Systems Thinking Concepts and Applications for Engineering Leadership Development

Dr. B. Michael Aucoin, Leading Edge Management, LLC

B. Michael Aucoin is President of Leading Edge Management, LLC and Electrical Expert, Inc. in College Station, Texas. He earned a B.S. in Engineering from the University of New Orleans, an M.Engr. in Electrical Engineering and a D.Engr. from Texas A&M University, and an M.A. in Organizational Leadership from Gonzaga University. Dr. Aucoin has performed research and teaching in academia and has worked in large and small organizations. He served on a Mishap Investigation Board with the NASA Johnson Space Center. He received the IEEE Third Millennium Award, and projects he helped lead received the NSPE Outstanding Engineering Achievement Award and R&D 100 Award. He is a Registered Professional Engineer and earned the Project Management Professional Certification.

Prof. Dennis Arthur Conners

©American Society for Engineering Education, 2019

Systems Thinking Concepts and Applications for Engineering Leadership Development

Abstract

Many important and worthwhile initiatives in engineering leadership development focus on the development of communication, social, and business skills among engineers [1]. The objective of this paper is to explore and demonstrate the value of leveraging engineers' deep knowledge of systems in a more deliberate and explicit way in leadership development. These skills are particularly valuable for analyzing, improving, and optimizing organizational processes.

Concepts in systems thinking as applied to organizational behavior are often framed visually in the form of an iceberg. Above the surface, we see events, but beneath the surface there are typically patterns of events that are sustained from beneath by organizational structures, which in turn are established by mental models. Exploration of these latter three areas offer leverage opportunities for significant improvements in behaviors [2], [3]. Such exploration is facilitated through various systems thinking tools, especially when used in groups. Three well-established tools are presented: behavior over time, causal loop [4], and process flow [5] diagrams. Such tools are comfortable extensions or analogs to similar tools used in engineering applications.

These three tools are explained, and simple examples are given. The tools have been in use in an Organizational Behavior and Theory course for the M.A. degree in Organizational Leadership at Gonzaga University. Students from varied disciplines, including engineering, enroll in this program. The content for this topic consists of: 1) readings to help students with the concepts, 2) application of these tools to fictitious problems as well as real issues that they face, e.g. in their jobs, and 3) reflection on the tools through journaling. Student evaluations and feedback have demonstrated the power of these tools for significant improvements and even transformation in organizational behavior. Future work is needed to potentially isolate effects of such skill development for engineers as compared with other populations, and to gather data on the relative benefits of this approach as compared with others.

Given the extensive systems skills that engineers have, such systems thinking tools can provide a powerful way for them to exercise leadership through improvement and optimization of organizational behavior. Such an approach can complement and augment the prevalent initiatives for communication, social, and business skill development in engineering leadership.

Introduction

There is a growing need for the development of leadership competencies in engineers. This need has led to the ABET [6] accreditation requirement that undergraduate engineering programs demonstrate the attainment of student outcomes that include leadership in a team setting. Given this requirement, there presents the important research problem of determining how engineering educators can satisfy this criterion within curricula that are already heavily loaded, and with faculty who may not have relevant knowledge and skill in teaching about leadership. It is worthwhile to consider how to use the existing engineering skillset as a bridge to important leadership skills as one means to help both students and faculty achieve valuable leadership competencies in a reasonable amount of time. The purpose of this paper is to explore the application of one foundational engineering competency, systems thinking, to the development of leadership skills for students in an engineering program. Specifically, this paper presents experiences and outcomes of teaching systems thinking in an Organizational Leadership course to help investigate whether its pedagogical approach may be worthwhile for engineering students. This paper includes a review of relevant literature, background and experiences with the subject course, a qualitative analysis of student comments on the systems thinking content of the course, discussion, implications and recommendations for future research, and a conclusion.

Literature Review

The literature review for our exploration includes the following topics: 1) the importance of engineering leadership development, 2) approaches to engineering leadership development, 3) connecting engineering and leadership, 4) the organization as a system, 5) systems thinking in organizational leadership, and 6) connecting systems thinking and leadership development in education.

Importance of Engineering Leadership Development

As a discipline, engineering leadership is rapidly growing in interest as both industry and academia recognize the inherent and expanding need for the practice of leadership in the profession. The prototypical engineer spends the majority of his or her career either in a team setting or in managing and leading others [7], and companies signal to universities to produce graduates with leadership skills [8]. Responding to this demand, ABET [6] is requiring that undergraduate engineering programs demonstrate attainment of student outcomes that include leadership in a team setting. It remains to be seen how universities will demonstrate leadership competencies in student outcomes [9] and how well these educational experiences will translate into valued workplace behaviors. Despite a purported high level of interest, leadership development in industry is often hit or miss, and on-the-job-training in leadership is the norm [10]. Indeed, none of the engineering graduates surveyed by Watson [11] mentioned any workplace training in the area of leadership. Kumar and Hsaio [12] cleverly summarized that engineers are forced to learn “soft skills the hard way.”

Approaches to Engineering Leadership Development

A significant challenge in developing engineering leaders stems from ambiguities in defining engineering leadership. In their review of eleven university engineering leadership programs, Paul and Falls [13] identified 72 different competencies, while Kumar and Hsaio [12] reported several hundred definitions for the term “leader.” Notwithstanding these many possible manifestations, much of the work of practicing engineers depends on teamwork and communication [14], suggesting a particular area of focus for leadership practice.

In their study, Rottmann, Sacks, and Reeve [15] determined that engineers valued three characteristics in their leaders: 1) technical competence, 2) facilitation of collaborative optimization, and 3) organizational innovation. The researchers noted that these characteristics are indicative of servant leaders who have technical expertise. Of this triad of competencies, one could say that the technical element provides the ticket to entry into engineering leadership and sets the context for its practice.

Many important and worthwhile initiatives in engineering leadership development are focused on the development of communication, social, and business skills among engineers (e.g. [1]). To restate, this area of development is oriented to predominantly non-engineering skills. Often, improvement in such skills is presented in a manner that is disconnected from engineering practice; when this is the case, the benefits may suffer [16]. Engineers often come to believe that leadership is separate from and *not* engineering [15].

Connecting Engineering and Leadership

It is worthwhile to consider aspects of leadership that are similar to and congruent to the practice of engineering and skills that engineers already possess [17]. Identifying similar skills in both practices can accelerate leadership development for engineers and make leadership more attractive to them [18]. Indeed, the Rottmann, et al. [15] findings provide important clues toward this end. Two of their three competencies used the terms *optimization* and *innovation*, terms that are integral parts of engineering practice. In describing the foundation of the practice, Koen [19, p. 10] defines the *engineering method* as, "the strategy for causing the best change in a poorly understood or uncertain situation within the available resources." One could succinctly use the words *optimization* or *innovation* in place of the Koen definition. Furthermore, change the context or application and this portrayal of the engineering method is equally meaningful to the practice of leadership! In a nutshell, we have identified solid and robust common ground between engineering and leadership.

To follow this theme in more detail, let us consider the Lucas and Hanson [20] list of six elements that they call *engineering habits of mind.* In other words, the following are six fundamental skill sets of engineering: 1) systems thinking, 2) problem finding, 3) visualizing, 4) improving, 5) creative problem solving, and 6) adapting. Again, it is no stretch to conclude that these six skills are as applicable in leadership as they are in engineering albeit in potentially different ways.

The difference can be cast in the types of systems with which each discipline works. Engineers commonly work with physical or engineered systems, while the work of leaders is in human or organizational systems. If an engineer can come to see a group, team, or organization as a system, there is the potential to use his or her deep reservoir of systems thinking skills in the practice of leadership. Engineering leadership literature does acknowledge systems thinking, yet such references are few and typically made in passing (e.g., [10]). In a few cases, (e.g., [21]) there is a deeper treatment, but the focus is on technology or the engineered system and less on understanding and optimizing the function of social system. An important exception to this theme has been explored in Engineers Without Borders as will be explained later in this paper.

We suggest that the ability of engineers to think in systems terms promotes their leadership skills in team and organizational settings. Better development of this thread is likely to provide substantial benefits in engineering leadership development. Such an approach can complement and augment the prevalent initiatives for communication, social, and business skill development in engineering leadership.

While Aucoin [22] explores multiple commonalities of engineering and leadership in more depth and breadth, this paper focuses on the common skill of systems thinking. Specifically, practice in systems thinking has been shown to provide practitioners deep insights into organizational behavior; these insights can illuminate leverage points for interventions that can *optimize* and *innovate* the organization. It is worthwhile to explore how to leverage engineers' deep knowledge of systems in a more conscious and deliberate way in the practice of engineering leadership, particularly in analyzing, improving, optimizing, and innovating organizational processes.

The Organization as a System

A system is "a group of interacting, interrelated, or interdependent components that form a complex and unified whole" [4, p. 2]. Systems are scalable: each may have a purpose as part of a larger system and can be composed of multiple subsystems. Similarly, a system can exist in and interact with its environment, which itself can be considered a system. Given these features, an organization can be considered just such a system [23]. A team or department is a system unto itself, but it is also part of a singular organizational system, which is part of an environment or other system, such as society.

The engineering design process often involves the development of models to represent physical systems that will be built [24]. In many cases, we may visually represent various factors to help with deriving meaning and insights. For example, we may graph changes in parameters or variables of components or subsystems over time; we may also diagram logical relationships or stages in a process. In these cases, and others, the visualizations help with our understanding and mental models of what is happening in a physical or engineered system.

With the vast majority of systems in the engineering design process, we deal with physical properties and engineered systems that follow deterministic rules. Designers decide how the system will work based on known and reliable principles. But while a social system does follow established principles, such a system is not deterministic. The components of the system, i.e. human beings as individuals or collectives, have the ability to think, feel, and change themselves. They have the ability to communicate, coordinate, innovate, and self organize. These are fundamental and critical differences from an engineered system.

These considerations must guide how engineers use systems thinking in an organizational context. Viewing an organization as a system is establishing a mental model of it. As Senge [3] describes, mental models hold our fundamental perceptions, assumptions, expectations, beliefs, paradigms, and narratives about how the world works and the actions we should take in it. In essence these are internal images, pictures, and stories; we may even say that they take the form of mental movie scenes complete with actors and scripts. In a social system, all elements have the ability to think and act; we call them *actors.* When I consider my own organization, I am an actor within the system: I am influenced by it, and I influence it. Here is another critical difference between engineered and organizational systems. In the former, the engineer as designer is separate from the system; in the latter, the engineer is immersed in and inseparable from the system.

Systems Thinking in Organizational Leadership

The social interactions within an organization are complex. Yet those who manage organizations often attempt to understand and control behaviors in simplistic and deterministic ways. This approach is understandable; it provides the illusion that we can control complex and ambiguous realities. But taking the simplistic approach to organizational improvement typically does not scratch the surface of behaviors. There are hidden ways in which those realities elude understanding. A deeper understanding of complexities and dynamics can offer ways to accomplish greater control, even if we never have total control.

Chen and Kanfer [25] highlighted the application of systems to the understanding of organizational teams, particularly regarding motivation and leadership. The value of systems thinking as a tool in leadership has been demonstrated in engineering [26] and in the more general leadership literature [2], [3], [27], [28]. Behaviors are commonly supported by structures and beliefs or paradigms. As with engineered systems, being able to see and act upon structural and behavioral systems in an organization can permit dramatic improvements. A helpful way to introduce these concepts is to consider the iceberg model. We see a single event as the visible tip of the iceberg, but factors that have led to the event often involve structures and beliefs that are initially hidden from sight. Similar events repeat in a pattern. Patterns of behavior are typically initiated and sustained by structures, such as how groups are organized, or policies are enacted. Finally, mental models, including assumptions, and beliefs, drive the conscious or unconscious establishment of structures. Because patterns, structures, and mental models are initially hidden, we must deliberately explore for them. Organizational culture is a manifestation of our mental models. As we go deeper into the iceberg, we develop increasing leverage over the issue.

Table 1 provides a guide for how to navigate the "iceberg" in systems thinking. Each row offers insights on the relevant characteristics of that level of the iceberg, as well as guidance on how to make sense of it and to gain leverage on the issue at hand. This table provides a useful quick reference to stimulate individual or team efforts.

Mastering systems thinking involves seeing patterns where others only see events. Seeing such patterns enables us to intervene beneficially in a systemic manner rather than only react to correct an immediate issue. The area of greatest leverage is in the mental model or paradigm [2], and to gain this leverage, we must examine our basic assumptions. Improving systems results in high leverage change whereas correcting a single event may offer only low leverage and temporary improvement [3].

As with engineered systems, visualization of features of the system can illuminate information from which we can derive important meaning. This medium can be particularly helpful in understanding organizational behaviors, those that are intended, and those that we actually observe. In doing so, it is important to remember that there is no one right way to describe a system, a truism that is particularly relevant to social systems. Each actor in an organization is unique, and therefore there may be many different perceptions of reality as well as different ideas about future direction. When nurtured well in collaboration, this diversity can work powerfully for the good of the group. The tools we describe later in this paper facilitate such collaboration.

	Action Mode	Time Orientation	Way of Perceiving	Questions to Ask
Events	React	Present	Witness event	What is the fastest way to correct this event?
Patterns	Adapt	|	Track patterns with behavior-over-time graphs	What trends of events seem to recur?
Structure	Create change	|	Behavior-over-time graphs, casual loop diagrams, and other tools	What structures are causing these patterns?
Mental Models	Intervene Systemically	Future	Identify and explore assumptions and paradigms	Are there more effective paradigms?

Table 1. Levels of understanding in systems thinking, Adapted from [5, p. 9].

Connecting Systems Thinking and Leadership Development in Education

While it has been established that engineers have a solid understanding of systems, educators have struggled with how to apply and assess systems thinking skills particularly in engineering curricula [29]. Nevertheless, some relevant findings have demonstrated the connection between gaining competence in systems thinking and leadership development, whether in different disciplines or more specifically in engineering.

Kordova and Frank [30] reported that the ability to demonstrate systems thinking skills can at least in part be an acquired competency. Gero [31] demonstrated improvement of systems thinking skills in freshman engineering students through teaching. Andenoro, Sowcik, and Balser [32] specifically connect the application of systems thinking with the development of leadership competencies. In an undergraduate course composed of interdisciplinary students studying global social problems, they reported improved systems thinking capabilities for 76% of students, and increased capacity for adaptive leadership for 87% of students. The authors summarized the importance that students gave to this connection of systems thinking and leadership: "they provided that if they do not consider the systems impacted by a given problem, they are at a severe disadvantage for mitigating that problem" [32, p. 12].

Burleson, Butcher, Goodwin, Sharp, and Ruder [33] established the growing need for engineers to accommodate complex relationships between technological systems and the social systems in which they are used. Crawley, Malmqvist, Östlund, and Brodeur [34] emphasized the use of systems thinking skills in engineering, including societal and other concerns, with implications for leadership development. In a similar manner, systems thinking has been used to help improve the success of projects executed for Engineers Without Borders (EWB). This organization provides infrastructure systems in developing areas using teams composed of engineering students [35]. A critical factor in the success of these projects concerns the complex relationships among the engineered systems, the culture of the local community, available resources, complementary agency projects, and governmental environment [36]. Walters, Greiner, O'Morrow, and Amadei [29] and Pugel and Walters [37] implemented a methodology for teaching systems thinking skills to students working on EWB projects; their training included the use of causal loop diagrams (CLDs), which are explained later in this paper. These authors reported a significant improvement in the capacity for students in appreciating the complexity of interactive factors on EWB projects and in identifying the most important factors for project success. If one accepts the reasonable predicate that attending to critical success factors on a project is an important way to exercise leadership and ensure better outcomes (e.g. [38]), then these researchers have demonstrated a solid connection between the use of CLDs and leadership development.

The role of analyzing systems is to promote agency [39], that is to act upon the results of the analysis and in so doing improve the situation. A fundamental element of leadership is action. Senge underscores this theme with the choice of the title in one of his book sections, "How Our Actions Create Our Reality… And How We Can Change It" [3, loc. 145].

Course Overview

Gonzaga University in Spokane, Washington, USA offers an online Master of Arts degree in Organizational Leadership (ORGL). One of the core courses for this degree is Organizational Theory and Behavior (ORGL 615). This course design incorporates a heavy emphasis on a systems thinking approach to leadership and improvement of organizational behavior. Among other course objectives, ORGL 615 helps students understand the dynamics of teams and ways to use them more effectively. ORGL 615 is delivered in an eight-week session. Students in the ORGL program are commonly already into their careers for five, ten, or more years. They work in for-profit, non-profit, and governmental organizations. They enroll to grow in competencies needed for leading these organizations to better outcomes.

The systems thinking content relies heavily on two texts: Senge [3] and Anderson and Johnson [4]. Senge's *The Fifth Discipline* provides the solid conceptual foundation for seeing systemic effects in human interactions. Perhaps more importantly, it places a mirror squarely in sight so that we can see how our own beliefs dramatically affect our understanding of our experiences and of the world and how it "should" work. Anderson and Johnson's *Systems Thinking Basics* provides the language and tools for expressing our observations of organizational behaviors in visual form. A third resource is the video of Wujec's [5] TED Talk, *Got a Wicked Problem? First, Tell Me How You Make Toast.* In this entertaining video, Wujec presents a methodology for teaching teams to collectively understand and improve their organizational processes by sketching them; his starting point is inviting individuals to sketch how to make toast. Together, these three resources use the medium of graphs, diagrams, and images, because they readily promote individual and collective understanding, dialogue, and decision making on how we collaborate and how we might improve it. Many of the assignments in the course involve practice with these systems thinking diagrams and analysis of them for a case study published by Harvard Business Review, *EU Design* [40].

An important method for students to learn and practice systems thinking within the course is work in a Systems Thinking Journal. There are four installments in the journal; each typically has a specific activity combined with reflection on the activity. The activity may involve visual representation of a starter question, e.g. observed behavior in a fictitious organization from the Anderson and Johnson text, or the EU Design case. The reflective part of the journal asks students to analyze what they have shown in visual form based on another starter question. In their reflections, students are expected to demonstrate critical thinking, analysis, and synthesis that are supported by course concepts, personal experiences, and professional practice. The purpose of the journal is to help students learn and practice the development of meaning in organizational behaviors and self-assess in that endeavor.

This point is critical in an endeavor that is oriented to leadership development. Understanding organizations as they are and working on their improvement is all about deriving meaning through inquiry and advocacy. We must do so as individuals, and we must do so collectively. Doing so well truly requires genuine leadership. In the discipline of organizational leadership, the methodology of systems thinking has been established for several decades as a solid way to develop individual and collective meaning. It can be a vehicle for powerful insights that can illuminate the way forward.

Tools for Collaboration in Systems Thinking

In ORGL 615, students practice with and derive meaning from three systems thinking tools. These tools are the behavior over time (BOT) graph, the CLD, and the process diagram. While it is not specifically related to the BOT and CLD techniques, the Wujec method for creating process diagrams is often very helpful when ambiguities and different perspectives on what is being done and how it is being done can affect an issue. We will now describe the basics of these tools and how they might be used to understand organizational behavior as a way to promote good collaboration and innovation of that behavior. After introducing them, we will provide examples to illustrate their use. It is important to emphasize that while these tools certainly assist with individual understanding, their real power is when used in a group to promote dialogue, collaboration, problem solving, and process innovation. This perspective cannot be overemphasized; all the actors in a group have perceptions, insights, and ideas that are critical to healthy collaboration.

A good starting point for applying these three tools is to identify an issue that may appear to be systemic. Anderson and Johnson [4] note that there may be a systemic problem when: 1) the problem is chronic and recurs, and there is a history associated with it, and 2) attempts to solve the problem did not work, or only gave temporary relief, and 3) there is no obvious reason for the pattern associated with the problem.

The BOT graph simply involves taking one or more relevant variables and sketching how they change over time. BOT graphs are familiar in engineering applications and are already commonly used in organizations some form, e.g. a graph of sales or profit by month. In systems thinking, we expand on the concept to more liberally consider any variable that might illuminate organizational structures and mental models. We also consider variables that may not be explicitly measurable but can nevertheless be described by trend. One such variable may be employee morale. It might be interesting to visualize employee morale and monthly profit on the same graph; doing so may reveal some relationships that would otherwise remain hidden from view. Indeed, for typical organizational issues, the best use of BOTs is as a single graph to display several relevant variables. Then we develop theories about how the behaviors of the graph's variables may be related. Doing so may lead to the addition of more variables or additional BOT graphs. After some iteration, our theories lead us to the second tool.

The transition to developing a causal loop diagram is where we start to consider the systemic structure that results in the behavior of the BOT variables. CLDs incorporate several components: 1) feedback loops that reinforce or balance processes, 2) cause and effect relationships among variables, and 3) delays. These are the ingredients that give rise to structures. Here again, engineers are familiar with these three concepts as they are applied to physical or engineered systems. In a social system, structures may be physical in form, or they may not be. For example, a vacation and holiday policy in an organization creates a social structure. A CLD illustrates two or more variables that are connected by links in the form of arrows to show cause-and-effect relationships between the variables. A series of two or more of these links are formed in a closed circle to represent a feedback loop. Whenever there is a link, we identify if a change in the cause creates the same or opposite change in the result. The former is indicated by an "S" next to the arrow, and the latter an "O." It is common for there to be multiple connected and interacting loops for any problem in a real organization. Indeed, one can often come up with very complicated CLDs to adequately capture the fullness of an issue.

Wujec's exercise begins by asking participants in a group to each on their own sketch how to make toast. It is a simple exercise that anyone can do. In the next step, they share their sketches with the group. The sharing stage results in laughter. Some people draw one or two steps, while others may draw an elaborate process that involves a trip to the grocery or growing wheat. The point of the exercise is twofold. First it dramatically demonstrates the diversity of ways in which people may describe a "simple" process. This is an important realization when working in a team. Second, the methodology provides a great medium for team members to understand their work process, solve problems involving it, and to ultimately optimize and innovate it. The "drawing toast" method works hand-in-hand with BOTs and CLDs.

Examples of Systems Thinking Diagrams and Analysis

In this section, we present some examples of the three visual systems thinking tools described above. The first examples shown are simple ones to illustrate concepts and demonstrate some of the initial work students do with these tools. While the basic tools can be readily grasped in a short time, in depth learning and practice take participants into complexities of work in groups. Students in this course take several weeks to go deeply into the organizational dynamics that systems thinking tools are capable of revealing. The deeper levels of analysis of complex diagrams provide the areas of greatest leverage in organizational dynamics. A more complex CLD is also provided to demonstrate how the tools can be used in their ultimate forms. In all cases, remember that there is no one right way to draw these graphs and diagrams.

Let us start with a familiar scenario, a simple example of taking a shower [3]. I want to change the temperature of the water coming from the sprayer in my shower, but there is a considerable delay between the time I turn faucet and the time the water temperature changes. It is far more challenging to achieve a comfortable water temperature when the delay is considerable, say 30 seconds, than when it is only a couple of seconds. It may take several cycles of attempts on my part to find the faucet position that gives water at my desired temperature. Figure 1 shows a composite BOT sketch of the shower faucet position and the water temperature.

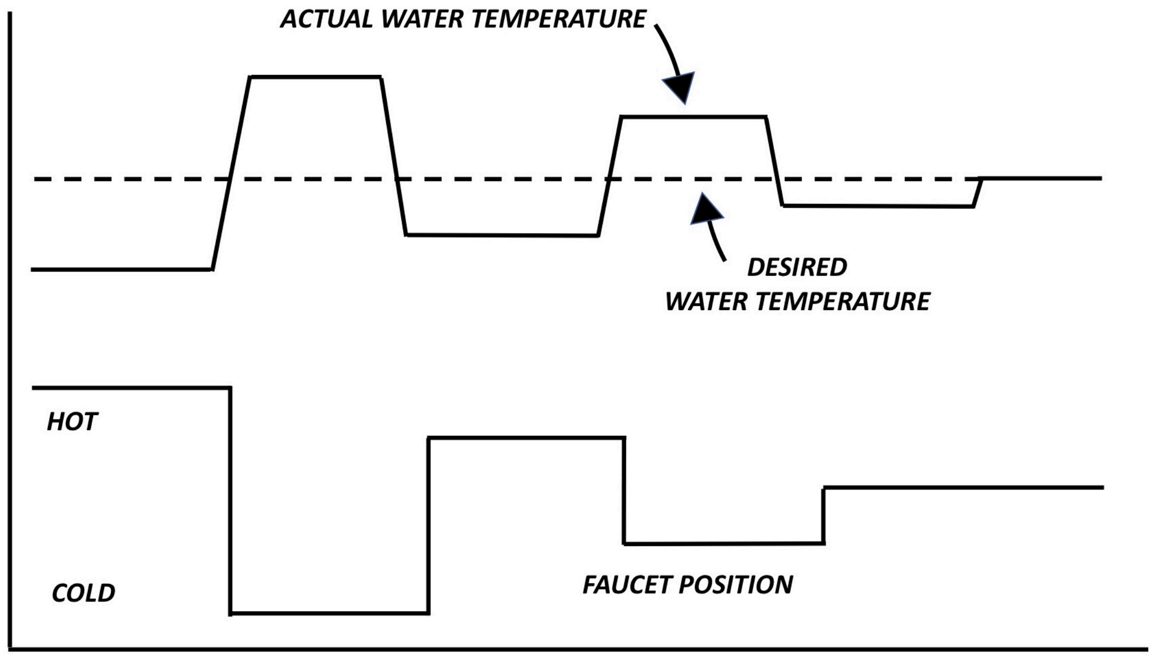

Figure 1. BOT of achieving desired temperature of shower water.

Figure 2 presents a possible CLD of this shower control scenario. It shows the variable "difference from desired temperature" that is based on the reference "desired water temperature." I adjust the faucet position based on the difference variable, and this position then produces an effect in the actual water temperature, but only after a delay. The loop is closed by the link from the actual water temperature back to the difference variable. While the BOT shows that I eventually reach my desired water temperature, the dashed "temptation" link in the CLD from the delay back to the faucet position represents an important potential issue that can illustrate the power of visualization of systems behavior as follows.

This everyday example is indicative of a common behavior in systems. Whenever there is feedback in a system, it is common for there to be a delay in the feedback loop; the longer the delay, the more challenging it is to make sense of achieving control over desired outcomes. A lengthy delay may lead us to think that our control action has had no effect. We become tempted to amplify or escalate the control action, potentially leading to unintended or even undesirable results. In the shower, successive turns of the faucet toward "hot" before the delay is complete will eventually produce a spray that is scalding.

This simple example of the shower control is illustrative of what can be done with BOTs and CLDs. This example also is representative of a system *archetype*, or a common systems "story." Each archetype represents a systemic structure that supports and sustains a pattern. For example, Anderson and Johnson [4] have identified eight such archetypes while Senge [3] has ten.

Knowledge of the toolkit of such archetypes is very useful to practitioners for understanding the common “stories” that are present in social systems and providing leadership guidance for useful intervention strategies for improvements.

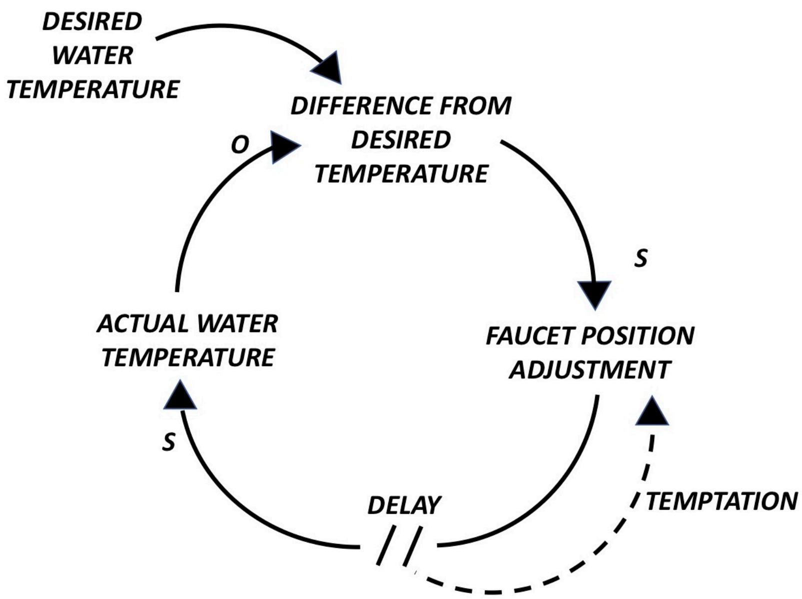

Figure 2. CLD of achieving desired temperature of shower water.

Figure 3 is a more complicated CLD that is offered here without commentary simply to illustrate that it may require numerous interacting loops to fully capture real organizational characteristics and issues. When considering these, it is helpful to also make use of the third tool, the process diagram. An example of this tool is presented in Figure 4, in this case, a sketch of the simple process of “making toast.” Wujec’s methodology is very similar to flowcharting, which is commonly used in engineering applications, however, the pictorial sketches provide for more familiarity for a broader audience. What starts as a simple tool as a starting point can lead groups and organizations to produce complex sketches to fully capture their processes. In his video, Wujec tells about a three-day effort by the executive team of one organization to fully describe the processes across its business. As he explains, this process visualization effort recaptured $50 million of revenue and moved the company from a D rating to an A rating among its customers.

With a small and simple system such as the shower, it is conceivable to readily recognize the control and response issues involved. However, such features in more complex or larger systems often remain hidden without in-depth exploration. Furthermore, in an organizational setting, each of us may initially only have a limited picture of what is happening. Here, when used in collaboration, the systems thinking tools enable groups of individuals to collectively see the big picture. Many troublesome issues, e.g. lengthy delays, in organizational processes are structural in nature. Without knowledge of systems thinking, it is difficult for individual actors to know to look for such a structure. Instead, actors experience frustration that is blamed on a variety of unrelated or non-existent factors, e.g. poor motivation on the part of others. Unhealthy conflict can result and mislead us on what is really happening.

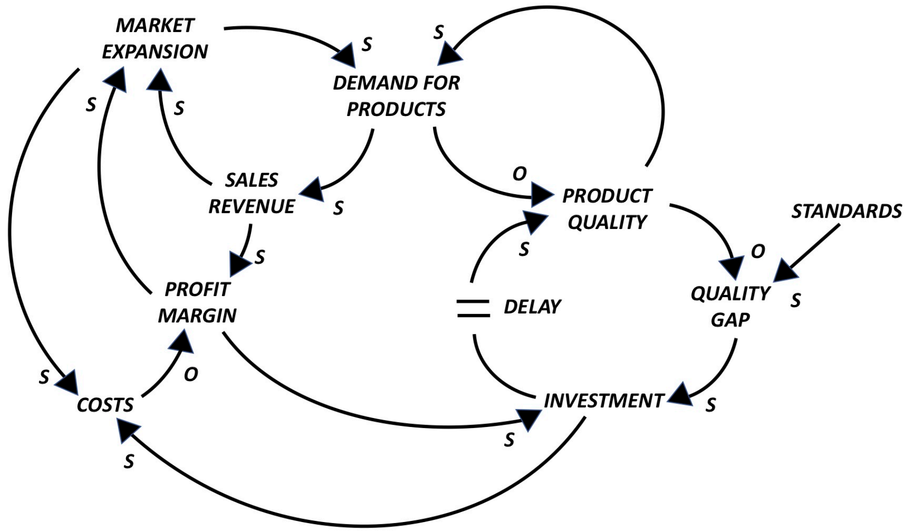

Figure 3. Example of more complex CLD. Adapted from [4, p. 85].

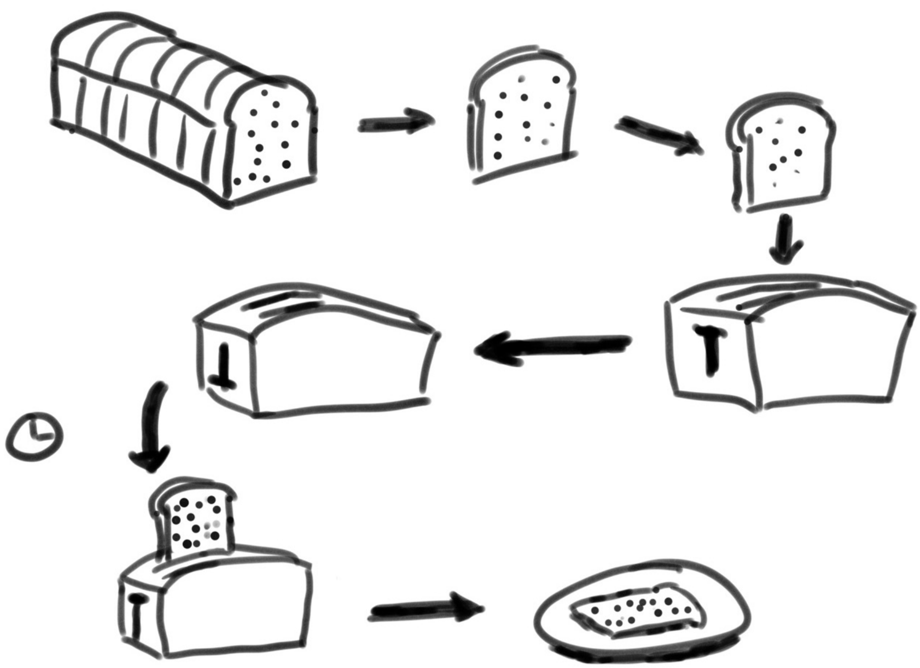

Figure 4. Example of process diagram for “making toast.”

As much effort and leadership as it may take to get a grasp of the big picture of a complex organizational issue, in many cases the knotty challenges of leadership have just started because we are only at the pattern stage. Remember that patterns are kept in place by structures, and these arise and sustain for reasons. Often actors come to depend on these structures and may resist changing them. Additionally, few people in organizations are encouraged to think in this manner. Indeed, organizations often *discourage* such thinking [3]. This result occurs in part because different departments in large organizations will defend their own turf rather than show interest in solving cross-disciplinary issues. This is what is happening when people complain about impenetrable "silos" in their organizations. The entrenched, unconscious mental model is that silos are a given part of organizational life; it is far easier and less threatening to correct symptoms than the underlying factors that cause the symptoms. People in organizations "trap" themselves into defensive routines that insulate structures and mental models from examination. Many managers feel threatened by the sort of group inquiry and analysis that comes with systems thinking [41].

While this may sound discouraging, it is here that true team and organizational innovation starts. Good leaders help actors see deeply what is happening, and then help these actors on a return to fundamental organizing principles that cut through defensive behaviors. Reconnecting (or perhaps connecting for the first time) with organizational purpose, mission, vision, and goals enables individuals and groups to move beyond defensive behaviors to profound and deep improvements.

Course Impact on Students and Their Leadership

It is worthwhile to consider how students react to the immersion in systems thinking and their perceptions of its usefulness. For this purpose, we used a qualitative approach to analysis of student comments [42], [43].

Student comments were collected and evaluated from 2018. This approach was taken to be representative of course content and delivery methods that had been settled and consistent over several sessions. Two sources of student comments were used in the analysis, entries from the student systems thinking journals and relevant responses from end-of-course formal evaluations.

The final reflection assignment for the systems thinking journal was chosen for evaluation as it is most indicative of what students self-assess regarding their development of competency and its perceived value. The final reflections of all 26 students from both of the Fall 2018 sessions were analyzed by characterization. Because the reflections are open-ended, such characterization can be challenging. Nevertheless, for the two outcomes of improved competency and perceived value, we assessed according to a simple scale: strongly negative, negative, neutral, positive, strongly positive, or missing. Selection of negative assessment was made if comments were either explicitly or implicitly negative or noted significant difficulty. Positive assessment was made if comments were either explicitly or implicitly positive. An inherent assessment, whether positive or negative, was assigned for reasons that include, for example, comments that were not explicit but nevertheless detailed.

End-of-course formal student evaluations from Spring 2018 were also analyzed. These evaluations are voluntary, and not all respondents answer every question; therefore, the evaluations may offer an incomplete understanding of student experiences. Evaluation questions offer the opportunity for students to provide a numerical score and to enter their comments in text. We have not considered a quantitative analysis of these student evaluations because none of the questions applied specifically to the systems thinking content. In the end, we limited our investigation to a qualitative analysis of student comments that addressed systems thinking content from a broad question on the quality of course readings. There were eight comments that were relevant after consideration of these filters.

The analysis results are provided in Table 2. The competency assessments were assigned according to 26 responses from the system journal entries and one end-of-course evaluation comment, resulting in 27 total assessments. The value assessments were assigned from 26 journal entries and seven evaluation comments, or 33 total assessments.

	Strongly negative	Negative	Neutral	Positive	Strongly positive	Missing
Improved competency	0	2	0	21	4	0
Perceived value	0	1	0	8	19	5

Table 2. Analysis of student journal entries.

Student Comments

The following comments are from selected final student journal postings and from end-of-course formal evaluations. These venues offer students the opportunity to make sense about the experience and reflect on its potential usefulness in their work and other aspects of their lives. Minor edits have been made for clarity.

- "The focus on identifying underlying behaviors was significant because it really taught me to step back and look at the big picture. Many problems are made worse because one only treats the symptoms rather than the disease."
- "Systems thinking is such a valuable perspective to have that it's hard to believe that it is not a core requirement for business students everywhere. Now that I have received the training from this course in how to identify and develop causal loops, I think I will find endless applications for their use."
- "This course challenged how I view organizations, particularly as it relates to assumptions and systems thinking. Great course. Tough course."
- "Really interesting content around Systems Thinking. This is a skill which I am going to make an effort to integrate into my practice of leadership over the next few weeks and months. I realize it is something I will have to practice developing, and I am going to try to do just that to make it a habit."
- "This course honestly could be offered in all degree plans because it's so significant to how we connect with other people."
- "The systems learning was very valuable as it made me look at organizations differently. Organizations are truly systems and as leaders make changes, or consider changes, they

must understand the effects on the overall system. I had never considered this as a way of thinking, and it was helpful to me to view this approach."

- "This was one of the hardest classes to digest but out of all of my courses in my degree plan the one I find most useful in my future. The System Journal was very practical and useful and many of the exercises made me dig really deep in my own thinking."
- "Great course that pushed me academically and that introduced me to the view-altering concept of systems theory."
- "The systems journal was great because it was a real-life workbook. It was an opportunity to test and grapple with various course concepts in actual work life scenarios and settings."
- "By far the best and most challenging course in regard to practicality and learning theories and behavior to be leaders in the business world!"
- "Very easy to apply in the work place as well as in personal life."

Discussion

The course design is intended to be challenging and to push students academically. However, what they often perceive as difficult concerns the extent to which ORGL 615 differs from their acculturated expectations of education. Many students still expect or want to have the course proceed linearly with singular "right" answers to problems or situations that are presented. As noted by some of the excerpts from student comments above, the course content helps students change *how* they think about leadership and organizations. In keeping with the challenges of considering our own mental models, and as one student noted, changes in thinking necessarily require that we "dig really deep."

Student comments about systems thinking gravitate to two common points. First, they find that systems thinking and its visual tools provide a very meaningful way of understanding organizational behavior, as indicated by the predominance of the "Strongly positive" assessments in Table 2. Second, the journey of learning and practicing systems thinking can be challenging and difficult as indicated from many student comments. A common theme in comments was that students felt they had mastered simple problems but that more complex situations (e.g. at work) would require that they stretch further. Systems thinking tools help bring into light and consciousness what has been hidden. The real work of leadership begins once we appreciate the structures and mental models that give rise to patterns of events. With these considerations, the assessment results that we presented in Table 2 demonstrate that students have found the systems thinking material to be both capable of mastery and worthwhile for application outside of this course.

Application to Engineering Leadership Development

Our experience in ORGL 615 demonstrates that systems thinking and the related tools are powerful for individuals of all backgrounds. We believe that they can be particularly beneficial for engineers given their prior extensive training in understanding systems. Engineers already have familiarity with visual tools that are similar to BOTs, CLDs, and process diagrams. The ability to think in systemic, big picture terms that comes from physical and engineered systems can serve as a bridge to the applications in organizations we describe here. As stated above, it is important that engineers understand that the nature of social systems is very different from physical and engineered systems. Absent this understanding, an engineer may unilaterally attempt to impose his or her own understanding and intervention strategy, potentially leading to pushback or undesirable results. Components of an engineered system are incapable of reflection or adaptation; in a social system the actors all have different and important perspectives to bring to the table.

It is helpful to connect the concepts presented here to the concepts of quality control and process management. These functions are well-established in engineering applications that involve manufacturing or processes. If a process is not sufficiently understood, we are incapable of adequately controlling it. Attempts to improve it will simply involve trial and error that may or may not bring about desirable outcomes. Commenting on the work of the quality management icon W. Edwards Deming, James Martin captures the deep connection of systems thinking and leadership.

> A leader must understand the system he or she is attempting to manage. Without this understanding the system cannot be managed or improved… Optimization of the parts does not optimize the whole. System optimization requires coordination and cooperation of the parts which requires leadership [44].

As noted by Rottmann, et al. [15] and Racine [45], engineers may resist leadership roles for various reasons that include misunderstanding it and perceptions that it is hard to move groups of people to improve. Systems thinking concepts and tools can make the actions of leadership more familiar and concrete and can demonstrate how substantive improvements are possible when used collectively in a group setting. Indeed, leadership becomes more natural when the group members collectively see reality and what may be possible when improvements are made.

As stated earlier, the practice of engineering relies heavily on teamwork and communication [14]. These systems tools promote meaningful communication and enable teams to collaborate on understanding and improvement. Rottmann et al. [15] concluded that engineers value three characteristics in their leaders: 1) technical competence, 2) facilitation of collaborative optimization, and 3) organizational innovation. Systems thinking concepts and tools enable engineers to build upon their technical competence and skills to optimize and innovate collaboration in their organizations. Perhaps even more importantly, this approach can make leadership familiar and attractive. These connections demonstrate a potentially powerful leadership development path for engineers. The relevant cited research clearly supports the thesis that teaching systems thinking tools enables them to develop important leadership competencies.

Limitations and Future Research

The concepts and tools presented in this paper have a solid foundation from several decades of use in organizational leadership. Similarly, they have been used effectively in educational settings, including the one described here. Our experience and the qualitative results presented demonstrates that students find considerable value in learning and practicing these concepts with these tools. While it has not been possible to separate the experiences and perceptions of engineers from the population of students of all backgrounds, it nevertheless makes sense from cited sources that engineers would be particularly quick studies in learning these concepts and tools for the reasons presented. We hope to test this hypothesis in the ongoing research and experience with presentation of systems thinking in ORGL 615 and other venues as appropriate.

Conclusion

Our investigation involved connecting the delivery of systems thinking education with development of leadership competencies in a university setting and potential application to engineering leadership development. In addition to readings in systems thinking, students applied systems thinking tools and reflected on their experiences in a journal. Qualitative analysis of their comments and relevant supporting secondary research demonstrates improvement in leadership competencies, thus suggesting that such an approach would be valuable for engineering leadership development.

References

[1] M. Handley, J. M. Plumblee, and A. M. Erdman, “The engineering leader of the future: Research and perspectives,” presented at the ASEE 125th Annu. Conf. and Expo., Salt Lake City, UT, USA, Jun. 24-27, 2018, Paper 21520.

[2] D. H. Meadows, *Thinking in Systems: A Primer,* White River Junction, VT: Chelsea Green, 2008.

[3] P. M. Senge, *The Fifth Discipline: The Art and Practice of the Learning Organization,* [Kindle ed.], New York: Doubleday, 2006.

[4] V. Anderson and L. Johnson, *Systems Thinking Basics: From Concepts to Causal Loops.* Acton, MA: Leverage Networks, 1997.

[5] T. Wujec, “Draw how to make toast: A simple and fun introduction to systems thinking,” [Online]. Available: https://www.drawtoast.com. [Accessed on Oct. 8, 2018].

[6] ABET, “Criteria for accrediting engineering programs, 2019-2020,” [Online]. Available: https://www.abet.org/wp-content/uploads/2018/11/E001-19-20-EAC-Criteria-11-24-18.pdf. [Accessed on Jan. 31, 2019].

[7] J. A. Hoschette, *The engineer's career guide*. Hoboken, NJ: Wiley, 2010.

[8] B. L. Hartmann and C. T. Jahren, “Leadership: Industry needs for entry-level engineering positions,” *J. STEM Education,* vol. 16, no. 3, pp. 13-19, Aug.-Sep. 2015.

[9] D. Bayless, E. P. Douglas, A. M. Erdman, M. R. Kendall, W. J. Schell, IV, and J. Warnock, “Addressing the leadership requirement in the new ABET criteria,” [Panel discussion], ASEE 125th Annu. Conf. and Expo., Salt Lake City, UT, USA, Jun. 24-27, 2018.

[10] J. V. Farr and D. M. Brazil, “Leadership skills development for engineers,” *Eng. Management J.*, vol. 21, no. 1, pp. 3-8, Mar. 2009.

[11] F. E. Watson, “Self-perceptions of interpersonal, intrapersonal, and leadership skills among recent engineering graduates: A qualitative study,” Ph.D. dissertation, Sch. Org. Leadership, Univ. Rockies, Denver, CO, 2013.

[12] S. Kumar and J. Hsiao, “Engineers learn ‘soft skills’ the ‘hard way’: Planting a seed of leadership in engineering classes,” *Leadership and Management in Eng.,* vol. 7, iss. 1, pp. 18-23, Jan. 2007.

[13] R. Paul and L. G. C. Falls, "Engineering leadership education: A review of best practices," presented at the 122nd ASEE Annu. Conf. and Expo., Seattle, WA, USA, Jun. 14-17, 2015, Paper 13725.
[14] H. J. Passow, "Which ABET competencies do engineering graduates find most important in their work?" *J. Eng. Education,* vol. 101, no. 1, pp. 95-118, Jan. 2012.
[15] C. Rottmann, R. Sacks, and D. Reeve, "Engineering leadership: Grounding leadership theory in engineers' professional identities," *Leadership*, vol. 11, no. 3, pp. 351-373, 2015.
[16] R. Graham, E. Crawley, and B. R. Mendelsohn, "Engineering leadership education: A snapshot review of international good practice," Bernard M. Gordon MIT Engineering Leadership Program, [Online], Available: http://www.rhgraham.org, 2009, Accessed on Jan. 31, 2019.
[17] B. M. Aucoin, "Exploring paradigms: Leadership development for engineers using the engineering skill set," presented at the ASEE Gulf Southwest Sect. 2019 Ann. Meeting and Conf., Tyler, TX, USA, Mar. 10-12, 2019.
[18] B. M. Aucoin, "The leader within: The engineer's [secret] advantage in the transition to leadership," [Online course], Available: https://the-leader-within.mykajabi.com/p/sales-page, Accessed on Jan. 31, 2019.
[19] B. V. Koen, *Definition of the Engineering Method,* Washington, DC: ASEE, 1985.
[20] B. Lucas and J. Hanson, "Thinking like an engineer: Using engineering habits of mind and signature pedagogies to redesign engineering education," *Int. J. Eng. Pedagogy*, vol. 6, no. 2, pp. 4-13, 2016.
[21] D. L. Farber, "Understanding engineering systems futures: Using scenario analysis and planning to develop engineering systems leadership," Social Science Research Network, 2011.
[22] B. M. Aucoin, "Leadership development for engineers using a systems and skill set framework," unpublished.
[23] W. R. Scott and G. F. Davis, *Organizations and Organizing: Rational, Natural, and Open System Perspectives,* 5th ed. Upper Saddle River, NJ: Pearson, 2003.
[24] J. Boardman and B. Sauser, *Systems Thinking: Coping with 21st Century Problems,* Boca Raton, FL: Taylor & Francis, 2008.
[25] G. Chen, and R. Kanfer, "Toward a systems theory of motivated behavior in work teams," *Res. Organizational Behavior,* vol. 27, pp. 223-267, 2006.
[26] D. H. Olszewski, "The use of systems thinking by the industrial engineer as organizational leader," D. Management Exec. Leadership report, Dept. Management, Walsh Coll. Accountancy Bus., Troy, MI, 2015.
[27] G. W. Coffey, *A Systems Approach to Leadership: How to Create Sustained High Performance in a Complex and Uncertain Environment*, London: Springer, 2010.
[28] W. E. Ormond, "Thinking ahead: A systems approach to understanding individual leadership capacity and performance effectiveness in organizations," Ph.D. thesis, Dept. Psychology, Univ. Calgary, Calgary, AB, Canada, 2005.
[29] J. P. Walters, B. Greiner, E. O'Morrow, and B. Amadei, "Fostering systems thinking within Engineers Without Borders student teams using group model building." *Int. J. Eng. Educ.*, vol. 33, no. 1A, 247-60, Jan. 2017.
[30] S. Kordova and M. Frank, "The concept of systems thinking education- Moving from the parts to the whole," *Proc. 2018 IEEE Int. Conf. on Industrial Eng. and Eng. Management,* 303-306, Dec. 2018.

[31] A. Gero, "Enhancing systems thinking skills of sophomore students: An introductory project in electrical engineering," *Int. J. Eng. Educ.*, vol. 30, no. 3, pp. 738–745, 2014.
[32] A. C. Andenoro, M. J. Sowcik, and T. C. Balser, "Addressing complex problems: Using authentic audiences and challenges to develop adaptive leadership and socially responsible agency in leadership learners," *J. Leadership Educ.*, vol. 16, no. 4, pp. 1–19, Oct. 2017.
[33] G. Burleson, B. Butcher, B. Goodwin, K. Sharp, and B. Ruder, "Soap-making process improvement: Including social, cultural and resource constraints in the engineering design process," *Int. J. Service Learning Eng., Humanitarian Eng. and Social Entrepreneurship*, vol. 12, no. 2, 81-102, Fall 2017.
[34] E. F. Crawley, J. Malmqvist, S. Östlund, and D. R. Brodeur, *Re-thinking Engineering Education: The CDIO Approach,* New York: Springer, 2007.
[35] Engineers Without Borders USA, "Mission and history," Available: https://www.ewb-usa.org/mission-and-history/, Accessed on Mar. 22, 2019.
[36] B. Amadei, *A Systems Approach to Modeling Community Development Projects,* New York, NY: Momentum Press, 2015.
[37] K. Pugel and J. P. Walters, "Embedding systems thinking into EWB project planning and development: Assessing the utility of a group model building approach," *J. Humanitarian Eng.,* vol. 5, no. 2, 10-20, 2017.
[38] M. Atencio, "A critical success factors framework that includes leadership competencies for successful delivery of projects," Ph.D. thesis, Sch. Built Environment, Univ. Salford, Salford, UK, 2012.
[39] A. Diaz and C. Olaya, "An engineering view for social systems: Agency as an operational principle for designing higher education access policies," *Systemic Practice and Action Res.*, vol. 30, no. 6, 627-649, Dec. 2017.
[40] N. O'Connor and E. de Vries Robbe, "EU Design's rise in the apparel and fashion industry: Management and incentive systems," Harvard Business School, Available: http://hbsp.harvard.edu, 2010, Accessed on Mar. 22, 2019.
[41] C. Argyris, *Organizational Traps: Leadership, Culture, Organizational Design* [Kindle ed.]. Oxford, UK: Oxford University Press, 2010.
[42] S. B. Merriam and E. J. Tisdell, *Qualitative Research: A Guide to Design and Implementation,* 4th ed. San Francisco, CA: Jossey-Bass, 2016.
[43] P. Eriksson and A. Kovalainen, *Qualitative Methods in Business Research,* Los Angeles, CA: Sage, 2008.
[44] J. R. Martin, "Deming's theory of profound knowledge," Management and Accounting Web [Online]. Available: https://maaw.info/DemingExhibit.htm, [Accessed on January 31, 2019].
[45] W. P. Racine, "Social identity development and the situation of scientists and engineers as new leaders," *J. Leadership Studies*, vol. 9, no. 3, pp. 23-41, 2015.