y., Orion, N., & Eylon, B.S. (2003). Effect of knowledge integration activities on students' perception of the earth's crust as a cyclic system. *Journal of Research in Science Teaching, 40*(6), 545–565. https://doi.org/10.1002/tea.10096

Kereluik, K., Mishra, P., Fahnoe, C., & Terry, L. (2013). What knowledge is of most worth: Teacher knowledge for 21st century learning. *Journal of Digital Learning in Teacher Education, 29*(4), 127–140. https://doi.org/10.1080/21532974.2013.10784716

Klerkx, L., & Begemann, S. (2020). Supporting food systems transformation: The what, why, who, where and how of mission-oriented agricultural innovation systems. *Agricultural Systems, 184,* 102901. https://doi.org/10.1016/j.agsy.2020.102901

Knight, J. (2004). Internationalization remodeled: Definition, approaches, and rationales. *Journal of Studies in International Education, 8*(1), 5–31. https://doi.org/10.1177/1028315303260832

Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Prentice Hall.

Lattuca, L. (2003). Creating interdisciplinarity: Grounded definitions from the college and university faculty. *History of Intellectual culture, 3*(1). https://journalhosting.ucalgary.ca/index.php/hic/article/view/68806

Lavi, R., Tal, M., & Dori, Y. J. (2021). Perceptions of STEM alumni and students on developing 21st century skills through methods of teaching and learning. *Studies in Educational Evaluation, 70*, 101002. https://doi.org/10.1016/j.stueduc.2021.101002

Leischow, S. J., & Milstein, B. (2006). Systems thinking and modeling for public health practice. *American Journal of Public Health, 96*(3), 403–405. https://doi.org/10.2105/AJPH.2005.082842

Mbow, C., Rosenzweig, C., Barioni, L.G., Benton, T.G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M.G., Sapkota, T., Tubiello, F.N., & Xu,Y. (2019). Food security. In P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (Eds.), (2019). *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. https://doi.org/10.1017/9781009157988.007

McGuire, W. J. (2017). Theory orientated research in natural settings: The best of both worlds for social psychology. *In Interdisciplinary relationships in the social sciences* (pp. 21-51). Routledge.

McKim, A., & McKendree, R. (2020). Metacognition, systems thinking, and problem-solving ability in school-based agriculture, food, and natural resources education. *Advancements in Agricultural Development, 1*(1), 38–47. https://doi.org/10.37433/aad.v1i1.21

Meadows, D. H. (2008). *Thinking in systems: A primer.* Chelsea Green Publishing.

Mulej, M., Potocan, V., Zenko, Z., Kajzer, S., Ursic, D., Knez-Riedl, J., Lynn, M., & Ovsenik, J. (2004). How to restore Bertalanffian systems thinking. *Kybernetes, 33(*1), 48–61. https://doi.org/10.1108/03684920410514346

National Research Council. (2009). *Transforming agricultural education for a changing world.* The National Academies Press. https://doi.org/10.17226/12602

Palmadessa, A. L. (2020). *Higher education divided: National expectations and the bifurcation of purpose and national identity, 1946-2016*. Palgrave Macmillian. https://doi.org/10.1007/978-3-030-50746-6_1s

Plate, R. (2010). Assessing individuals' individuals' understanding of nonlinear causal structures in complex systems. *System Dynamics Review, 26*(1), 19–33. https://doi.org/10.1002/sdr.432

Randle, J. M., & Stroink, M. L. (2018). The development and initial validation of the paradigm of systems thinking. *Systems Research and Behavioral Science, 35*(6), 645–657. https://doi.org/10.1002/sres.2508

Riess, W., & Mischo, C. (2009). Promoting systems thinking through biology lessons. *International Journal of Science Education, 32*(6), 705–725. https://doi.org/10.1080/09500690902769946

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences, 4*(2), 155–169. https://doi.org/10.1007/BF01405730

Ritchie, T. A. (2017). *Developing and measuring systems thinking skills in students and teachers* [Unpublished doctoral dissertation]. The University of Florida

Roberts, N. (2001). Coping with wicked problems: The case of Afghanistan. In L. Jones, J. Guthrie & P. Steane (Eds.), *International Public management reform: Lessons from experience* (pp 353–375). Emerald Group Publishing.

Roberts, T. G. (2006). A philosophical examination of experiential learning theory for agricultural educators. *Journal of Agricultural Education, 47*(1), 17–29. https://doi.org/10.5032/jae.2006.01017

Rosenkränzer, F., Hörsch, C., Schuler, S., & Riess, W. (2017). Student teachers' pedagogical content knowledge for teaching systems thinking: Effects of different interventions. *International Journal of Science Education, 39*(14), 1932–1951. https://doi.org/10.1080/09500693.2017.1362603

Rountree, J. H. (1977). Systems thinking—Some fundamental aspects. *Agricultural Systems, 2(*4), 247–254. https://doi.org/10.1016/0308-521x(77)90019-1

Senge, P. (1990). *The fifth discipline, the art and practice of the learning organization.* Doubleday.

Stalter, A. M., Phillips, J. M., Ruggiero, J. S., Scardaville, D. L., Merriam, D., Dolansky, M. A., Goldschmidt, K. A., Wiggs, C. M., & Winegardner, S. (2016). A concept analysis of systems thinking. *Nursing Forum, 52*(4), 323–330. https://doi.org/10.1111/nuf.12196

Trochim, W. M., Cabrera, D. A., Milstein, B., Gallagher, R. S., & Leischow, S. J. (2006). Practical challenges of systems thinking and modeling in public health. *American Journal of Public Health, 96*(3), 538–546. https://doi.org/10.2105/AJPH.2005.066001

von Bertalanffy, L. (1972). The history and status of general systems theory. *Academy of Management Journal, 15*(4), 407–426. https://doi.org/10.5465/255139

West, P. C., Gerber, J. S., Engstrom, P. M., Mueller, N. D., Brauman, K. A., Calrson, K. M., Cassidy, E. S., Johnston, M., MacDonald, G. K., Ray, D. K., Siebert, S. (2014). Leverage points from improving global food security and the environment. *Science, 345*(6194), 325–328. https://doi.org/10.1126/science.1246067

Whyte, K. P., & Thompson, P. B. (2011). Ideas for how to take wicked problems seriously. *Journal of Agricultural and Environmental Ethics, 25*, 441–445. https://doi.org/10.1007/s10806-011-9348-9

Zexian, Y., & Xuhui, Y. (2010). A revolution in the field of systems thinking—a review of Checkland's system thinking. *Systems Research and Behavioral Science, 27*(2), 140–155. https://doi.org/10.1002/sres.1021