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Preparing Our Graduates to be More Effective Leaders In a World of Systems-Oriented Risk

Dr. Eva Andrijcic, Rose-Hulman Institute of Technology

Eva Andrijcic serves as an Assistant Professor of Engineering Management at Rose-Hulman Institute of Technology. She received her Ph.D. and M.S. in Systems and Information Engineering from University of Virginia, where she worked at the Center for Risk Management of Engineering Systems. She received a B.S. in mathematics from Randolph-Macon Woman's College. Her major interests are in the areas of risk analysis and management, critical infrastructure management and protection, interdisciplinary engineering education, and risk education.

Mr. William D. Schindel, ICTT System Sciences

William D. Schindel is president of ICTT System Sciences, a systems engineering company, and developer of the Systematica Methodology for model and pattern-based systems engineering. His 40-year engineering career began in mil/aero systems with IBM Federal Systems, Owego, NY, included service as a faculty member of Rose-Hulman Institute of Technology, and founding of three commercial systems-based enterprises. He has consulted on improvement of engineering processes within automotive, medical/health care, manufacturing, telecommunications, aerospace, and consumer products businesses. Schindel earned the BS and MS in Mathematics.

Dr. Craig G Downing, Rose-Hulman Institute of Technology

Craig G. Downing is Department Head and Associate Professor of Engineering Management at Rose-Hulman Institute of Technology. His teaching responsibilities are focused on delivering graduate-level instruction related to Operations and Quality Systems. His interests are rooted in Academic-Industrial partnerships, Process Improvement, and Action Research in Engineering Management. He is a certified Lean Six Sigma Master Black Belt.

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Abstract

Today's systems are becoming increasingly more complex and more interdependent - therefore the need for engineers who can effectively innovate, design and manage such systems is becoming more critical. In order to develop the skill set necessary to succeed in a leadership position in a competitive and risky workplace, an engineer must be able to deal with systems situations. Systems engineering and systems thinking provide a framework for anticipating or envisioning possible future changes (both within the system boundaries and within the interactive system's environment) and for effectively responding to internal and external risks and opportunities in a timely manner.

Accordingly, this paper concerns itself with identifying and illustrating a set of teachable System Competencies for Leaders. Much like the technical System Competencies for engineers, which Rose-Hulman Institute of Technology has already identified and employed in classroom settings, System Competencies for Leaders must contain a set of teachable instrumental principles, ideas and methods. These should enable leaders from all educational backgrounds to appropriately assess and deal with complex systems situations that require a holistic approach to succeed in a competitive marketplace.

It is with this dictum that the authors began a pilot study to research how the Department of Engineering Management at our school could enhance its instructional activities to include the competencies reported in this paper. This will include developing activities applicable for both the traditional engineering classroom as well as advanced professional development. Ultimately, our goal is to identify and confirm the systems competencies required for leaders which will prepare them for a competitive global workplace dominated by complex systems problems.

Introduction

The purpose of this exploratory paper is to identify and define a set of teachable System Competencies for Leaders (SCL), as well as to provide an initial and brief discussion about how SCL could be taught in a traditional engineering classroom setting, and in the advanced professional development setting. At Rose-Hulman Institute of Technology, the goal of these systems-infused leadership competencies is to enable leaders from diverse educational backgrounds to appropriately assess and deal with *complex systems situations* that require a holistic approach to succeed in a competitive marketplace.

This paper is not intended to replicate the well-established literature on the systems engineering competency models, such as the INCOSE, MITRE, NASA, JPL, CEST and others[1, 7, 10, 14, 15, 24, 25, 26], which focus primarily on the technical systems competencies; or the existing leadership competency models[9]. Furthermore, this paper is not intended to reinvent prior works in the area of systems thinking[17, 18, 22]. Indeed, this paper is not about teaching systems engineering methods to leaders, but is instead about identifying desirable leadership capabilities that would enable leaders of varied educational backgrounds to succeed in *complex systems situations* (which we define after introducing some specific examples later in this section).

This paper considers an altogether different audience and need from those previously addressed in literature: leaders of varied educational backgrounds that serve in senior (and often non-technical) leadership positions, and have a need to properly identify systems problems and manage them as such, often without a direct use or knowledge of technical systems engineering competencies. Figure 1 illustrates the problem under consideration and the target audience (organization's leadership). The SCL represent leadership competencies of an organization's leadership, and they are aimed at enabling leaders to deal with systemic challenges that arise from a target system of interest[21]. In such a way SCL competencies are differentiated from the technical systems competencies of the team members, which have been discussed in detail in Schindel *et al*.[20]. In order to put the need for such leadership skills into context, we briefly recall two real-world examples – one of which resulted in a costly failure, and the other of which resulted in a success and therefore illustrated the benefit of systemic thinking at leadership levels.

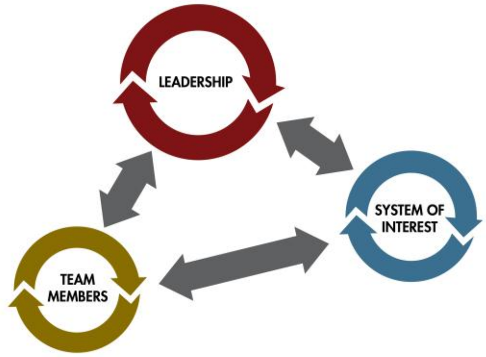


Figure 1: Interaction between the target system of interest, organization managing the system of interest and the leader of the team. The focus of the SCL is on the team leader.

In July of 2006, Pfizer introduced to the market a novel insulin inhaler, Exubera™, which was aimed at replacing the traditional insulin injection methods. Several factors led Pfizer to introduce this product, among which was an attempt to capitalize on a novel derivative of a chemical-based medicine before its patent-protection expired. Immediately upon its release, Exubera's sales suffered as medical practitioners wondered about its ability to effectively deliver insulin into the blood stream, doctors refused to prescribe it due to the time it took them to teach patients how to use the device, and patients refused to use the device for fear that it resembled a device used for inhaling narcotics. As a result of poor sales, in 2007 Pfizer withdrew Exubera from the market, and instead of reaching the initially projected yearly revenues of $2 billion, the company suffered a $2.8 billion loss[11].

In the 1930s Douglas Aircraft introduced the DC-3 aircraft, which has been called by many the most successful airplane ever built. It had an incredibly long life and was very successfully used for many, originally unintended, commercial purposes in the US and abroad[12]. Consequently, Douglas Aircraft experienced great success, primarily because it was able to satisfy initially unanticipated stakeholder needs and general market changes. What was Douglas Aircraft able to do that Pfizer was not? Among other things, Douglas Aircraft's leadership recognized the need to base all organizational decision-making, trade-offs and planning on the complete and commonly understood set of system stakeholders and their values, while Pfizer was unable to do so.

We suggest that the success of the DC-3, the failure of Pfizer's Exubera, and numerous other similar stories can be used to illuminate the critically needed System Competencies for Leaders (SCL). In the following paragraphs we outline the need for skills which enable leaders to successfully deal with complex systems situations, we define a set of initial competencies, describe the plans for a pilot study that aims to vet these competencies among leaders in the industry, and outline plans for subsequent educational strategies and activities.

Increasing systems-oriented risk and complexity and special challenges of leadership in systems situations

The goal of SCL is to enable leaders from all educational backgrounds to appropriately assess and deal with systems situations that require a holistic approach to succeed in a competitive marketplace. Rietsema and Watkins[19] consider the *2010 IBM Global CEO Report Capitalizing on Complexity* and suggest that of the surveyed organizational leaders, more than half doubted their own abilities to deal with systems problems in a complex world. These leaders, while versed in traditional management skills, exhibited "diminished cognitive capacity to manage the complexity of their environments." Rietsema and Watkins furthermore suggest that surveyed organizational leaders appeared to be missing a "meta-goal focus that allows leadership to engage as much of the system as possible from a complex systems perspective," and that instead they participated in the "so-called "patching" behavior" where they attempted to deal independently with many seemingly isolated and small problems[19]. Marion and Uhl-Bien[13] further describe the idea of a "patching" management effort: "We interpret situations in terms of the things that are happening to us immediately and fail to see the larger picture … consequently, we move from one localized incident to the next stamping out the fires but never seeing the broader patterns of events. We perceive problems as events that happened to us and fail to understand that we are a part of the network of events that created the problem".

Today's leaders must deal with systems that are much more complex and interdependent than a few decades ago, yet management strategies taught even at the best schools have been very slow to advance to accommodate these changing needs. Systems of concern to today's leaders are more than simply the sum of their individual sub-systems (components). Local and global organizations and businesses represent examples of such systems, as do various socio-technical and anthropogenic systems. Such systems satisfy purposes that could not be accomplished by any of the individual components, and are often characterized by non-linear and sometimes unplanned interactions, strong sub-system correlations, varying response times of different sub-systems, complex functions and controls, competition, innovation, supply chain challenges, and many types of interdependencies. Interdependencies among systems have created numerous technological, economic, and social benefits and opportunities, but at the same time "the underlying networks have created pathways along which dangerous and damaging events can spread rapidly and globally"[8].

Physical, virtual, economic, social and other interdependencies present in such systems create opportunities for systemic risks, and occasionally for systemic opportunities. Systemic risks (opportunities) result from interconnected systems, in which a perturbation to a single system can spread to other interconnected systems generally through non-linear and often unknown channels, emerging in other forms, and in which the extent of the potential damage (opportunity) is largely determined by the number and size of the interconnected systems[6]. Some examples of such systemic risks are the Northeast power blackout of 2003, and the global economic collapse of 2007-2009. These systems represent a true leadership challenge.

Rietsema and Watkins[19] consider the global supply chain system, and show how changing federal immigration laws left Washington state with many unpicked apple crops, which had a more serious impact not only on the regional and national supply chain for apple products, but also on some unexpected sectors of the local economy. The need for leaders to consider systems problems from a holistic perspective is probably best illustrated in what is now well known as the "Operation Cat Drop"[3]. In the 1950s people of Borneo suffered a significant outbreak of malaria which is spread by mosquitoes. The World Health Organization (WHO) immediately responded and utilized DDT to rid the area of these pests. DDT not only killed mosquitos and reduced the number of people with malaria, but it also caused cats to eat lizards which ate poisoned insects. Island cats died off, and in turn the local rat population flourished, bringing to the people of Borneo two new serious diseases, namely the Bubonic plague and typhus. In order to combat these new diseases WHO had to parachute new populations of cats into Borneo. These cats were able to control the rat population and therefore the spread of the new diseases. This example very clearly illustrates some major issues in systems problems – when not considered holistically, short-term band aid solutions solve localized problems, but create other problems in the process. While WHO was in the end able to remedy their poor decision, in many situations once the initial decision is put into action, emergent results are very difficult to control.

But interdependencies do not always result in negative consequences, and do in fact sometimes result in unprecedented opportunities. Skok[23] tells a story of Amazon's struggle to scale its e-commerce infrastructure and illustrates the opportunities that can emerge from systemic thinking. Under pressure to complete its internal software projects in a shorter period of time, Amazon discovered that many of their internal teams were building plans and project architectures that were not scaling beyond individual projects. Amazon's leadership not only solved the problem internally by encouraging a system architecture that could be reused by different teams for various projects, but by realizing that their problem was a part of a much larger problem/network, they were able to capitalize in a major way on their discovery by developing a new business line that offered such services to other companies facing the same problems, leading to the creation of Amazon Web Services.

So, what do these examples imply for individuals in leadership positions? A holistic solution to a large systems problem has to be based on diverse knowledge which is generally not possessed by a single leader, but is more likely located throughout the organization/system. Nor is the senior leader expected to be a systems engineer or architect. Moreover, systems problems encountered by leaders today are often unprecedented and emergent, suggesting that even the most astute leaders might not have the knowledge, skills, or prior experience to deal with such problems. Large-scale systems problems of interest in this paper are multi-dimensional and often uncontrollable, so traditional management tools of hierarchical control and forecasting are generally of very limited use.

Einstein suggested that “we cannot solve our problems with the same thinking we used when we created them”, yet many leaders persist on trying to fix new problems with methods and approaches that work only in controlled environments, with limited external interaction consequences. Bain[2] suggests that this habit is difficult to break as individuals experience mental and psychological difficulties breaking away from their existing and established mental models, even when they have proven to be incorrect and useless. Petrie[16] suggests that what leaders really need to learn is how to challenge the basic assumptions and thinking that their established mental models are based on. So the main question is, how do we develop educational strategies that enable current and future leaders to improve their current approaches to dealing with systems problems?

We suggest that systems engineering and systems thinking, when mapped to related leadership competencies, provide leaders with a framework for anticipating or envisioning possible future changes (both within the system boundaries and within the interactive system’s environment) and for effectively responding to internal and external risks and opportunities in a timely manner. Furthermore, by enabling leaders to envision the impact that their current decisions might have on the future decision making options, a systems thinking framework can encourage leaders to move away from the traditional hierarchical leadership theory toward a way of thinking that requires a collaborative multi-level organizational effort in solving the problem. The following section identifies and describes seven initial systems-infused competencies for leaders, without requiring technical systems competencies.

Systems competencies for leaders

The System Competencies for Leaders are associated with *leadership situations* where the context has a systemic aspect: A system-based product, service, business process, or environment. In all these cases, by “system” we mean a set of interacting things, called “system components”, leading to emergent behavior at the system level, as illustrated in Figure 2.

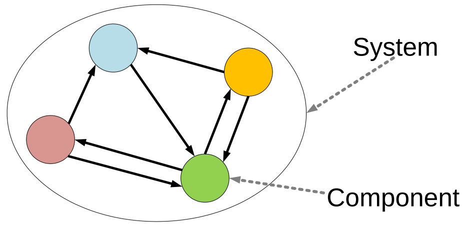


Figure 2: The Systems Perspective

The idea that business leaders ought to be familiar with systems thinking skills to deal with complex problems is not new, and has been previously explored in systems engineering literature[17, 18, 22, 24]. More than two decades ago, Richmond[17, 18] discussed the need for individuals to be systems thinkers, and he identified seven critical systems thinking skills that an individual ought to adopt (dynamic thinking, closed-loop thinking, generic thinking, structural thinking, operational thinking, continuum thinking, and scientific thinking). More recently Squires *et al.*[24] identified a systems engineering competency taxonomy consisting of five categories of competencies (technical leadership, technical management, project management, broad professional, technical/analytical skills) for lead program system engineers. As these examples illustrate, existing works have focused predominantly on identifying technical, analytical and professional competencies for: (i) individuals who serve in systems engineering positions, and (ii) individuals who need to develop systems engineering technical skills. In contrast, the goal of SCL developed in this paper is not to increase a leader's level of systems engineering competencies, but instead to equip him/her with *leadership competencies* that will enable him/her to successfully deal with systems problems.

Table 1 represents seven System Competencies for Leaders (L1 – L7) in a tabular form. The table consists of four major columns where: the first column indicates the "systemic problems" that leaders encounter; the second column indicates the "leadership competencies" that leaders ought to possess to adequately deal with problems presented in column one; the third column represents the characteristics through which leaders demonstrate their familiarity with specific competencies presented in column two; and column four indicates the means through which these leadership competencies can be learned and refined. The competencies are made more tangible and practical to learn and acquire by their association with tangible "system models" that express the key systemic ideas in structured graphic or tabular form. The "solutions" discussed in column three were influenced by the model-based technical competencies discussed in Schindel *et al.*[20] .While the seven leadership competencies described in Table 1, and the related demonstrations of those competencies broadly support the general ideas previously identified in systems thinking literature, these competencies are clearly focused on leadership skills (i.e., leaders in these situations are not themselves required to apply systems engineering tools, but they must have the ability to recognize a systems situation, and to appropriately allocate and manage resources and people), and are therefore differentiated from technical systems competencies.

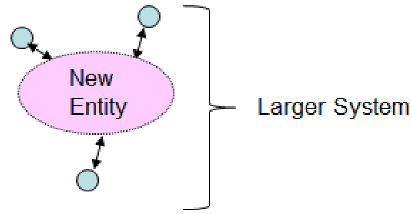
	Systemic Phenomenon & Related Challenge	Related Systems Competency for Leaders	Competency Demonstrated By	Competency Learned and Refined By
L1	Inherently systems-oriented situations must be recognized as such, in order to address systemic opportunities and risks.	Recognition of system situations: Skill in recognizing the larger system in which one's entity of interest is or will become a component; skill in recognizing that one's entity of interest is itself a system of interacting components.	Familiarity with related external and internal system models; awareness of system interactions; assigns or asks for these models; makes these models part of plans and communications.	Practice in explaining these models to others.
L2	Decisions and team behavior become disconnected from the values of system stakeholders.	Ability to drive the organization to consistently refer to the complete and commonly-understood set of system stakeholders and their values (system features) as the acknowledged basis for all decision-making, trade-offs, and planning.	Familiar with feature model and consistently drives others to it to support and test decision-making, trade-offs, and planning. Assigns or asks for these models.	Practice in explaining stakeholder-feature model to others. Practice in using the feature model to support and test decision-making.
L3	The emergent consequences, at a system level, of local actions or changes are not obvious.	Recognition that the nature of emergence requires the resources of systems science and systems engineering to manage and exploit, and leading the organization to call upon these as appropriate.	Assigns explicit responsibility for determining consistency of intended emergent behavior and local actions or changes; asks for models and support of same; identifies resources able to generate and interpret these models.	Practice in assigning responsibility and understanding reports. Practice in conditioning decisions and actions on understanding of systemic consequences.
L4	The required behavior of a system is distinct from the design that realizes it. More than one system design may achieve the same result.	Leading the organization to appreciate the difference between system requirements and system design, and to appropriately explore the range of solution options.	Assigns resources to generate and validate requirements, to verify candidate designs satisfy them, and to select optimized solutions; monitors status of same and conditions decisions and commitments on their completion	Practice in differentiating requirements from design. Practice in asking what is required, or stating what is required, versus tampering with the technology that delivers it.
L5	Robust systems tolerate faults in their components or environments that minimize stakeholder impact, while fragile systems do not.	Leading the organization to effectively identify and manage systemic risks.	Assigns resources to identify, assess, mitigate, and monitor risks. Conditions decisions and commitments on them.	Practice in seeking out and consulting risk assessments and risk management plans as an integral part of the decision-making and commitment-making process.

	Systemic Phenomenon & Related Challenge	Related Systems Competency for Leaders	Competency Demonstrated By	Competency Learned and Refined By
L6	Systemic solutions that effectively address a range of different applications, customers, or markets can survive those which do not.	Leading the organization to develop flexible but common systemic platform approaches that address a range of different configurations.	Demonstrates awareness the specific market segments, applications, or configurations are related and not independent "one-offs"; assigns resources to specify configurable platform solutions that cover them. Conditions decisions and commitments on this strategy.	Practice in assigning and accounting for investments and returns across multiple projects, versus on a one-off basis. Practice in assigning resources to manage platforms across multiple product or system life cycles.
L7	Individuals and organizations with superior system skills can out-perform others.	Rewarding individuals and encouraging organizations that display superior systems skills.	Explicit plans for organization and individuals, as well as development of same, their recognition and reward, all reflect the importance of systems skills to the success of the organization.	Practice in drawing up or approving organizational plans, job descriptions, and professional development plans that include systems-related considerations.

Table 1: Systems Competencies for Leaders

Notice that the SCL are mainly acquired and refined by active practice, not by passive study, and involve direct interaction with simple but accurate models. For example, for L1, Table 1 indicates the competency is demonstrated by the learning outcomes illustrated in Figure 3.

– Demonstrate awareness and understanding that a contemplated new or modified entity is in turn a component of a larger system of users, output consumers, upstream or downstream entities, external infrastructure, materials, operators and maintainers, or other environment with which it interacts, having emergent overall systemic impacts on the larger system as a whole:



– Demonstrate awareness and understanding that a contemplated new or modified entity is itself made up of multiple interacting components, leading to emergent overall impacts:

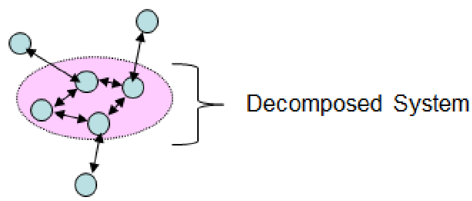


Figure 3: Example learning outcomes for L1

Initial study

The authors are currently in the process of organizing a pilot study, which will be completed by June of 2014. The pilot study will consist of a survey instrument that will target business leaders from a variety of industries, as well as academic and industry members of the INCOSE Great Lakes Leaders and Systems Working Group. The goal of the pilot study will be to vet the SCL, identified in the prior section, with industry leaders, specifically with regards to their validity, usefulness, and “teachability”. By capturing surveyed leaders’ personal experiences, the study will aim to: (i) harvest specific behaviors associated with L1-L7 that led to positive or negative outcomes for these business leaders, and (ii) develop realistic case studies that can be used for classroom instruction, as will be described in more detail in the next section.

The end state of this exploratory study will help us refine our systems-infused leadership competencies in a manner that can serve both academics and practitioners. Because the issues relating to leadership cut across all types of human activity and thought, true understanding of such a complex, systems-like, phenomenon requires a broadly conceived approach[27]. As such, a mixed-method design will be used to achieve the previously mentioned research aims. This approach will include both quantitative data (measurable evidence of SCL pervasiveness) and qualitative data (detailed information about setting or context of SCL) reflecting multiple collection techniques and shareholders. More specifically, an exploratory sequential design will be used as it begins with the collection and analysis of quantitative data, with the quantitative data being given priority for addressing the research questions. Further, this approach allows the researcher to gather and analyze qualitative data to provide more in-depth follow-up on the initial quantitative results[4].

The primary means for quantitative data acquisition will be a survey instrument. The instrument will be developed in conjunction with the Offices of Institutional Research, Planning and Assessment (IRPA) at our school. This collaboration will seek to enrich the instrument structure, item clarity, and ease of use. On the other hand, face-to-face interviews and electronic communication (email, telephone, and/or Skype) will be used to obtain the qualitative data. No geographic boundaries will be placed on participants; however, systems and leadership experience (academic and/or professional) will be the primary driver for inclusion in the study.

The questions in the survey instrument will primarily focus on the column of Table 1 labeled "Systemic Phenomenon & Related Challenge", and less so on the column labeled "Related Systems Competency for Leaders." The proposed opinion survey will be able to inform us about the occurrence and recognition of the stated systems problems, and will control for exposure bias by not focusing the questions on the respondents' opinions about the suggested competencies. In other words, the respondents will be asked about the underlying problems and how they have dealt with specific problems in the past, and they will not be asked to agree or disagree with the proposed leadership competencies. For each problem presented in the "Systemic Phenomenon & Related Challenge" respondents will be asked to identify the frequency of event occurrence at their organization, the severity of impact, the availability of acceptable mitigation, and an example of occurrence of each problem. To reduce the bias in responses, the survey instrument will utilize a fixed, clearly defined, Likert-type scale, and options will be provided to enable respondents to list other problems which were not originally included in the survey.

Initial conclusions and future plans

The second part of the study will commence once the SCL have been vetted by the business community interviewed in the pilot study. This part of the study will focus on developing pedagogical tools to deliver SCL in both the traditional engineering education setting, as well as in the professional development setting targeting our school's alumni and the leaders in the regional business community.

We recognize the complexity of designing effective learning experiences that facilitate maximum retention and immediate internalization of the SCL among learners with varied degrees of existing leadership skills and experiences. In an effort to create educational modules for the professional development setting, we plan on exploring the most effective ways through which professionals with established leadership models can internalize the SCL in a compressed time frame. This includes creating interactive case studies through which leaders will be encouraged to engage in behaviors described in the rightmost column of Table 1. The SCL learning and refinement skills described in Table 1 are sufficiently general to be applicable to a wide variety of decision-making contexts and designed to allow practitioners to examine the SCL through their own lens and adopt them as credible problem-solving skills. At the same time these action items identify very specific behaviors that leaders in all systems situations need to develop in order to learn and internalize the seven proposed SCL.

In the traditional engineering education setting we will assess whether SCL would be more effectively taught as: (i) specially designed modules interspersed through required classes in different engineering departments (i.e., integrated multidisciplinary curricula); (ii) special elective seminars; (iii) special programs presented during our school's annual student leadership academy; or (iv) through multiple activities organized by a specialty student group, for example, an INCOSE student group. We recognize that SCL are unlikely to be fully understood, appreciated and internalized by students who have had very little to no leadership experience outside of the classroom environment. Therefore, our efforts will focus primarily on determining whether SCL can be better taught through fragmented and targeted case studies, or through an integrated simulated learning environment.

According to Bain[2], learners often fail to internalize new knowledge unless they are forced to engage in a situation in which their existing mental models will not suffice, and unless they are in a situation to care enough that their existing mental models are not good enough. Fink[6] and Felder *et al*.[5] furthermore emphasize the need for creating opportunities for meaningful and significant learning. The envisioned simulated learning environment would provide students with such a learning situation, and moreover, would enable students to engage in a fast-track "learner directed"[17] learn-as-you-go (or learn-as-you-fail) educational framework. Several small groups of students would participate in a semester long simulation in which they would be asked to manage and lead specific aspects of an explicit complex system. During the course of the semester, instructors would introduce certain unexpected (to the student) interruptions into the system, causing students to encounter management and leadership situations which they are not ready to handle. They would initially receive no guidance from the instructors, and would likely make a decision which could in the long run cause unwanted consequences in the complex system and within its operating environment. These ripple effects caused by their decisions could be illustrated in the simulated environment, so that students could experience firsthand the effect that their decisions today have on the system and its environment. Students would then be introduced to some aspect of SCL and would be allowed to experience how a different decision might affect the system in the long run.

The simulated learning environment would give students a safe, yet realistic learning space in which the instructor could help them create new ideas in a controlled and guided manner, leading them to discover on their own the need for certain leadership competencies that are of essence in the real world of complex system. Current practices in the traditional engineering Capstone courses provide students with numerous opportunities to address systems-oriented technical challenges, but they are less frequently used as vehicles to practice leadership competencies.

This exploratory paper identified a set of teachable System Competencies for Leaders, provided some initial learning outcomes for each of the seven competencies, as well as some examples of how these competencies could be internalized by learners with varying levels of leadership expertise. The upcoming phases of our study will focus on vetting these competencies with the leadership community before they are employed in a classroom. We believe that these systems-infused leadership competencies will enable experienced (and possibly non-technical) leaders as well as young engineering students to become better leaders by preparing them to more effectively deal with complex systems situations that require a holistic approach to succeed in a competitive marketplace.

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