Modelling the Design Systems Thinking Paradigm

Mr. Sabin Gianelloni

Student at the University of Illinois Urbana-Champaign, studying Systems Engineering and Design. Interested in analyzing the connection between Systems Engineering and Design for application to the SED curriculum at UIUC.

Dr. Molly H Goldstein, University of Illinois at Urbana - Champaign

Molly H. Goldstein is an engineering design educator and researcher at University of Illinois, Urbana-Champaign. She previously worked as an environmental engineer specializing in air quality influencing her focus in engineering design with environmental concerns. Her research interests include how students approach decision making in an engineering design context. She obtained her BS in General Engineering (Systems & Design) and MS in Systems and Entrepreneurial Engineering from the University of Illinois and PhD in Engineering Education from Purdue University.

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Abstract

Systems thinking and design thinking have always been considered separate concepts. Systems thinking is described as the cognition a person uses in the solution and design of large-scale complex systems, often requiring hypothetical and holistic approach. Design thinking prioritizes the consumer and describes the cognition of a person completing a design task. Design thinking is often iterative and dynamic requiring creativity and expertise. On the surface the two seem very distant, but as both are becoming more and more important in the world of engineering so does the relationship between them. Recently Greene, Gonzalez, Papalambros, and McGowan questioned this separation by examining the history and application of both systems and design thinking. They hope to find applications of trusted design training techniques to advance the development of systems engineers and to better understand systems thinking as a concept. By initiating research into this subject, they offered various models to describe the systems/design thinking relationship with an open request for further research to support or deny the proposed models.

This paper aims to provide support for a model of the Systems/Design Thinking relationship by examining the emergent characteristics of active designers and systems engineers in order to identify traits and skills that relate to success. We did this by analyzing prominent literature around Systems Thinking and Design Thinking and comparing the findings and models of multiple studies. We then compared the emergent characteristics identified in our analysis to form conclusions about the Systems/Design Thinking relationship. Our paper provides support for the close interplay between Systems Thinking and Design Thinking and suggests applications in education and avenues for future research. We aim to provide the foundation for future research into the application of design thinking teaching and learning strategies into a mixed systems design engineering curriculum.

Introduction

Traditionally, systems thinking and design thinking have been looked at as separate concepts. However, Green, Gonzalez, Papalambros, and McGowan [1] recently proposed a more thorough investigation between the concepts with the purpose of potentially applying well understood cognitive science approaches from design thinking to better understand systems thinking. Greene and her coauthors' research focus on the applications of design thinking methods and research into the world of complex systems management education and development. In their recent paper, they give the history and background of industrial application for systems thinking and design thinking [1]. The relationship between the two is then hypothesized in a series of four concept models.

Each concept model presented contained a brief description of the theory and possible support for the proposed relationship and included a main claim regarding the systems/design thinking relationship accompanied by a visual representation of the claim. The first concept model, the Distinctive Concept Model, suggests that design thinking and systems thinking are separate concepts, having evolved separately to achieve different goals in design [1]. The Comparative Concept Model suggests that there is overlap in the cognitive capabilities for systems and design thinking and that their differences are due to differences in application and the nature of their use in a process [1]. The Inclusive Concept Model suggests that systems thinking is merely a specific application of design thinking and falls under the category of design thinking [1]. Lastly was the Integrative Concept Model which suggests that systems and design thinking are part of the same type of cognition with the perceived difference between them being due to a gap between their application in industry and formal research. Using Greene et al.'s work as a springboard, we continued exploration of the systems/design thinking relationship.

Our paper is structured to first examine the emergent cognitive abilities and attributes of design thinking and systems thinking by synthesizing literature describing each concept in order to understand similarities in markers of success. Traits that appear more than once from two separate sources are likely to be highly related to successful design or systems thinking. By comparing the key traits that characterize design thinking and systems thinking we can gain insight on the relationship between them. The paper will conclude by proposing a model of this relationship and will discuss implications and future directions for this work.

The goal of this paper is to provide support for these models and to attempt to characterize the underlying relationship between design thinking and systems thinking. The peripheral goal is to utilize these findings for application in integrating these concepts more explicitly into the curriculum at the University of Illinois Urbana-Champaign's BS in Systems Engineering & Design. Understanding systems thinking, design thinking and their relationship has value for designing a curriculum that can more fully prepare students to excel in both systems engineering and professional design, enhancing students' impact after graduation.

2.1 Design Thinking Overview

Design thinking is cognition, or the process of thinking, that includes the usage of solution-based methods to explore human centered values throughout the engineering design process [1][2]. It has also been described as "high order intellectual activity" that "requires practice and is learnable" [1]. There are various methods describing the process of design thinking, but all hold that design thinking is solution-based and includes multiple prototyping and iteration phases. The process and solution are human centered, and they draw on the experiences, beliefs, knowledge, and inspirations of the designer. The IDEO model for design thinking [2] includes three stages, Inspiration, Ideation, and Implementation. This model is careful to show that movement between phases happens fluidly and that movement through phases is cyclical until the best solution has been discovered or chosen from available options [2]. Divergent and Convergent thinking are central to the design thinking process [3], as a designer explores a problem space or potential solutions (divergent thinking) and then narrows the choices down by factors such as production cost or reliability (convergent thinking). The concept of design thinking has been studied since the 1970's [1] and its teaching methods and central characteristics are quite well known [4]–[6].

2.2 Design Methods

Design thinking is a type of cognition, but it also describes the process of design, otherwise known as a method. In many cases the method is simply the journey the designer takes throughout the course of design project, though some have modeled the process visually. Tim Brown, Stanford, SAP and a few others' design thinking models were compared in a paper by Efeoglu, Moller, Serie, and Boer [3]. Each model they analyzed showed human values at the core of the process which was often included multiple iteration phases and an inherent fluidity. The models show the tendency to flow between ideation and prototyping phases, to gather knowledge and weigh options before picking the best solution to a problem. Skilled designers are often given poorly defined problems and asked to provide an effective, cost-efficient, and elegant solution. To do this the designer must first explore the problem space. This term used to describe the bounds of the solutions and goals of a specific ill-defined problem and dates back to the late 60's [3]. Throughout the design process the designer iterates between divergent and convergent stages [3] of thinking. The divergent stages represent the exploration of many possible ideas and solutions, the convergent thinking stage follows with a narrowing process identifying the best solutions of those proposed. A key difference between expert and novice designers is the amount of time they spend exploring the problem space before attempting to find solutions to the problem [7][8][9], with expert designers spending considerable more time in contrast to beginning designers. This is an example of how the methods of an experienced and a novice designer differ and how the history of research in the concept allows us to recognize the importance of that difference.

2.3 Design Thinking Characterization

Due to the history of research into design thinking, there is a much more centralized understanding for what characterizes "good" design thinking. Thus, in developing a list of essential traits and abilities required we relied on two sources that synthesized other lists. For that reason, there was less of a need to piece together multiple lists of traits and abilities in order to understand how it is characterized in an ideal designer. The two lists of skills and traits, though different in wording, provide extremely similar images of good design thinking. The first set was compiled by Efeoglu et. al [3], and was created by comparing the essential traits required for a variety of different design thinking methods. Their list amounted to 13 cognitive traits and abilities that are present in a design thinker. Charles Owen identified a similar list in his research on the topic [10], resulting in 14 traits and abilities. Together their research provides a clearer image of an ideal designer. Table 1 shows the overlaps and core characteristics between the two sets of descriptors; these terms describe both the cognitive capabilities of the designer as well as necessary values for the designer to effectively work through design challenges, providing insight not only into capabilities of the designer but also into their cognitive outlook and tendencies.

Table 1. Characteristics of Strong Design Thinking based on Efeoglu et al. [3] and Owen [10]

	Cognitive Characteristics	
Skills	**Communication**: *the ability to translate and relay information to other people effectively*	[3], [9]
	Take Holistic View: *understanding large scale interconnections of products and systems*	[3], [10]
	Effective Questioning: a*bility to ask the right questions to gather information from experts and to examine complexities of a problem*	[3], [8]
	Divergent & Convergent Thinking: *e.g. exploring a problem space or potential solutions and narrowing the choices down by factors such as production cost or reliability, respectively*	[3], [8]
	Understand Dependencies: *understanding how things relate to one another*	[3], [8]
Traits	**Empathetic/Human Centered**: *focus on the values and needs of the consumer/user when problem solving*	[3], [8]
	Openminded: *openness to ideas and deference of the necessity of choice*	[3], [8]
	Broad and Specific Knowledge Base: *expertise in a certain discipline and general understanding of terms and concepts from other relevant disciplines*	[3], [8]
	Creative	[3], [8]
	Innovative	[3], [8]
	Optimistic: *tempered optimism for maintaining creative drive*	[3], [8]

Unsurprisingly, empathy was a core part of the ideal design thinker, showing a grounding in the IDEO model of human-centered design and the importance of empathy throughout the design process. The ability to understand and relate to the problems and needs of the consumer is essential for understanding the problem and solution space. This coupled with optimism, specifically an optimistic mindset to focus on maintaining creative drive, is very important to follow a project to completion [10], but is often-underemphasized in engineering and particularly in an engineering education. Effective questioning and communication skills are essential for information gathering and communicating with clients and managers. Together, these skills describe a person able to fully explore the problem and solution space of a poorly defined problem, creatively iterate, identify the best product or solution, understand the place of that product within the market, and to be able to communicate its importance with consumers and stakeholders. Hence, these skills should be emphasized during an engineering education in order to help facilitate the development of future effective designers.

3.1 Systems Thinking

Where design thinking focusses on the product and the consumer, systems thinking focuses on understanding and predicting changes to a dynamic and complex system. This is where things get difficult. The term was introduced in the 90's [11] and while an abundance of research has been done on systems engineering, the understanding of systems thinking as a kind of cognition is vague. In 2007 year, a large study with over 205 systems engineers and field specialists interviews, was conducted to determine how senior systems engineers develop [12]. When they were asked to describe systems thinking, they often articulated different concepts [12]. As a result of their findings, Davidz and her team created this definition of systems thinking, "Systems thinking is utilizing modal elements to consider the componential, relational, contextual, and dynamic elements of the system of interest." [9, pg. 6-7]. Almost all the 205 definitions from their study can fit into one of the five foundational elements of this definition. While this definition is comprehensive, it is not necessarily useful to educators or businesses because of its broadness.

With or without a central definition, research suggests that strong systems thinking skills strongly correlate to project success [13], and that successful systems engineers also have strong systems thinking skills [14]. Due to the lack of a central definition and a history of research into the topic, our best way to examine this cognitive ability has been to study the people who actively use it.

3.2 Systems Thinking Characterization

There is plenty of evidence to support the characteristics of good systems thinking. A study conducted by Derro and Williams at NASA found 40 behaviors that characterize great systems engineers [15] by interviewing the "go to" people for systems engineering and comparing responses. Another study, conducted by Frank, found 10 cognitive characteristics and 11 abilities of successful engineers [14] using an approach similar to the one used by Derro and Williams.

Greene and Papalambros added to Frank's list with comparisons to cognitive psychology terms in a shortened list of 16 key terms [16]. Davidz and Nightingale performed a study conducting 205 interviews in 10 host companies to understand how systems thinking is developed, and therefore what characterizes systems thinking. Davidz and Nightingale's findings result, in a list of 8 terms characteristic of developed systems thinking [12]. The traits and abilities in these lists are suggestive of either strong systems engineering skills or systems thinking skills, but it has been suggested that systems engineering is merely the application of systems thinking [12] and that analysis of strong systems engineers is therefore analysis of strong systems thinking. There are many overlaps and recurrences among the traits identified in these studies. We saw value in creating a master list of terms that appeared in at least two of the four original lists. Table 2 shows the compiled list of cognitive capabilities and traits that make up strong systems engineers.

Table 2. Characteristics of Strong Systems Thinking based on Derro and Williams [15]*, Frank* [14]*, Greene and Papalambros* [16]*, and Davidz and Nightingale* [12]

	Cognitive Characteristics	
Skills	**Leadership**: *ability to lead and inspire cohesion and productivity within a team*	[14], [15]
	Strong Communication: *ability to translate and communicate ideas effectively*	[12], [14], [15]
	Effective Questioning: a*bility to ask the right questions to gather information from experts and to examine complexities of a problem*	[12], [14], [15]
	Take Holistic view: a*bility to take a broad view of a complex system*	[12], [14], [15]
	Strong Learning: *quickly process and incorporate new information for immediate use*	[14], [15]
	Pattern finding/ Understanding Synergy: *see and predict patterns and relationships within complex systems*	[14], [15]
	Divergent and Convergent Thinking: *e.g. exploring a problem space or potential solutions and narrowing the choices down by factors such as production cost or reliability, respectively*	[15], [16]
Traits	**Openminded**: *open-mindedness to ideas and solutions*	[12], [14], [15]
	Innovative	[12], [14]
	Broad and Specialized Knowledge: e*xpertise in a certain discipline and general understanding of terms and concepts from other relevant disciplines*	[14], [15]
	Creative	[12], [14], [15]

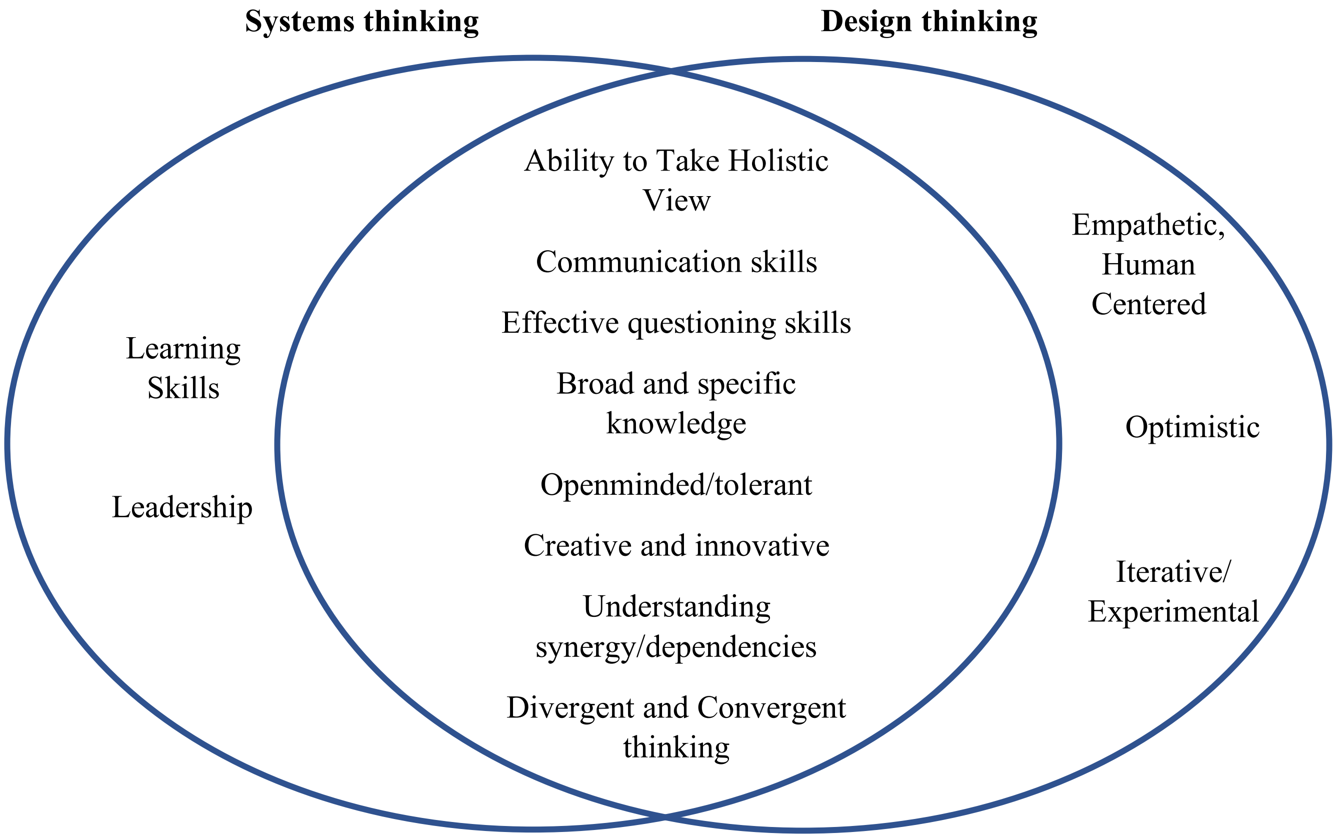
When dealing with large scale complex systems, design is often accomplished by large teams rather than an individual or small group of people. Knowing this, the importance of leadership, communication and interdisciplinary knowledge become huge factors for successful systems thinking [14], [15]. Ignoring all else, the ability to simply understand and communicate with engineers and designers of different backgrounds is incredibly desirable for a company. Then adding the creative and holistic abilities related to a systems thinker, the value of someone with these skills becomes extremely clear. The systems thinker is diverse and intelligent, able to create new ideas and share them efficiently with others.

4.1 Comparison and Findings

The core traits that make up a systems thinker and a design thinker are strikingly similar. In fact, both share the majority of the same core characteristics. This could suggest a very close relationship between the two concepts. The common traits imply a similarity in the core cognitive capabilities between the two concepts while the differences seem to relate to their application in industry. For example, we find that empathy is not noted as a key cognitive trait for systems thinking, which might make sense considering the application of systems thinking in complex engineering projects that are often not directly used by standard consumers. Design thinking portrays the opposite and is used in methods for designing products and services directly for consumers and users. We propose that the core cognition to perform both types of thinking is the same and that the minor differences in emergent characteristics is due to the difference in application between the two. We reason that a strong systems thinker could likely complete a design task at an advanced level. Not to say that an expert systems thinker is as capable as an expert designer, but rather that the two are very closely related and rely strongly on the same type of cognition with differences attributable to professional application.

These findings also become relevant when compared to the National Academy of Engineering's predicted necessary traits for the engineer of 2020 [14, pg 53-58]. The traits NAE outline very closely resemble the leading characteristics of an engineering systems and designer thinker, including communication, leadership, creativity, analytical skills, and the mindset of a lifelong learner. This suggests that the modern engineer is becoming increasingly similar to the systems engineer and designer, and makes sense considering the growing complexity of our technological systems and manufacturing processes. The need for systems thinking and design thinking is becoming ever more relevant to modern engineering and the education of the next generation of engineers must reflect this vital new aspect of modern engineering.

Figure 1. Systems thinking vs. Design thinking



5.1 Conclusion and Future Research

Based upon a synthesis of literature analyzing the core characteristics of systems thinking and design thinking, we conclude that the emergent characteristics of design and systems thinking are largely the same. These findings are in support the Comparative Model offered by Greene et al. that states both systems thinking and design thinking require similar cognitive skill sets in practice. The findings also support the differences between the two concepts being attributable to the bounded physical process of design and the abstraction-driven nature of systems thinking (one that does not emphasize tangibility or prototyping) [1]. We suggest the differences between the two concepts are resultant of this difference and not due to a difference in cognitive capability.

There is a large opportunity for application of these findings in education. By understanding that design and systems thinking are characterized by largely the same core characteristics, there becomes potential to train both skills peripherally by training the common core skills and traits. In other words, an education that emphasizes project-based design and design thinking values will simultaneously train the communication and leadership skills central to systems thinking, as well as other analytical and problem-solving skills. This would prove useful for implementation in UIUC's BS Systems Engineering & Design program or similar programs that combine both systems engineering and design, such as the University of Michigan's Master of Engineering in Systems Engineering + Design. The findings also provide support for the usage of design thinking and training techniques to train systems thinking. Due to the novelty of systems thinking in formal research, there is a lack of supported educational training methods for systems thinking. Research has shown that experience is the leading factor to the development of systems thinking [12], [15], [18], so the ability to apply proven techniques to help the development of junior engineers before they get into the industry becomes increasingly valuable. Students can gain this experience through internships and co-ops [19], or through design projects at the capstone through cornerstone levels [4]. Structuring design projects in ways that meaningfully facilitate the growth of these core characteristics would give students experience in approaching design.

Future research is required for application of these findings in education, and while there have been attempts to teach systems engineering using different formats, such as a studio art class [20], or as an entirely lab based course [21], the overall success of these attempts quantitively remains vague. The future of our research will be into the application of design thinking and training techniques to help accelerate the development of systems engineering and design skills for Bachelor's students within the SED program at the University of Illinois in order to better prepare them for the industry of their choice.

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