SYSTEMS THINKING IN SOCIALLY ENGAGED DESIGN SETTINGS

by

Chanel Beebe

A Thesis

Submitted to the Faculty of Purdue University
In Partial Fulfillment of the Requirements for the degree of

Master of Science

School of Industrial Engineering
West Lafayette, Indiana
May 2021

THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. C. Robert Kenley, Chair
School of Industrial Engineering

Dr. Monica Cardella
School of Industrial Engineering

Dr. Vincent Duffy
School of Industrial Engineering

Approved by:
Dr. Abhijit Deshmukh

For my mom, dad, grandparents, family and community
that have thought systemically about my survival.
Thank You.

ACKNOWLEDGMENTS

Dr. Kenley, Thank You for your openness, your honesty, and your compassion towards me, my ideas and my goals. Your support has meant so much!

Dr. Cardella, Thank You for listening with both compassion and encouragement. You have deeply altered the course of my life!

Dr. Duffy, Thank you for your approach to teaching learning and life. Your presence has deeply inspired what I think is possible as an engineer and educator.

Community Partners, Thank you for your time and perspective! Your work means so much to me!

Site Coordinators, Thank you for your flexibility and openness to this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Socially engaged design programs, community development coalitions, and intentional and unintentional design spaces are rich with expertise and thinkers who are developing solutions to very pressing, yet complicated problems. Little research has been conducted on the expertise and sense-making of the community partners who participate in these situations. The goal of this research endeavor is to unpack the ways various community partners make meaning of their design experiences by answering the question: What evidence of system's thinking can be seen in the way community partners describe their work or context? A qualitative research study was conducted in which three community partners were interviewed at various points during their engagement with socially engaged design programs. They demonstrated their systems thinking ability most strongly across the following domains: differentiate and qualify elements, explore multiple perspectives, consider issues appropriately, recognize systems, identify and characterize relationships. These findings imply that the community partners are not only capable of systems thinking but have the potential to be more deeply involved in developing solutions within these settings. Future studies should investigate systems thinking beyond socially engaged design in formal settings and should consider investigation protocols that more directly surface systems thinking domains. Overall, this study contributes to existing work in systems thinking by calling for a more expansive and inclusive engagement of community partners in socially engaged work.

1 INTRODUCTION AND BACKGROUND

When thinking about the issues facing the next generation of engineers, one cannot help but consider the complexity of problem solving that will be required to make advances in healthcare, education, and technology in general. This complex problem solving will require the incorporation of stakeholders and thinking across disciplines and ways of knowing. Given its propensity for addressing complex issues, systems thinking is positioned to be very useful. Systems thinking can be thought of as a "diagnostic tool" used to address issues with the following characteristics:

- The issue is important.
- The problem is chronic, not a one-time event.
- The problem is familiar and has a known history.
- People have unsuccessfully tried to solve the problem before (Goodman, 2018).

1.1 The Context of Systems Thinking

Though this definition of systems thinking does not require those using it to be professionals, within academia, we often assume that systems thinking is our domain. Studies of systems thinkers are often focused on how engineers are addressing complex issues. While the systems thinking of engineers is worthy of study, something is lost and problematized when practicing engineering students are depicted as solely being responsible for using systems thinking (Eatman, Cantor, & Englot, 2017). Though we may consider the problems we solve to be important, we must reckon with our own elitism and the social distance between ourselves and those who face some of the most complicated problems.

1.1.1 What is Social Distance and why does it matter?

Social Distance has been defined as the perceived or desired degree of remoteness between a member of one social group and the members of another, as evidenced in the level of intimacy tolerated between them (Qin, 2016). Though the study of engineering is technically available to all identities, it functions as a space of privilege. Be it racially or professionally, engineers and engineering often serve to reinforce social and cultural hierarchies (Douglas, 2015). Though it can be argued that this phenomenon is a natural by-product of the capitalistic paradigm of the discipline, the ramifications have become a topic of focus across disciplines (Karwat, Eagle, Wooldridge, & Princen, 2014). Academia in general, and the corporations and institutions connected to it can be regarded as a space of social and professional elite. Though individual actors within these spaces may prioritize issues that do not directly affect them, they still do so from their perspectives of power.

In his book *Winners Take All: The Elite Charade of Changing the World*, Anand Giridharads describes potential issues with the elite positioning themselves as leaders for social change. He describes the implicit tendencies of elite professionals to "change the world in ways that essentially keep it the same." He writes: "much of what appears to be reform... is often as defense of stasis." Here, he implies that it is difficult for people within elite professions to truly imagine solutions to complex issues because much of their life and identity are intricately supported by some levels of that system staying the same. In this vein, professionals find themselves looking to "do good" in the world by "doing their job well."

To illustrate this point, Giridharads tells the story of various professionals who found themselves in corporate structure who either directly or tangentially aimed to "make the world a better place." In each of these examples, professionals found that though the intention to "help" existed, that "help" was relegated to things that would not alter the existing structures that supported their work. For example, when the collective problem solving of one organization revealed that immediate reform of social policy was needed, it became difficult for professionals to negotiate this needed shift and the economic implications of taking such a stance. In a sense, their hands were tied between conflicting constraints and stakeholders. Though these professionals had systematically understood the need, the opted for solutions that appeased their own relation to the stakeholders - which in the end did very little for those affected by the problem.

1.1.2 Addressing Issues beyond professional privileges.

While the scenarios described by Giridharads seem to point all blame at the institutions and professionals unable to self-sacrifice, these examples serve a purpose larger than finger pointing. His work points out on key fact: as we consider how to address the next generation of issues, we must not do so solely from our places of professional privilege. Instead, we must look at how those who do not have our privilege see these issues. How do people without our institutional connections address issues? How do those with a different set of stakeholders think about the systems they find themselves a part of?

These questions are the genesis for the research study presented here. With hopes of unpacking how systems thinking looks beyond the institution, I will attempt to answer the question: What evidence of **systems thinking** can be seen in the way community partners describe their work or context when participating in engineering engagement programs?

1.1.3 Engineering Engagement Programs.

In order to unpack these questions, this study takes a look at settings where institutions connect with stakeholders outside of their professional industries. Specifically, we will look at engineering engagement programs to understand how community partners engage with systems thinking by investigating their experiences within engineering engagement programs. These programs offer engineering students learning opportunities that take on different formats and naming. Some examples of nomenclature used to describe the approach or philosophy of engineering engagement programs are:

- community engaged design
- service-learning
- problem-based learning
- project-based learning
- in-service learning
- community service
- human centered design
- user centered design
- participatory design
- community driven design
- co-design

These design approaches range widely in their engagement of community partners though they often involve a cross-disciplinary set of stakeholders. These settings are ideal for understanding the systems thinking of community partners because they represent a cross-section of their work and problem solving. Before unpacking these programs, we will unpack systems thinking and what literature has to say about how evidence of systems thinking manifests.

2 LITERATURE REVIEW

2.1 Thinking in Systems

After thirty years of distilling wisdom from systems modeling and teaching, Donna Meadows uses her book "Thinking in Systems" to give readers basic insights on dealing with complex systems (Meadows, 2009). In her introduction, Meadows asserts:

"Serious problems have been solved by focusing on external agents— preventing smallpox, increasing food production, moving large weights and many people rapidly over long distances. Because they are embedded in larger systems, however, some of our "solutions" have created further problems. And some problems, those most rooted in the internal structure of complex systems, the real messes, have refused to go away. Hunger, poverty, environmental degradation, economic instability, unemployment, chronic disease, drug addiction, and war, for example, persist in spite of the analytical ability and technical brilliance that have been directed toward eradicating them." (p 4)

This quote contributes to the idea that systems thinking about complex issues is a persistent issue that will not be solved by individual or discipline-based brilliance alone. She goes on to say that these issues will " yield only as we reclaim our intuition, stop casting blame, see the system as the source of its own problems, and find the courage and wisdom to restructure it." Next, she outlines useful prompting questions for looking at systems:

Can you identify parts? . . . and

Do the parts affect each other? . . . and

Do the parts together produce an effect that is different from the effect of each part on its own? And perhaps

Does the effect, the behavior over time, persist in a variety of circumstances?

In discussing the inner workings of a system, Meadows adds that "many of the interconnections in systems operate through the flow of information" and that often times "Information holds systems together and plays a great role in determining how they operate." This operation is different from the function of the system. In this regard, Meadows clarifies that the function or purpose of a system is often the least obvious component but also the most crucial in determining its behavior. (p 16) Though this behavior may be difficult to track, systems thinking skills allow practitioners to bound and understand the behaviors. One of these skills involves understanding how elements of the system provide information and initiate action within other components. This idea is called “feedback” within a system and often presents itself in loops. These loops generate the complex behaviors of a system by causing one loop to dominate another. (p. 45) Loops generate growth, decline or stabilization of systems. Loops and the information-driven nature of systems can often give rise to delays in which an element of the system is constrained from its typical operation. Depending on the nature of the loop, delays can cause systems to oscillate around a less-than-optimal functionality. (p. 54)

After discussing how the complexity of these concepts increases as the number of inputs to and stocks (accumulations of material or information inside the system that have built up over time) within a system increases, Meadows goes on to make arguments for why thinking in systems is useful. She describes resilience as “a measure of a system’s ability to survive and persist within a variable environment” and goes on to assert that the resilience of a system “arises from a rich structure of many feedback loops that can work in different ways to restore a system even after a large perturbation.” Because all systems will endure some perturbation, internally or externally, Meadows adds that “Systems need to be managed not only for productivity, they also need to be managed for resilience — the ability to recover from perturbation, the ability to restore or repair themselves.”

Continuing to outline features of systems that generate value in thinking in systems, Meadows describes self-organization as “capacity of a system to make its own structure more complex.” This property is so natural to systems, that Meadows adds it is easy for practitioners to overlook the beauty and necessity of this property. Because of this, self-organization is often overlooked in favor of short-term productivity or stability. (p. 80) Though self-organization used to be too complex to study, understand or replicate, Meadows presents a few simple organizing structures that lead to a diversity in self-organization of systems. As an example, she demonstrates Koch’s snowflakes that generate a self-organizing system by recursively adding triangles to the midpoint of an equilateral triangle. The resulting patterns illustrate this point and can be seen in Figure 2.1

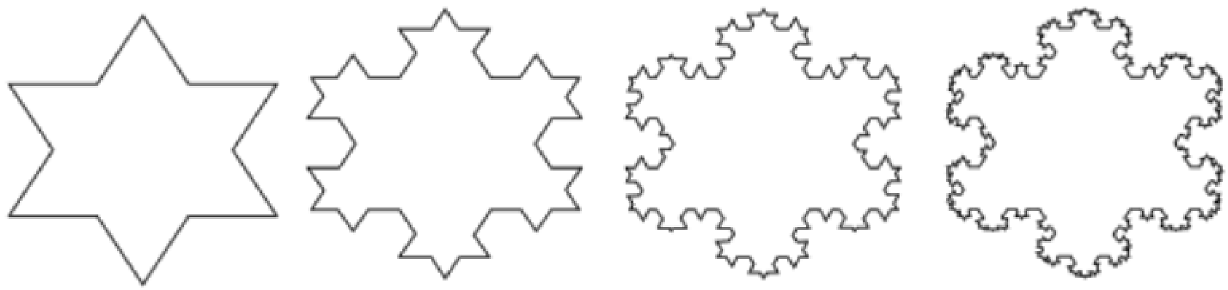

Figure 2.1. Koch Triangles from Meadows book p. 80

The self-organization of systems is often guided by another, less explicit property of systems: hierarchy. Meadows describes hierarchies to be "are brilliant systems inventions, not only because they give a system stability and resilience, but also because they reduce the amount of information that any part of the system has to keep track of." Hierarchies are often decomposable and create subsystems that are often easier to grapple with than the complete system. (Sometimes the goals of a subsystem can dominate the larger system, resulting in what Meadows defines as "sub-optimization" - a sometimes damaging effect of systemic hierarchies.)

As she concludes Part Two of her book, Meadows describes that thinking in systems surprises us because it illuminates the silent models we hold about the world. We prefer to think in a manner that does not consider the effects of current actions in one part of the system on other parts of the system due to boundaries between the parts of the system. This includes overlooking impacts on parts of the system within a prescribed boundary at a future time due to feedback loops. We exist in a world where interactions between parts of a system and feedback loops over time complicate our ability to foresee the full impact of our actions and often complicate our abilities to adapt and change effectively. These issues give rise to sub-optimal experiences of our models and world. In this vein, thinking in systems can be very helpful for conceptualizing the situations we find ourselves in.

Gerald Midgley, another expert on systems thinking, expands upon these conceptions in his article "The sacred and profane in critical systems thinking." After positioning marginalization as the process of transferring elements outside of a primary boundary, Midgley shows that value judgments not only are related to what is or is not contained within given boundaries, but also are related to what lies in the margins (Midgley, 1992). This idea builds on the notion of the significance of the relationship between ethical reasoning and making boundary judgments.

Because most ethical issues and their boundary judgments can be said to have roots in culture, Midgley argues that evidence for cultural reactions to the ethical tensions that arise will involve the imposition of value judgments on elements that are marginal to boundary definitions. This means that elements become demarked as either valued or devalued ("sacred" or "profane".) When this happens, either the primary boundary becomes sacred and is reinforced or the primary boundary becomes profane and the secondary boundary (and its associated ethics) are centralized. Naturally, this whole process becomes overlaid with behavior that contains certain stereotypical elements that involve the symbolic expression of wider social concerns. This behavior is defined by Douglas and Reach as a "social ritual (Midgley, 1992)." In short, Midgley explains that conflicts between certain boundaries will give rise to a complex systemic web of primary and secondary boundary judgments, marginalization, ethical conflicts, value judgments, and symbolic rituals. (demonstrated in figure 2.2) (p. 16)

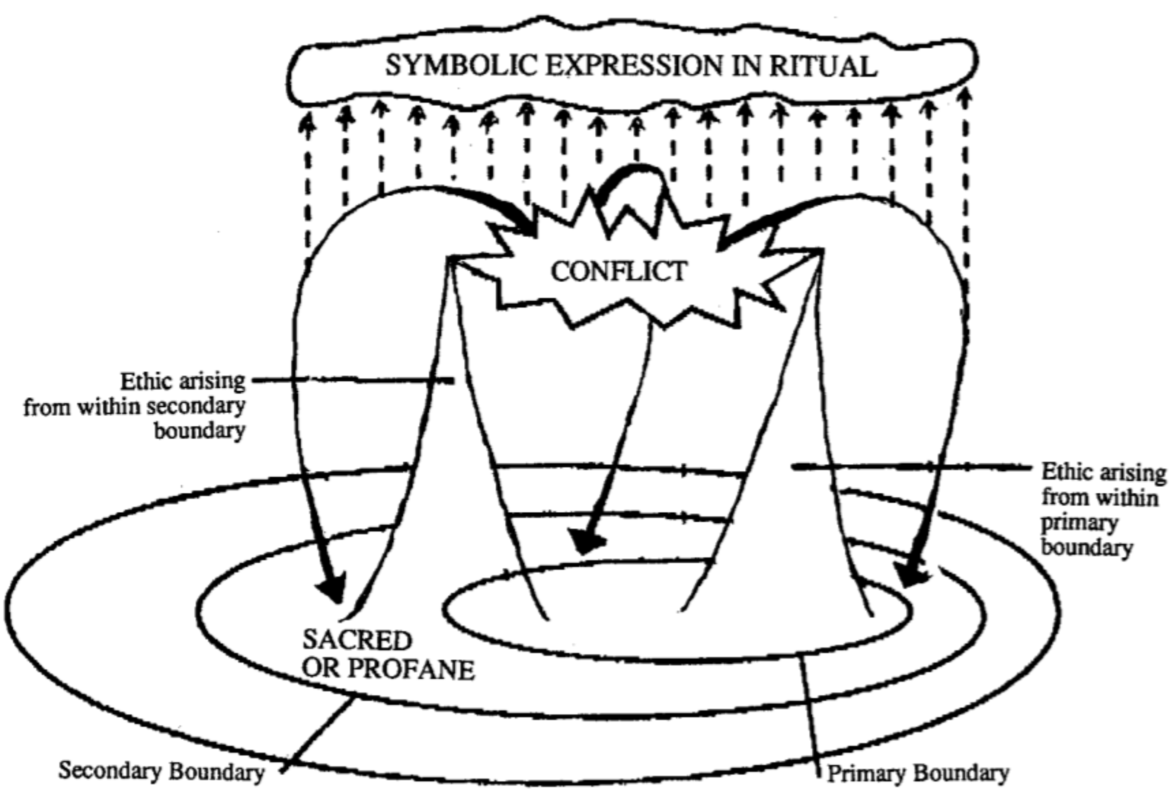

Figure 2.2. Relationship between Sacred and Profane according to Midgley

2.2 Other ways of conceptualizing Systems Thinking

Evidence of system thinking has been tackled from many disciplinary disciplines. Issues of complexity have been categorized by Johnson to have the following characteristics:

- The system contains a collection of many interacting objects or "agents"
- These objects' behavior is affected by memory or "feedback"
- The objects can adapt their strategies according to their history
- The system is typically "open"
- The system appears to be "alive".
- The system exhibits emergent phenomena which are generally surprising, and may be extreme
- The emergent phenomena typically arise in the absence of any sort of "invisible hand" or central controller.
- The system shows a complicated mix of ordered and disordered behavior (Johnson, 2007).

Dealing with the complexities of systems is the major function of systems engineering. How we teach systems engineering, however, is a much more complicated endeavor that reflects our clear and definitive understanding of what we mean to teach, and to whom, for what (Caldwell, 2009). As such, systems engineering has been defined by Caldwell as a phenomenon that manifest in four primary forms within education. The first, posits systems as a synonym for global, high-level analysis of a complex phenomenon. This form is easiest for new undergraduates and has an advantage of helping them communicate on a non-quantitative level with stakeholders. The second, is a more quantitative, mathematical framework for analysis in which probabilities of flow along a path and network analysis of stochastic behaviors becomes paramount. This form contributes to math and science fundamentals of operations research. The third focuses more on relationships as building blocks for systems and contributes to manufacturing fields by defining and maintaining quantitative rigor. The fourth focuses on processes and can provide tools for discipline-based engineering work. Caldwell contends that whichever form manifest within the education of engineers will be directly constrained by the point of view and priorities of the educator.

Yet another perspective of systems thinking centralizes point of view. Building upon Richmond's model of forest and the trees Nadine Schieritz and Peter M. Milling discuss a comparison of system dynamics and agent-based simulation which delineates the fact that systems thinkers may think of an individual agent within a system (a tree) or the larger functions of the system in which agents act (the forest) (Schieritz. Nadine & Milling, 2003). After connecting with previous scholars who have posited something similar, Shieritz and Milling suggest that an integrated approach has the potential to help decision makers develop the capacity of thinking at one and the same time of both, the forest and the trees (Schieritz. Nadine & Milling, 2003). This sentiment was shared by Hatfield who discussed the importance of seeing both the whole and the parts of systems (Hatfield, 2012).

The theories of systems thinking presented thus far indicate the complexity of establishing a single accurate definition of what systems thinking is. Arnold and Wade grapple with this truth by stating that systems thinking is its own system with supporting skills (Arnold & Wade, 2017). Arnold and Wade argue that systems thinking cannot be regarded solely by the skills, just as a system may not be regarded solely by its parts. Instead, Arnold and Wade suggest that both the individual skills and systems thinking as a whole are key to assessing the maturity of system thinking being exhibited by an individual.

While Arnold and Wade assert that the systems thinker tends to exercise Content, Structure, and Behavior skills while using insight, these exercises are not to be regarded as confining boundaries. In fact, they argue that these skills are negotiated through an iterative process of gaining and using insight. (Figure 2.3)

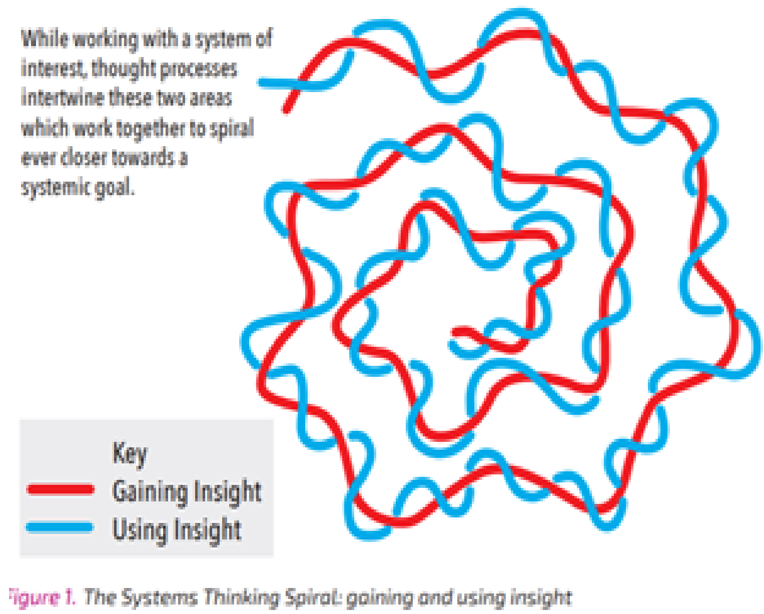

Figure 2.3. The Process of using systems thinking skills according to Arnold and Wade

In order to understand skills that support this process, Arnold and Wade suggest four domains: mindset, content, structure and behavior. The mindset domain focuses on how to approach systemic problems while content focuses on identifying the boundaries and elements within a system. Structure focuses on relationships, feedback loops and how systems are organized while behavior looks at what happens when parts of content and structure domains interact.

Understanding each of these domains requires an intricate blend of many perspectives on systems thinking. Thus, table 1 summarizes components of each domain along with the spectrum of behavior for systems thinking. (High and low maturity levels for each domain can be found in Table 2 of the Appendix.)

Table 2.1. Domains for Understanding Systems Thinking Skills

Mindset	Explore Multiple Perspectives
Mindset	Consider the Wholes and Parts
Mindset	Effectively Respond to Uncertainty and Ambiguity
Mindset	Consider Issues Appropriately
Mindset	Use Mental Modeling and Abstraction
Content	Recognize Systems
Content	Maintain Boundaries
Content	Differentiate and Quantify Elements
Structure	Identify Relationships
Structure	Characterize Relationships
Structure	Identify Feedback Loops
Structure	Characterize Feedback Loops
Behavior	Describe Past System Behavior
Behavior	Predict Future System Behavior
Behavior	Respond to Changes Over Time

Though there are many ways literature speaks to how evidence of systems thinking arise, many of these conceptions arise from studying those who are practicing engineers or systems engineers directly. Within the pre-college space, Science education has seen studies on student use of systems thinking to address issues of biology and climate change (Hmelo-Silver, C. et al, 2000; Puttick, G. & Tucker-Raymond, E., 2018; Riess, W., & Mischo, C., 2010). Studies beyond the pre-college space also within Science education focus on climate change and chemical engineering learning of students. (Berry, H.L. et. al, 2018; Orgill M. et al., 2019). However, none of these studies look at the abilities or experiences of non-technical or non-student engagement with systems thinking. Given the nature of systems thinking and its propensity for scaffolding thinking around complex issues, it is a wonder that more research has not been done on systems thinking in non-technical settings practiced by community partners. It is possible that these practitioners are experiencing and practicing systems thinking (intentionally or unintentionally) and that these experiences can shine light on techniques for affecting the complicated, persistent issues described by Meadows. Thus, in the following chapter, I will describe a study to unpack the ways community partners experience systems thinking.

3 METHODOLOGY

In order to understand the ways community partners conceptualize systems thinking, we must locate a scenario in which they are engaged in some complex problem solving. Though many studies attempt to accomplish this by investigating non-engineers' problem solving outside of the institution, this study focuses on community partners doing work within formal educational settings. In particular, it focuses on community partners participating in engineering engagement programming. These design approaches, as discussed in chapter 2, emphasize various approaches or philosophies:

- community engaged design
- service-learning
- problem-based learning
- project-based learning
- in-service learning
- community service
- human centered design
- user centered design
- participatory design
- community driven design
- co-design

Attempting to answer the research question "What evidence of **systems thinking** can be seen in the way community partners describe their work or context when participating in engineering engagement programs?" this chapter will focus on the research design of this study, the participants and programs they are involved in, and how data was collected from these programs. The following chapter will unpack how that data was collected.

3.1 Research Design

Investigating evidence of systems thinking requires a holistic conception of the context of thinking and problem solving. Thus, a qualitative research design was developed. Qualitative research or qualitative inquiry rose out of anthropology and sociology "answering questions about people's lives, the social and cultural context in which they lived, the ways in which they understood their worlds and so on" Qualitative research prioritizes "naturalistic" environments as opposed to laboratory or simulated environments (Merriam & Tisdell, 2015). Given this characteristic of qualitative research, there exists much confusion and disagreement on the best ways to implement a qualitative research study.

Given the fact that our research question attempts to describe, understand, and interpret systems thinking by unpacking evidence of systems thinking from the voices of community partners, the epistemic perspective that aligns best with this inquiry is interpretivist and constructivist. Participants exist within multiple realities: the reality of their own work and communities, and the reality of the program and project at hand. Based on these truths, this study was designed to allow participants to give voice to their conceptions of those realities.

3.1.1 Data Collection

Within qualitative research, data collection methodologies include observations, interviews, documents and audio-visual materials (Creswell, 2002). Each of these forms of data involves different data types and purposes. Though observations and document collection would provide a rich picture of the context of the community partners, a good amount of interpretation would need to be done in order to understand how the community partners are making sense of that data. Thus, this study is centered on semi-structured interviews of community partners before, during and after their participation in an engineering engagement program. Interviews were primarily conducted over the phone, though a select few were conducted in person.

3.1.2 Semi Structured Interviews

Semi-structured interviews are a data collection strategy in which the researcher asks participants a series of predetermined but open-ended questions (Creswell, 2002). These questions are intended to generate discussion of a context without leading the participant into responding in any particular response (Creswell, 2002). To avoid leading participants to "think in systems" because of the interview questions, an interview protocol was developed that focused on their problem space and work within the program. Interviews began with focusing on the participants' work before arriving at the project. Conversations then flowed to their work within the project, what they were expecting or were excited about, and what their concerns were. Sequential interviews built on prior interviews and allowed participants to make deviations based on what had arisen as salient for them. Table 1 in the appendix presents the interview protocol for each stage of the data collection process.

3.1.3 Data Types

In qualitative research involving interviews, data takes the form of the voice recordings and transcriptions of interviews. In this study, interviews were recorded and transcribed using third-party transcription services. Once these transcriptions were generated, they were reviewed and compared with audio files for accuracy.

3.1.4 Participant Selection

Given the myriad of project formations within engineering engagement programs, participants within this study were chosen based on the nature of their interaction within the program. In particular, participants in this study were working on problems that were directly connected to their work in function. Though community partners are often stakeholders of engineering engagement programs, participants in this study also had their own conception of stakeholders and how the work on the problem would better their work or eco-system. This criterion was key because it suggests that the community partners are also invested in problem solving and are not solely observers of the work. Additionally, participants within this study were engaged in a program in which they interacted regularly with the project and project team. Though this regularity varied across participants, each participant interacted in different ways with their problem. The goal of this criterion was to ensure that the engagement on behalf of the community partners is not one-off and evolves over time. These characteristics are key to establishing the possibility systems thinking may be employed by participants to deal with significant interactions between parts of the problem space and a time span that allows feedback loops to have an effect. Participants were not compensated for their participation in this study.

3.1.5 Positionality

Though my formal relationship to these participants will be described in the following section, this section unpacks my personal positionality as it relates to the study. As a graduate researcher involved with this study, I shared mediated control of the study with my advisor and committee members. This control allowed me to decide which participants would be interviewed and how to conduct the interviews including where to probe and how deeply. Additionally, as a person from a myriad of disenfranchised communities (people of color, women of color, low socioeconomic status) my approach to this study was based in a desire to advocate for and surface the perspectives of community partners who can be seen as the most marginalized participants of these design settings. However, having an undergraduate degree in engineering paired with my mediated control of the study meant that I had tangible and social capital within the study that could affect the way participants relate to my presence and respond to the interview questions. The follow section unpacks my relationship to selecting participants and the efforts taken to minimize the potentially disenfranchising aspects of my positionality.

3.1.6 Role of Researcher in Participant Selection

Due to the nature of the interview process, the last criterion in selecting participants was the pre-existing proximity to the researcher. In an effort to increase familiarity and comfort with speaking candidly, the participants selected for this study were associated with the researcher in some informal way. In some cases, this association was direct (i.e. being a grader or assistant in the course that housed the project), in other cases it was indirect (i.e. being loosely affiliated with the program that coordinates the project). These associations and proximity served a dual purpose. First, the sense of familiarity allowed conversations to start from a place of commonality. Having seen the researcher associated with the project or program loosely, the participants were able to gauge my investment in the program. Secondly, this proximity allowed the researcher to be familiar with the details of the program which allowed for an increased ability to probe into the nuance of the participant responses.

3.2 Participant Descriptions

Participants in this study were from three different engineering engagement program types. The following section describes these programs, the associated participant and the focus of the projects. Participants and Programs have been given pseudonyms to protect identities. A summary of this information can be seen in Table 3.1.

Table 3.1. Participant and Program Description

Participant Pseudonym	Program Pseudonym	Class Focus	Length of Class	Length of Project	Project Focus	Group Size	Interaction pattern	My Role
Toni VanWeiser and Joanne Duncan	Program I	Academic & Professional Excellence & Skill Building	Semester	Semester	Design Process + Partner Problem	4	Weekly	Coordinator + Researcher
Yasmine Gavarti	Program II	Community Service & the Design Process	Semester	Semester+	Design Process + Partner Problem	4	Monthly	Researcher
Tiffany Smitherman	Program III	Systems Thinking	Semester	3 weeks	Systems Thinking + Partner Problem	5-6	Bi-weekly	Grader + Researcher

3.2.1 Program I: Toni VanWeiser and Joanne Duncan

Program I was a semester-long program in which engineering students were paired with local community partners to solve problems that mattered to the community partners. Students were expected to meet with their community partners weekly to discuss the problem at hand and co-design solutions to the problem. Though the focus of the class was academic and professional skills development, the focus of the project was to give the students practice using and working through the design process. As such, students were supposed to learn diligence and collaborative problem solving.

Within Program I, Community partners were expected to communicate and interact with their students often. This communication was primarily focused on the problem at hand, though more collegial bonds were often built. Within Program I, partners Toni VanWeiser and Joanne Duncan were interviewed at the beginning, middle and end of their semester-long work with the students. Outside of this program, their work focused on the health and safety of rural communities, so their project was centered around developing a walkway for residents of a particular area. Though neither Toni VanWeiser nor Joanne Duncan lived in the area themselves, their work focused on that area and they each had their own experience and investment in the area.

Within the space of the project, Toni VanWeiser and Joanne Duncan worked with the same four students, communicating weekly and co-developing a pathway that would meet the constraints of the students.

3.2.2 Program II: Yasmine Gavarti

Program II was a program in which engineering students were paired with local community partners to solve problems that mattered to the community partners. Community partners are given the options to work with students for as many semesters as they would like, though the group of students changes per semester. Students were expected to meet with their community partners monthly to discuss their progress with the problem at hand. Though community partners are asked to give directions and feedback to the students, the project is to be primarily completed by the students. Though the focus of the class was community development and design process skills development, the focus of the project is determined by the community partner, in this case Yasmine Gavarti.

Within Program I, partner Yasmine Gavarti was interviewed at the beginning, middle and end of her semester-long work with students. Though she had worked with different students in prior semester, Yasmine Gavarti insisted that her work during the investigated semester was "unique yet supportive" to prior semester projects. Outside of this program, Yasmine Gavarti's work focuses on the education and experiences of the hearing-impaired community. As such, the problem her students were working on was to design a technology to help deaf people experience music via haptic sensors. Yasmine Gavarti was both professionally and personally invested in this project as one of her family members was deaf. Within the space of the project, Yasmine Gavarti worked with the same four students, communicating monthly and providing feedback to the students during their project.

3.2.3 Program III: Tiffany Smitherman

Program III was a month-long program in which engineering students were paired with local community partners to solve problems that mattered to the community partners. This program was situated within a semester long class in which students learned about systems thinking in preparation for their work with the community partner. Students were expected to meet with their community partners bi-weekly to discuss the problem at hand and their selected solutions to the problem. Though the focus of the class was systems thinking, the focus of the project selected by the community partner. Tiffany Smitherman's work outside of the project focused on advising university students who may be struggling academically. As such, the problem she presented to the students within Program III involved the issue of communicating services to students who need them.

Within Program III, Community partners were expected to communicate and interact with their students at specified points of check in. This communication was primarily focused on the problem at hand. Within Program III, partners Tiffany Smitherman was interviewed at the beginning, middle and end of their semester-long work with the students.

Once interviews were completed and transcribed, they were investigated for evidence of systems thinking. Chapter 4 will explore this in more detail.

4 DATA ANALYSIS

Once Data collection had been completed for each participant, Interview transcripts were analyzed using NVIVO Coding Software. Three rounds of coding were conducted: the first pass looked for emerging themes, the second refined those codes and the third connected those themes to the framework for systems thinking outlined by Arnold and Wade (Arnold & Wade, 2017). The following chapter will describe these rounds of coding and the next chapter will discuss the results of this analysis.

4.1 Round 1: Emergent Coding

Because participants were not directly interviewed about the systems they interacted with, the first round of coding sought to categorize and organize their responses to the interview questions. To accomplish this, interview transcripts were reviewed in NVIVO software and coded according to topics and themes that arose. For example, when Toni VanWeiser commented "I was hoping for a little more depth, but I realize they probably ran out of time, you know, with an exact route," it was coded as "Time Limitations" because she is describing an element of the work that could not be completed because of limited time. Coding this way resulted in approximately 38 major codes (shown in Figure 4.1) and 75 sub codes.

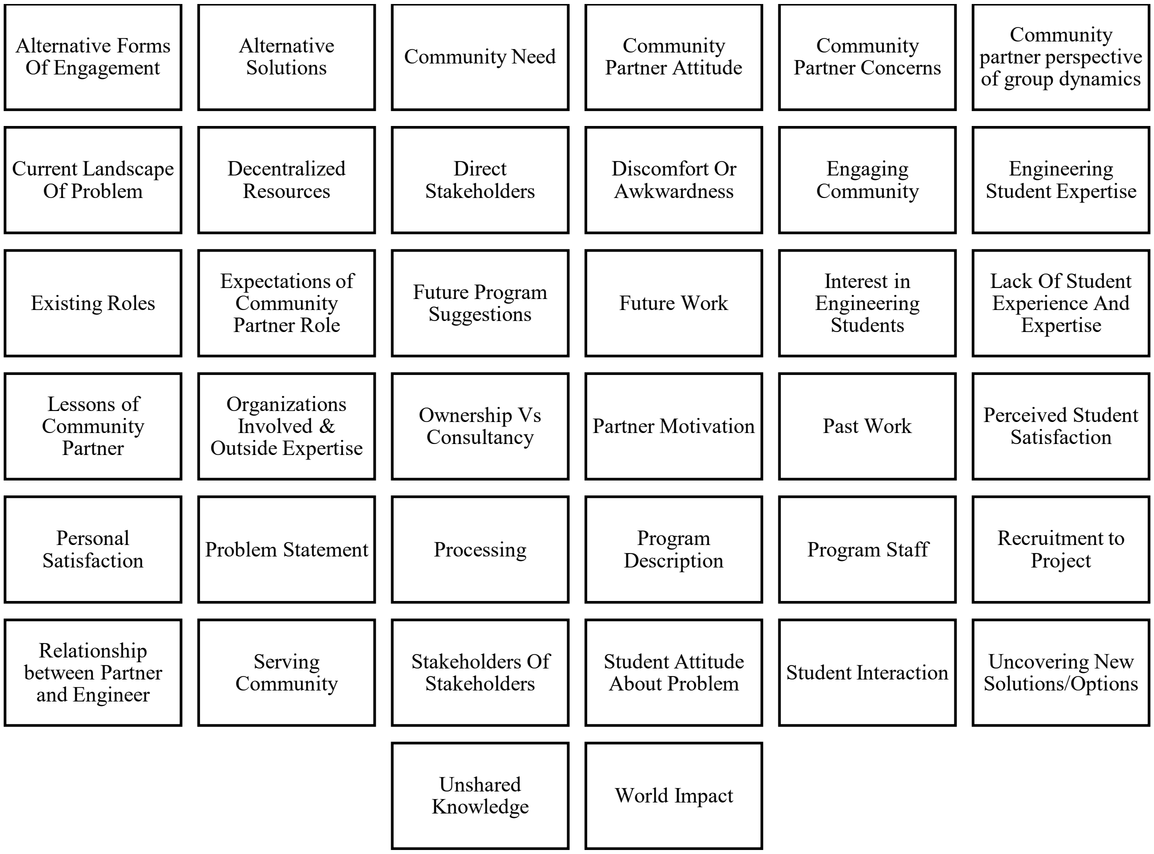

Figure 4.1. Preliminary Code Book of Emerging Major Codes

4.2 Round 2: Emergent Code Book Refining

Next emergent codes were organized into larger buckets and then refined to surface more clear conceptions from the participants. To accomplish this, the the 38 major codes and 75 sub codes were organized into seven categories and displayed in Figure 5:

- Community Partner Concerns
- Community Partner Commentary
- Relationship between Partner and Engineer
- Mention of Design Process
- Original Interest in Engineering Student
- Actual Input from Engineering Student
- Future Work

Community Partner Concerns

- Past Work on Project
  - Lack of expertise
  - Lack of Responsibility/Ownership
  - Misalignment of personalities
- Current Work Project
  - Infeasible solution
  - Scalability of Solution
  - Lack of Completion
  - Lack of innovation
- Student Engagement
  - Irrelevance to engineering students
  - Lack of engagement from Engineering Student
- Capacity Related
  - Lack of power
  - Lack of Resources
  - Time Limitations
- Context Related
  - Lack of University cohesion
  - Unshared Knowledge
  - Program Logistics
  - Time Limitations

Community Partner Commentary

- Recruitment to Program
  - Personal connection
  - Professional Connection
- Partner Motivation
  - Stakeholders
    - Low-income population
  - World Impact
  - Community Need
    - Lack of public transportation
    - Lack of Awareness
  - Serving Community
  - Personal Satisfaction
- Expectations of Community Partner Role
  - Confusion
  - Open to various ideas
  - Providing context and history
- Program Description

Relationship between Partner and Engineer

- Partner Existing Role
- Partner Input
  - History and Context
  - Keeper of Nuance
  - Providing feedback
  - Clarity and Guidance
  - Inside of work perspective
  - Inspiration
- Partner Role
  - Facilitation
  - Advisor
  - Mentoring
  - Resource
- Relationship Description
  - Consultancy
  - Independent
  - Respectful
  - Appropriate
  - Professional
  - Awe/Wow
  - Comfort
- Communication with student
  - Sporadic
  - Student initiated
  - Appropriate
  - Discomfort/awkwardness
- Partner Perspective of Group Dynamics

Mention of Design Process

- Stakeholders
  - Direct Stakeholders
  - Stakeholders of Stakeholder
  - Students as Stakeholders
- Iteration on Design
- Progress
- Non-feasible solutions
- Alternative solutions
- Learning from other projects
- Problem statement
- Outside expertise
- Outside organizations
- Interest or Mention of systems
  - Feasibility matrix

Original Interest in Engineering Student

- Engineering students as stakeholders
- Curiosity
- Engineering Student Expertise
  - Question Asking
  - New Solutions
  - Listening
  - New Solutions

Actual Input from Engineering Student

- Personal experience
- Concrete Expertise
  - Material Selection
- Mental Skillsets and Behaviors
  - Deductive Reasoning
  - Question Asking
  - Problem Solving
  - Systems approach
  - Improvement
- Qualities
  - Leadership
  - Consistency
  - Hardworking
  - Dependable
  - Maturity
  - Invested

Future Work

- Program Suggestions
- Pass off to next team
- Desire for different demographic of engineering students
- Re-work project to make more specific

Figure 4.2. Refined Codebook

Once the codes were re-organized, a second pass of coding was conducted to review the connections between the codes and the actual voices of the participants. This process resulted in dismissing 25 major codes and 39 sub codes due to very loose interpretations. For example, the code “progress” was dismissed because the participants voice associated with that code were better encapsulated in another code: “iteration on design.” Redefining and dismissing codes are a natural part of qualitative data analysis. (Lewis, 2009). This process resulted in a refined code book of 13 codes and 36 codes in Figure 4.3.

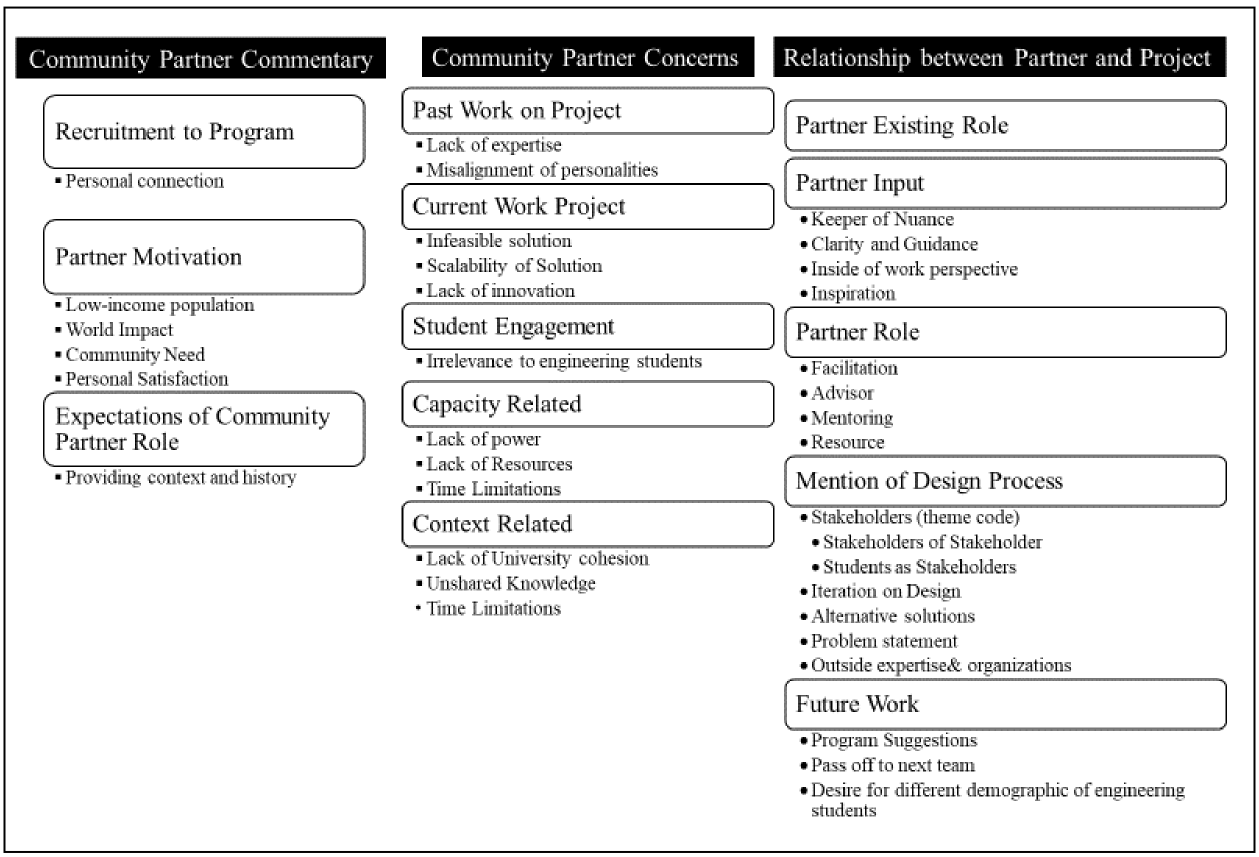

Figure 4.3. Refined Code Book After Second Pass Coding

4.3 Round 3: Connecting codes to Systems Thinking framework

Once a refined codebook was established, the remaining codes were mapped on to Arnold and Wade’s framework for systems thinking with end in mind that the mapping will help answer the research question: What evidence of **systems thinking** can be seen in the way community partners describe their work or context?

This framework was established to evaluate the maturity of systems thinking, the first level of the framework describes four different domains with various components. Table 4.1 describes those domains and components.

Table 4.1. Domains of Arnold and Wade's Framework (2017)

Mindset	Explore Multiple Perspectives
Mindset	Consider the Wholes and Parts
Mindset	Effectively Respond to Uncertainty and Ambiguity
Mindset	Consider Issues Appropriately
Mindset	Use Mental Modeling and Abstraction
Content	Recognize Systems
Content	Maintain Boundaries
Content	Differentiate and Quantify Elements
Structure	Identify Relationships
Structure	Character Relationships
Structure	Identify Feedback Loops
Structure	Characterize Feedback Loops
Behavior	Describe Past System Behavior
Behavior	Predict Future System Behavior
Behavior	Respond to Changes Over Time

The mapping of the codes onto the framework was established first by reviewing the codes and mapping them on to the framework with the perspective that the system that is being thought about is the work or context of the community partners rather than a collection of artefacts that the students are developing to hand over to the community partners to address the situation. This mapping is reflected in Figure 4.4.

Codebook x Wade Framework	Mindset					Content			Structure				Behavior		
	1A	1B	1C	1D	1E	2A	2B	2C	3A	3B	3C	3D	4A	4B	4C
Community Partner Concerns															
Past Work on Project															
Lack of expertise										X			X		
Misalignment of personalities										X			X		
Current Work Project															
Infeasible solution		X						X	X						
Scalability of Solution		X						X		X					
Lack of innovation			X					X		X					
Student Engagement															
Irrelevance to engineering students		X					X			X					
Capacity Related															
Lack of power		X	X	X		X									
Lack of Resources		X	X	X		X									
Time Limitations		X	X	X		X	X								
Context Related															
Lack of University cohesion						X	X		X	X	X	X			
Unshared Knowledge											X	X			
Time Limitations							X				X	X			
Community Partner Commentary															
Recruitment to Program															
Personal connection				X	X	X	X		X						
Partner Motivation															
Low income population								X	X	X	X				
World Impact		X				X		X	X	X	X				
Community Need		X							X	X	X	X			
Personal Satisfaction				X											
Expectations of Community Partner Role															
Providing context and history				X	X								X	X	
Relationship between Partner and Engineer															
Partner Existing Role						X	X	X						X	X
Partner Input															
Keeper of Nuance	X	X			X	X	X		X	X				X	X
Clarity and Guidance		X	X	X		X	X	X	X	X				X	
Inside of work perspective		X	X	X		X	X	X	X	X				X	X
Inspiration			X	X										X	X
Partner Role															
Facilitation	X	X	X	X	X	X		X	X						X
Advisor	X	X	X	X		X	X								X
Mentoring	X	X	X	X				X							X
Resource	X	X	X	X				X							X
Mention of Design Process															
Stakeholders (theme code)															
Stakeholders of Stakeholder	X	X		X		X	X	X	X	X	X	X			
Students as Stakeholders	X	X		X		X	X	X	X	X	X	X			
Iteration on Design			X					X			X	X		X	X
Alternative solutions	X	X		X	X		X	X							X
Problem statement					X	X	X		X	X					
Outside expertise	X						X		X	X					
Outside organizations	X						X		X	X					
Future Work															
Program Suggestions		X		X	X			X						X	
Pass off to next team			X	X										X	X
Desire for different demographic of engineering students	X														

Figure 4.4. Mapping Refined Code Book onto Arnold and Wade's Framework

Next, voices of participants were surfaced in connection to Arnold and Wade's framework and reviewed by each domain of their framework. The results of this analysis are presented and discussed in the following chapter.

5 FINDINGS AND DISCUSSION

As discussed in Chapter 2, Arnold and Wade's Framework for systems thinking is broken down into four domains: mindset, content, structure, and behavior. This chapter will explore the resulting transcripts associated with each domain of the framework.

5.1 Mindset Domain

Arnold and Wade assert that the Mindset domain concerns itself with how we approach systems and systemic problems. Though this is a higher-order set of skills that precedes all other systems work, they also assert "the key point is that the effective use of these skills results in a mindset and tends to manifest as problem-solving philosophy." This domain tends to develop over time and assist in gaining insight into a particular system.

5.1.1 Mindset 1A: Explore Multiple Perspectives

"A systems thinker investigates a problem by objectively examining multiple subjective perspectives" (Arnold & Wade, 2017). Participants in this study exhibited this domain primarily in their initial interest in being involved in the socially engaged design program. In deciding to participate, the partners were looking to explore more perspectives on the problems they were facing. Some partners were able to identify this explicitly in their first interviews. Toni Van Weiser mentioned that she was "intrigued to be able to work with engineering students" because she and her team had not been able to address their issue of developing a walkway for their neighborhood during their own brainstorming sessions.

Other partners made explicit mention to desiring more perspectives in expressing their dissatisfaction with their student group. Initially, Tiffany Smitherman was "hoping the students can provide the student perspective but (also) have some self-awareness of what their barriers or reasons for were not seeking resources proactively." As her experience with her students was ending, however, Tiffany Smitherman reflected "I think it's also interesting because they are juniors and seniors and some of their perspective is also lost because they aren't first year students." Though she was explicit is seeking out more perspectives for her project in general, her involvement in the program seems to have surfaced a more specific desire for alternative perspectives.

5.1.2 Mindset 1B: Consider the Wholes and Parts

Simultaneously appreciating both the wholes and parts is a critical systems thinking skill (Cabrera, 2008). Beyond exploring multiple perspectives, partners demonstrated the ability to consider the whole and parts of the systems they were working within. For example, Tiffany Smitherman was able to identify they parts of her project that were conflicting with other, before unaddressed, parts of the system her project was developing in. In regards to having a system with resources available to students at the right time, Tiffany commented "It's also hard if a student has a negative experience, I may know about it, but I'm not necessarily in a position of power to be able to change or impact the experience for other students. I just know that this one student felt a certain way." In this example, Tiffany is considering the parts of her role and goals that are beyond her realm of influence.

5.1.3 Mindset 1C: Effectively Respond to Uncertainty and Ambiguity

"When dealing with systems, uncertainty and ambiguity are often present. However, a systems thinker should be able to make decisions that guide a system towards a desired state" (Burandt 2011). Participants of this study made explicit mention to uncertainties related to the students they were working with and the scalability of their work. Tiffany Smitherman commented on the uncertainty related how the project would be owned once it was passed off: "So like, thinking through that like um, it may be a good idea, but when you scale it out and you're the one that's committing the time and money to it. It's easy for it to outweigh the cons [when] it's not your investment." Though she was unable to address this element within her work with the student, Tiffany goes on to discuss that she will have to continue to work with the student's design suggestions in order to make them scalable.

5.1.4 Mindset 1D: Consider Issues Appropriately

"An experienced systems thinker takes time to absorb the complexity of a situation rather than reacting immediately to (even stressful) stimuli (Waters and Waters 2014). Considering issues appropriately is a key part of the systems thinking mindset. The ability to determine what “appropriate” means for a given system is also part of this skill (Arnold & Wade, 2017)“ Participants in this study were the most explicit in dealing with issues related to their engagement with the students. For example, Toni and Joan were concerned that one of her students was not partipating as deeply as the other students. Instead of directly raising the issue to the student’s instructors, they spent some time observing the student and making more clear pathways for him to participate. “it’s not that he’s disengaged, he just has a different way of engagement ... he looks at things, he’ll be doing something… I initially was thinking he was just playing on his computer [but] he was looking up stuff that we were discussing. So, I mean he was engaged but differently.”

Tiffany also had issues arise related to student engagement. When she had a student, who adamantly disagreed with the usefulness of the services of her office, she continuously reframed the students concerns as a part of the problem they were planning to work on: “And I’m like, yeah, … that’s the situation I’m trying to address … how do we help, you know, to ***use*** resources. So, it was kinda funny that there were confirming part of that situation is yeah, you don’t think you need them, so how can we help you be more proactive.” In this example, Tiffany did not seem offended by the students potentially road-blocking behavior. Instead, she considered his concerns, and responded with clarity on the purpose of their work together in a light-hearted but assertive way.

5.1.5 Mindset 1E: Mental Abstraction and Modeling

“It is not possible to fit all of the reality into our minds; therefore, we model various aspects of reality (Richmond 2004)… Systems thinkers mentally model systems and parts of systems as a way to simplify and understand structure and behavior.” Participants made most explicit mention to this domain in describing their role within their student group. Tiffany Smittherman described her role as “having just a better context and historical perspective on the issue… and knowing some of the nuances of the situation was important.” She then went on to describe that “there is a difference in attacking a problem when you’re a creative consultant versus when you’re the person that would then have to own this forever, right?” Here, Tiffany is describing her ability to hold mental models of the work the students are doing and abstracting it down to the level she will eventually have to work with it on. Though Tiffany did not explicitly use the word “model” to describe her work, it is clear that she had to hold and manipulate her conception of her work in order to understand that the nuances would affect it.

5.2 Content Domain

The Content Domain of Systems Thinking concerns itself with what is inside and outside of the system. Within this domain, participants conduct a variety of activities including recognizing the system, maintaining system boundaries, and differentiating and qualifying different elements.

5.2.1 Content 2A: Recognize Systems

"Recognizing that a particular problem is systemic is often considered the first step when exercising systems thinking (International Council on Systems Engineering 2014). At this point, the thinker has not yet defined the boundaries of the system but recognizes that such a construct exists and may have a conceptual idea of its contents. (Arnold & Wade, 2017)" Participants in this study made mention to the micro and macro systems affecting their work. When describing some of the limitations of her work, Yasmin Gavarti recognized the university system as interacting with her work: "I feel that the university as a whole should be more cohesive in when it comes to these projects.... You have all these little labs and all these little silos that are separated from one another...And to me the tragedy is that everybody can benefit by being cohesive and aware of what each other is doing because they can contribute, you know."

Tiffany Smitherman identified a similar systems issue that create the basis for the problem she was working on with the students: "the problem is around tutoring and academic support resources on our campus, they're decentralized and so it's kind of a multistep problem or sub problems where it can be difficult for students to find different resources because it's not like one location, so there are all across." Here Tiffany is recognizing that the larger system of how student resources are purveyed is directly impacting her work.

5.2.2 Content 2B: Maintain Boundaries

"The boundary defines the content of the system. Maintaining that boundary is a key systems thinking skill (Boardman et al. 2009, Frank 2012, Valerdi 2012). Maintain is the key word here, as it indicates that this skill is continuously applied. (Arnold & Wade, 2017)" Participants spoke to this competency the most when they described the bounds of their roles as it relates to the project. In responding to the suggestion that marketing of the services be a larger function of her office Tiffany Smitherman responded: "my job is to provide students with academic support and so it's hard to separate out how it does and doesn't affect my job because if students don't know about the resources, part of my job is to help them know about it." Tiffany goes on to assert "I'm the director of the academic success center and we provide a lot of different supports and resources, but tutoring is not one of them... so my role as director of the ASC is to try to help students find the resources, understand which ones are available for them, um, and hopefully drive participation to those." Here, Tiffany initially attempts to establish and maintain the boundaries of her role, though her work within the program is possibly expanding her conceptions of those boundaries.

5.2.3 Content 2C: Differentiate and Qualify Elements

"Understanding and differentiating between the elements in a system, such as their properties, types, and natures, are critical to understanding systems (Plate and Monroe 2014, Stave and Hopper 2007). "Participants in this study exemplified this domain most when describing the solutions suggested by the students they were working with. Some partners qualified solutions based on feasibility, such as when Tiffany commented "my one concern is that they'll come up with a solution that's great and makes sense for them that we still won't be able to implement." Here, Tiffany is prepared for the students to generate a solution that she qualifies as infeasible. Yasmin articulated concerns related to the lack of innovation in student solutions when she says "I mean they are very thoughtful and they were doing a lot of deductive reasoning, you know, but I think that, um, they, they still need to push the boundaries of thinking out of the box..." Here Yasmin has qualified the work of the students thus far "inside the box."

Participants also qualified themselves as elements in the system. In describing their role when working with the students, Toni describes ""I think it kind of started out more facilitating and then I think it changed to being a resource." Here, Toni differentiates between the role she played with the students between facilitating the work and becoming a resource to the work. Tiffany does something similar when she specifies her role within the group to be "more like an advisor, you know, I think it's more along those lines... critiquing and in terms of yes is the right direction."

5.3 Structure Domain

The Structure Domain of Systems thinking revolves around how the content of the system is organize. This domain includes how participants identify and characterize both relationships and feedback loops within the system.

5.3.1 Structure 3A & B: Identify & Characterize Relationships

"Recognizing that two parts of a system relate to one another in some way is a basic systems thinking skill (Senge, et al. 1994; Squires et al. 2011; Stave and Hopper 2007; Arnold & Wade, 2017)" In identifying the way a lack of university cohesion affected students, Yasmine Gavarti demonstrated that she had identified and characterized the relationships between various university silos as problematic to the work she was trying to accomplish. Even further, Yasmin demonstrates a further grasp of the relationships at play when she comments on her own relationship with the team of students: "I'm the facilitator, I guess, you know, I kind of guide the projects… lead them to what projects would be useful. So, I guess I'm the one that kind of plants the seeds. They're the ones that take it to town, you know." Here, Yasmin characterizes her relationships with the students in terms of their respective functions.

Before beginning the project, Toni and Joan characterized the players working on the project and their limitations in getting progress accomplished: "stubborn personalities on [the board] and people would go to them with ideas and need their approval and… they weren't the least bit interested." Here, Joan recognizes that the relationship between previous elements of the system were not working because of the personalities and priorities of those who owned the project. Toni continues to characterize how they plan to address this relationship: "we're interested in having the presentation to take back to the community … because we had important players there that would need to take the next step to accomplishment." Here, Toni characterizes the relationship between the community and the project and their ability to take the project to the next level.

Toni and Joan go on to describe their relationship within the system when she describes that she and Joan are: "more of a community partner to the problem, because we're not on the town council; are not part of the county government." Here Toni demonstrates that she has identified and recognized the various relationships at play and their positionality within those relationships.

5.3.2 Structure 3C & D: Identify & Characterize Feedback Loops

"Relationships can form feedback loops… This skill is potentially different than just recognizing that relationships exist or recognizing their strengths; this is recognizing that something different occurred or is occurring here; something emergent. (Arnold & Wade, 2017)"

Though there is evidence of feedback loops that may have affected the work of the participants, participants made no comments that would demonstrate that they had identified or characterized any feedback loops.

5.4 Behavior Domain

The behavior domain deals with how elements interact to produce behavior and how that behavior can be altered. The domain incorporates the thinkers' ability to describe past system behavior. Predict future system behavior and respond to changes over time.

5.4.1 Behavior 4A: Describe Past System Behavior

"Describing past system behavior requires an understanding of how the system has worked in the past. (Arnold & Wade, 2017)" Participants were able to describe how the system of the problem they worked on with their students functioned in the past. After describing the stubborn personalities that posed as obstacles in the past, Toni commented: "what we were thinking would be good for the community and the sidewalk project had kind of started but stalled because they didn't have kind of the background info to help them and have somebody plot it out that really understands how to plot it out as well as maybe do some research on the statistics behind it and the need needs portion of it." Here she was able to identify that the existing elements of the system were not enough to complete the work.

5.4.2 Behavior 4B: Predict Future System Behavior

"Predict Future System Behavior skill emerges as a combination of all Content and Structure skills. … This includes an ability to recognize epochs of operation after which a system might change in substantial ways. (Arnold & Wade, 2017)" Participants in this study embodied this loosely when they made mention to future work. For example when Yasmine describes "ultimate goal is that … they should ultimately complete whatever their ideas are, um, or at least get close so that the next round of teams can take it another step further" she is demonstrating her understanding that whatever work is "done" by the students will need to be continued by the following teams. In a later interview, she describes that she is hoping "[their design] can be taken up many notches" demonstrating that she is aware that the process of her work will be iterative.

While this may not demonstrate her explicit awareness about how the system of her work will change, she does demonstrate an awareness that the work will change and evolve.

5.4.3 Behavior 4C: Respond to Changes Over Time

"A key systems thinking skill is the ability to effectively respond to changes in a system over time (Waters and Waters 2014), rather than treating a system as an unchanging entity. A systems thinker needs to continuously evaluate whether a given strategy is still valid, or whether system behavior is fundamentally different due to changes that occurred over time. (Arnold & Wade, 2017)" Though no participants made explicit mention to how their approach to the system of their work changed overtime, it is evident in the evolution of the problem statement of some groups. For example, Toni and Joan first described their problem as follows:

> "There has been several people in the community who have come to us after [a] workshop and said, Oh…we would really like to see a sidewalk going from town out to the grocery store because we see people walking on the wrong side of the road. They have no place to get over. It's on a state highway that they would really like to see something done and every time a group gets together and gets excited and then it kind of stops. It's happened a couple times."

Here Toni describes the problem and its source as it has been presented to her. During our next interview, the problem was described as follows:

> "I think initially we had hopes that we could figure out a way of getting the pathway along the highway but not very optimistic … after [the students] saw it and we've looked more closely in talking with the group, it's like okay, the pathway through the neighborhood definitely would be better."

Here it is evident that the initial framing of the problem statement implied that the pathway would need to be along the highway. At this point in the process, it would appear that Toni and Joan's work has shifted to focus on ***any*** pathway that may allow people to travel safely. By the final interview, Toni and Joan described the problem more concisely:

> Toni: "We're addressing providing a walkway to our local grocery store."
>
> Joanne: "I would say safer"
>
> Toni: "safer route for people to walk to a grocery store in our town."

By the final interview, Toni and Joan's conception of the problem statement had evolved and become more concise. Though it is hard to pinpoint which element in the system caused the shift in the problem statement, it is evident that the participants did respond to some shift in the system over time, resulting in a different and more clear problem statement.

5.5 Summary Across Domains

Evidence of Systems thinking was found for every domain in Arnold and Wade's framework except 3C & D Identify and Characterize Feedback Loops. Figure 8 Summarizes the findings surfaced in this chapter. Implications of these findings will be discussed in the following chapter.

I	X			X				X	X	X			X		X	7
II						X		X	X	X				X		5
III	X	X	X	X	X	X	X	X								8
	2	1	1	2	1	2	1	3	2	2	0	0	1	1	1	

Figure 5.1. Summary of Findings across Programs

5.6 Most Frequent Domains

The following section will describe the most salient domains of systems thinking that arose from participant responses. In order of how frequently they arose across programs, the most salient domains were as follows:

1. Content 2C: Differentiate and Qualify Elements

Mindset 1A: Explore Multiple Perspectives

Mindset 1D: Consider Issues Appropriately

Content 2A: Recognize Systems

Structure 3A & B: Identify & Characterize Relationships

5.6.1 Content 2C: Differentiate and Qualify Elements

Participants from all three programs demonstrated their ability to differentiate and qualify elements surrounding their work. Tiffany did so in expressing her concern about the feasibility of student solutions. Yasmine did so in expressing her concern about the level of innovation of the student work and Toni did so in describing her conception of her role for the students. In all cases, participants demonstrated their ability to differentiate elements of their work. Though Arnold and Wade's framework uses the domain to describe one's ability to "identify and differentiate between stocks, flows as well as other types of variables and elements," participant responses of this study imply that within the given purview of the participants, they were able to differentiate elements related to the quality of the solutions suggested by the students and the type of role they played in getting there.

Future studies could unpack this finding by asking participants to explicitly identify the elements of their work with the students and describe their understanding of it. Additionally, future programs can better support this domain by giving participants the chance to alter the bounds of their involvement based on their ability to identify elements limiting their involvement, which is related to Content: Maintain Boundaries. Another possible area of future investigation related to Differentiate & Qualify Elements and Maintain Boundaries is to more deeply explore boundary setting as described by Midgley (Midgley, 1992).

5.6.2 Mindset 1A: Explore Multiple Perspectives

Participants from programs I and III demonstrated their ability to explore multiple perspectives within this study. Toni did so as she described her motivation for joining the program, citing that thus far her team was limited in their ability to address the problem on their own and that she was hoping the students could provide a perspective they did not have. Tiffany similarly described her interest in working with students as a hunt for additional perspectives that had not yet informed the problem she was aiming to solve. (Though it can be assumed that most partners join programs like this because they assume students can provide a perspective like this, only Toni and Tiffany mentioned it directly.) Arnold and Wade's framework describes level four of five of this domain to be when one "actively explores unfamiliar perspectives but still tends to miss non-obvious perspectives." For Tiffany's problem of developing a system for students, exploring student perspective could be classified as an "obvious" perspective. For Toni's problem of developing a walkway, the exploration of engineering student perspectives was non-obvious and may nearly be classified as level five of Arnold and Wade's framework. Toni did not mention exploring multiple, non-obvious perspectives, which lands her demonstration just shy of level five.

Future studies can explore this domain more deeply by explicitly asking participants to describe the perspectives they have previously explored and plan to explore once their work with the students is completed. Future programs can capitalize on this ability of the participants by involving them in the design process more deeply and allowing participants to suggest perspective for students to explore and track which suggestions the student follow up on and investigate why they do or do not follow up.

5.6.3 Mindset 1D: Consider Issues Appropriately

Participants from programs I and III demonstrated their ability to consider issues appropriately within this study. Toni did so as she described the ways she dealt with the disengagement of one of her students. Tiffany similarly dealt with a student issue by deeply considering the student concern and responding with clarity. In both of these cases, neither partner jumped to conclusions but instead did what Arnold and Wade's fifth level describes as "allowing time for complexity to sink in and considering issues appropriately."

Future studies could explore this domain more deeply by explicitly asking about issues that arise during the project and how participants have handled it. Future programs can capitalize on this ability by providing space and guidance on how participants can handle issues that arise.

5.6.4 Content 2A: Recognize Systems

Participants from programs II and III demonstrated their ability to recognize systems within this study. Yasmin did so in her description of the university systems that she believed were holding up the impact of the student work. Tiffany similarly demonstrated her ability to recognize systems in her description of her problems space. In both of these cases, each partner was able to recognize the systemic nature of the issue and identify it in concrete terms, in alignment with the fifth level of Arnold and Wade's framework.

Future studies could explore this domain more deeply by explicitly asking about the systems that partners identify affecting their work. Future programs can capitalize on this ability by providing space for partners to point out their perceptions of the systems of their work.

5.6.5 Structure 3A & B: Identify & Characterize Relationships

Participants from programs I and II demonstrated their ability to identify and characterize relationships. Toni did so in her description of the relationships and personalities that had previously led to the incompletion of the project. Yasmine demonstrated her ability to identify and characterize relationships in her description of her relationship to the students and their expectations of her. In both cases, each partner was able to recognize the complex nature of the obvious relationships impacting their work, in alignment with the middle level of Arnold and Wade's framework for identifying relationships. In order to draw implications for the level of participants ability to "accurately" identify these relationships, more data would need to be collected from other parties within the relationships.

Future studies could explore this domain more deeply by investigating other parties of the relationships for the accuracy of partner conceptions. Future programs can capitalize on this aspect of systems thinking by leaving space for relationship building and mending. Beer's Viable System Model might be a useful resource in this regard (Beer, 1989.)

5.6.6 Summary of Most Frequent Domains

A summary of the most frequently demonstrated domains of systems thinking and their respective maturity levels according to Arnold and Wade's framework are summarized in Table 4 and Displayed graphically in Figure 6.1. Partners demonstrated the most maturity in domains 2A and 1D. Implying that for this study, partners have the most expertise related to recognizing systems and considering issues appropriately.

Table 5.1. Maturity Level of Most Frequent Domains of Systems Thinking

	Maturity Level	**2C**	**1A**	**1D**	**2A**	**3A**
Program	**I**	3	5	5	0	3
	II	3	0	0	5	3
	III	0	4	5	5	0

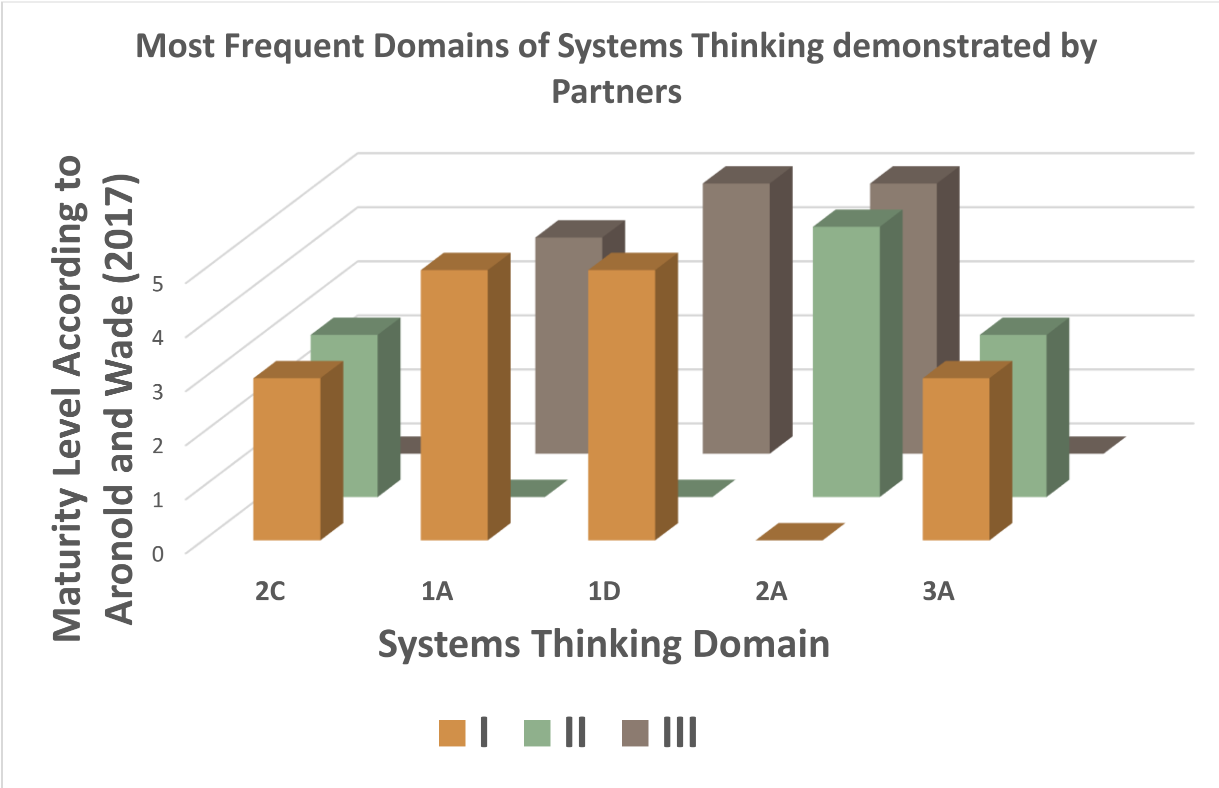

Figure 5.2. Maturity Level of Most Frequent Domains of Systems Thinking

5.7 Least Frequent Domains

The following section will describe the least salient domains of systems thinking that arose from participant responses. In decreasing order of how frequently they arose across programs, the least salient domains were as follows:

1. Structure 3C & D: Identify & Characterize Feedback Loops

Mindset 1B: Consider the Wholes and Parts

Mindset 1C: Effectively Respond to Uncertainty and Ambiguity

Mindset 1E: Mental Abstraction and Modeling

Content 2B: Maintain Boundaries

Behavior 4A: Describe Past System Behavior

Behavior 4B: Predict Future System Behavior

Behavior 4C: Respond to Changes Over Time

5.7.1 Structure 3C & D: Identify & Characterize Feedback Loops

No Participants from any of the three programs demonstrated an ability to identify and characterize feedback loops. This is likely because participants were not specifically asked about recursive relationships and interdependent variables of their work. Future studies could unpack this domain more deeply by asking participants to explicitly identify interdependent relationships and variables.

5.7.2 Mindset 1B: Consider the Wholes and Parts

The participant from Program III demonstrated her ability to consider the wholes and parts when she recognized how a negative student experience is relevant to her professional role. Because her consideration centers around a particular event, this finding implies level three of Arnold and Wade's framework in which one "considers the system holistically but tends to miss the importance of the parts; occasionally getting stuck on one event."

Closely related to recognizing systems and identifying feedback loops, future studies should explicitly ask participants to describe the wider context of their work to better unpack the participants conception of the wholes and the parts.

5.7.3 Mindset 1C: Effectively Respond to Uncertainty and Ambiguity

The participant from Program III demonstrated her ability to effectively respond to uncertainty and ambiguity when she recognized the uncertainty related to the scalability of student solutions. Because her consideration centers around the difficulty associated with issues of scalability, this finding implies level two of Arnold and Wade's framework in which one has "difficulty making decisions during uncertain times or in ambiguous circumstances." Future studies should explicitly ask participants to describe the uncertainty they face while working on the problems at hand.

5.7.4 Mindset 1E: Mental Abstraction and Modeling

The participant from Program III demonstrated her ability to abstract and create mental models when she discussed her ability to provide context and nuance, thereby connecting student solutions to their eventual ability to be implemented. Because her consideration recognizes that the student's model may limit them from seeing the fuller model, this finding implies level three of Arnold and Wade's framework. Future studies should explicitly ask participants to describe their mental processes/models in working with the students.

5.7.5 Content 2B: Maintain Boundaries

The participant from Program III demonstrated her ability to maintain boundaries when she described the limitations of her professional role as it related to her work with the students. Because her consideration maintains this boundary over time and includes most of the relevant key elements, this finding implies level three of Arnold and Wade's framework. Future studies could explicitly ask participants to describe the wait they see, create, and maintain boundaries within their work with the students.

5.7.6 Behavior 4A: Describe Past System Behavior

The participant from Program I demonstrated her ability to describe past system behavior when she described the project history and the elements that led to its previous incompletion. Since we cannot be sure of the accuracy of this description without investigating previously involved partners, this finding implies level four of Arnold and Wade's framework. Future studies should explicitly ask participants to describe their conception of the problematic situation and the system before the programs begin.

5.7.7 Behavior 4B: Predict Future System Behavior

The participant from Program II demonstrated her ability to predict the future system behavior when she discussed the goals of the project beyond her current semester's collaboration with the student. Because her consideration recognizes a short-term awareness of the future function of the project, this finding implies level three of Arnold and Wade's framework. Future studies should explicitly ask participants to describe their long terms goals with the project. Future programs can consider the longer-term lifespan of the problem facing the participants and incorporate it into the project.

5.7.8 Behavior 4C: Respond to Changes Over Time

The participant from Program I demonstrated her ability to respond to changes over time as her description of the problem statement evolved throughout the course of this study. Because the change in problem statement seemed to make the collaborative work with the students more effective in the eyes of the participant, this finding implies level four of Arnold and Wade's framework. Future studies should more explicitly track changes in partner conceptions over time. Based on the nature of the programs included in this study, future programs could allow for more flexibility and emergence of different system behaviors within the problem space and different solution strategies for the problem. This emergence may be a shift in problem statement or a reconceptualization of the relevant stakeholders, as we saw in Program I.

5.7.9 Summary of Most Frequent Domains

A summary of the least frequently demonstrated domains of systems thinking and their respective maturity levels according to Arnold and Wade's framework are summarized in Table 6.2 and Displayed graphically in Figure 6.2. Partners demonstrated the most maturity in domains 2A and 1D. Implying that for this study, partners have the most expertise related to recognizing systems and considering issues appropriately.

Table 5.2. Maturity Level of Least Frequent Domains of Systems Thinking

	Maturity Level	3C	3D	1B	1C	1E	2B	4A	4B	4C
Program	**I**	0	0	0	0	0	0	4	0	4
	II	0	0	0	0	0	0	0	3	0
	III	0	0	3	2	3	3	0	0	0

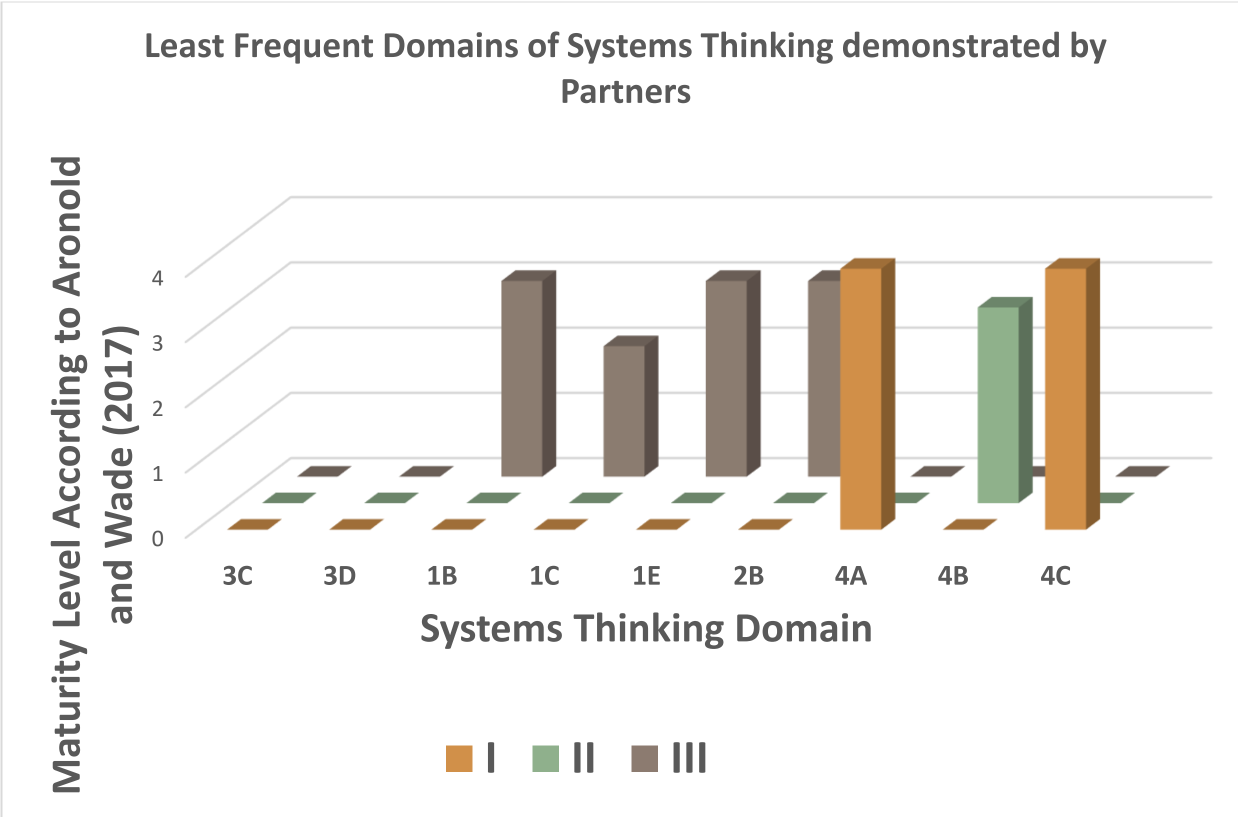

Figure 5.3. Maturity Level of Least Frequent Domains of Systems Thinking

5.8 Summary by Program

When viewed by program, the findings and implications of this study indicate that Program III had both the most occurrences of systems thinking and the highest maturity of that thinking. Program I follows close behind with the second most occurrences and the next highest maturity. Program II had the least occurrences and the least mature evidence of systems thinking. Figure 6.3 illustrate this fact.

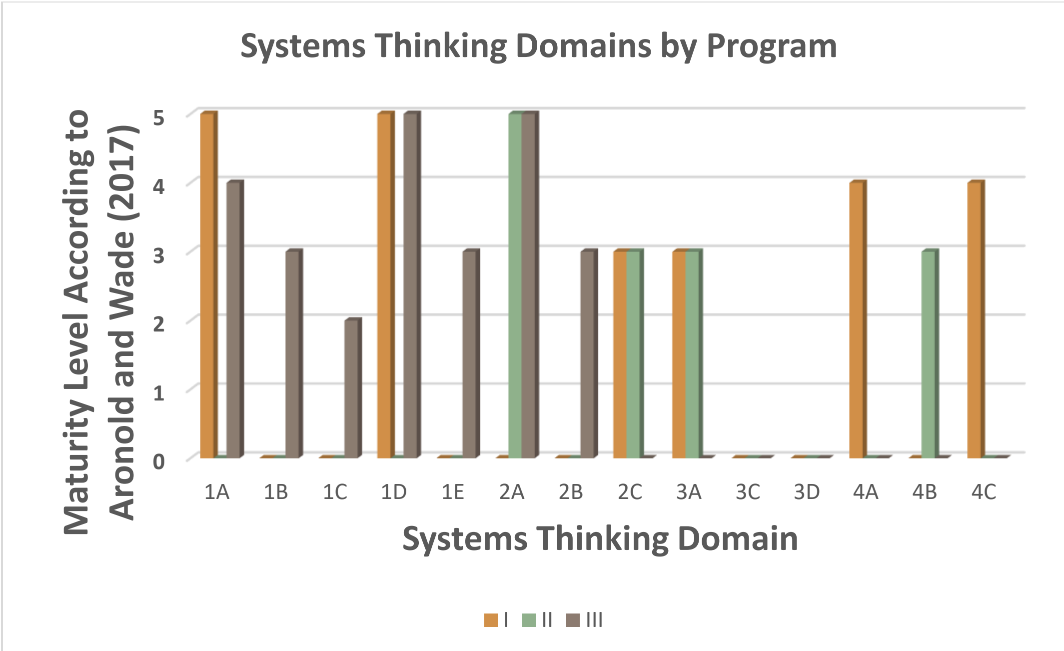

Figure 5.4. Summary of Maturity Level of Domains of Systems Thinking

The distribution of occurrences and maturity speaks more to the programmatic set up than to the participants' broad capacity for systems thinking. For example, the program that demonstrated the most evidence of systems thinking was housed in a class where the project was framed to the students amidst systems thinking curricula. Thus, the partner was likely able to understand and describe her work with language and concepts relating more closely to Arnold and Wade's framework (Arnold & Wade, 2017). Further, the program with the least demonstrated evidence of systems thinking in this study was set up to be a recurring project that occurred over multiple semesters beyond the scope of this study. It is possible, therefore, that a longitudinal study may have captured a more comprehensive view of the partners use of systems thinking competencies.

Given these findings, implications can be suggested for community partners and designers of socially engaged design programs. For community partners, this study indicates that partnerships with engineers in these setting will utilize more than partner expertise specific to the problem at hand. Thus, partners can expect to utilize deeper levels or their experience and may want to reflect the type of contributions they would like to make before partipating in socially engaged designed settings. More deeply, partners should consider how they would like to be served by the engagement. For designers of socially engaged design programs, this study implies that community partners can provide more than problem statements and constraints. Therefore, designers should reflect on how partners could be more deeply engaged. Further, designers should reflect on their institutional responsibilities to their local communities that does not necessarily serve the objective or interests of the programs.

6 IMPLICATIONS & LIMITATIONS

Participant responses suggest a host of implications for evidence of systems thinking. The following chapter describes the limitations of this study, future work that could address these limitations, implications and recommendations from the findings of this study and a final conclusion.

6.1 Limitations and Future Work

As alluded to in the above discussion of implications, there are many limitations of this study that could have hampered the data's ability to capture evidence of systems thinking. The following section addressing these limitations and summarizes how future studies can better capture useful data. The section concludes with recommendations for future socially engaged design programs that aim to better activate and include systems thinking on behalf of their community partner participants.

6.1.1 Interview Protocol Specificity + Variation across programs

Because the goal of the interview protocol was to broadly capture participants conceptions of their socially engaged design experience, questions were broadly focused on the participants holistic experience. While this was intended to prevent leading participants into thinking of their work in terms of systems thinking because of the interview questions, the broad focus of the interview protocol made it difficult to find explicit examples of systems thinking. Therefore, future studies should consider developing a research protocol that more explicitly probes systems thinking abilities. In particular, it may be useful to develop interview protocols designed to probe at one or more systems thinking domain, perhaps "Differentiating and Qualifying Elements" or other domains that surfaced frequently in this study.

Further, despite the interview protocol being asked by the same researcher across all programs, the depth of answers provided by participants seemed to vary based on the participants personality and conception of their engagement. Thus, future studies should consider interviewing and analyzing multiple community partners from the same program. This may require that interview protocols be better tailored to probe the specific logistics of the program at hand but may result in more clear findings with more specific recommendations.

6.1.2 Research Design

While a more intentionally designed interview protocol may lead to more clear findings and implications, the use of interviews to uncover mental conceptions is a bit limited due to the hindsight and reflective nature of interviews. Further, it may be possible, and more accurate to unpack mental conceptions via the use of "think aloud" protocols, in which participants are given a hypothetical scenario and asked to think aloud through how they would approach and respond to the scenario. (Mendoza Garcia, J., 2016) For participants of this study, this may have resulted in an increased cognitive load as thinking aloud is a bit more taxing than reflecting on actual completed work. Thus, future studies can account for this by compensating participants for their potential additional cognition and framing the study beyond their current work within socially engaged design setting. Alternatively, a socially engaged design setting could be developed that is completely organized around capturing conceptions of participants as they go through it. This would of course take increased planning in the development phase but may result in more accurate and useful findings.

In addition to the general research design, more attention could be paid to the use of the maturity metrics in Arnold and Wade's framework. Though maturity was associated with partner voice in this study, future studies should more deeply investigate the accuracy of these metrics for use in these contexts.

Beyond qualitative research approaches, future studies can investigate the neurological occurrence of systems thinking and the way the synapse in the brain connect or disconnect in order to approach complicated problems holistically. This would require more quantitative and technical measurement of the neuro-occurrence of systems thinking that may result in a richer picture of the way systems thinking occurs.

6.1.3 Non-formal socially engaged design settings

Participants of this study were all a part of formal socially engaged design programs housed within engineering programs. These programs are primarily intended to focus on the learning and thinking of the engineering students working with the participants of this study. Thus, future work should investigate informal occurrences of this program (such as block clubs, community organizing, etc.) in which the presence and learning of engineering students is not the driving force of the engagement. Further, future studies could more deeply explore the occurrence and use of systems thinking competencies in order to address wicked problems that do not bound themselves well to school semesters or curricula (such as housing dipartites, energy or food insecurity.) These studies may be able to capture a more natural and intrinsically motivated occurrence of systems thinking and could further expand the way academia understands and assesses systems thinking.

6.2 Implications

Participants in this study demonstrated a variety of systems thinking skills at varying levels of maturity. The following section outlines the implications from these findings.

6.2.1 Variety of Systems Thinking Skills

Participants in this study demonstrated systems thinking skills in the domain of Content, Mindset and Structure. This implies that their ability to use systems thinking skills is not only present, but multi-dimensional. For community partners, this implies that participation in the sorts of socially engaged design settings in this study can utilize more than their problem specific knowledge. Community Partners should be aware that though much of the work may be handled by the engineers they are engaging with, their mindset as well as their knowledge of the content and the structure of the problem space may be utilized to address the problem. Though this may not seem profound, the social distance between community partners and the engineers they work with in socially engaged design experiences can suggest that the expertise of the engineers will take precedent.

6.2.2 Maturity of Systems Thinking Skills

In addition to the variety of systems thinking skills demonstrated by community partners in this study, the maturity of the skills demonstrated were average (three out of the five possible levels) or above for all skills except one (Mindset 1C: Responding to uncertainty.) For community partners, this builds on the implication that their expertise will not only be utilized but may be mature enough to engage with and learn from highly mature systems thinkers.

For coordinators of socially engaged design settings, the presence and maturity of systems thinking skills demonstrated by participants in this study implies the possibility of more deeply involving community partners. The extent of this deeper engagement may be dependent on the goals and logistics of the program, but the findings of this study imply that investigating this area may be beneficial to the problem-solving efforts and potentially the community partners as well. Within the context of academic offerings, students can and should be made aware of the expertise of their community partners and can be encouraged to relate to them as partners in understanding the larger context and structure of the work they are collaborating on.

6.2.3 Recommendations

The findings of this study imply that community partners can provide more than problem statements and constraints to socially engaged design settings and that these partnerships will utilize more than their problem specific expertise. Therefore, the following reflection questions are recommended for community partners considering participation in socially engaged design settings:

1. What have your learned/practiced as it relates to the issue you are considering working on?

2. What of your skills and expertise would you like to contribute?

3. How would you like to be served by your engagement?

For coordinators of socially engaged design experiences, the following reflection questions are recommended:

1. What might our responsibility to our local communities be beyond this specific offering?

2. What are our assumptions about the expertise of the community partners we plan to engage?

3. How could we engage our partners more deeply in this offering or in the development of future offerings?

6.3 Conclusions

Community partners of socially engaged design settings are often only engaged for the sake of evaluating and facilitating student learning and work. The goal of this study was to unpack the ways community partners demonstrate their ability to use systems thinking in their work with students in socially engaged design settings. Using a semi-structured interview protocol, this study investigated community partner conceptions before, during, and after their engagement and analyzed their conceptions against a framework of systems thinking domains. Participants of this study demonstrated their systems thinking ability most strongly across the following domains: differentiate and qualify elements, explore multiple perspectives, consider issues appropriately, recognize systems, identify & characterize relationships. Additionally, participants demonstrate a moderate system thinking ability across the following domains: consider the wholes and parts, effectively respond to uncertainty and ambiguity, mental abstraction and modeling, maintain boundaries, describe past and future system behavior. The fact that participants demonstrated all domains of systems thinking except identify and clarify feedback loops implies that they are not only capable of systems thinking but have the potential to be more deeply involved in their work within these settings. Future studies should investigate systems thinking beyond formal socially engaged design settings and should consider investigation protocols that more directly surface systems thinking domains and perhaps aim to capture evidence of systems thinking in the moment using "think aloud" research designs and neurological research designs. Future work should also consider researching multiple participants of the same type of program and expand the scope of the study to include non-formal socially engaged design settings included block clubs, community organizing efforts, etc. Overall, this study contributes to existing work in systems thinking by calling for a more expansive and inclusive engagement of community partners in socially engaged work.

APPENDIX

Table 1. Interview Protocol

So how did you first hear about this project? What made you get involved?

How would you describe the students you are working with?

Do you know their age/discipline?

How often will you be meeting with the students you are working with?

How would you describe the problem you will be working on and is usefulness to your work/experience?

What are you hoping to get out of this project?

What do you expect it to be like?

What do you expect from engineers/designers?

What do you expect from other community partners?

What do you expect from other key players?

Mid Experience

How would you describe the problem you will be working on and is usefulness to your work/experience?

Tell me about how your meetings with the students usually go? How often have you met?

Do you interact with the students outside of your meetings? How would you describe those interactions?

What has been your favorite part of the experience for you thus far?

Can you describe a way that being involved in this experience has impacted you?

Can you describe a way that being involved in this experience has impacted problem you came here to address?

How would you describe your relationship with the engineers/designers you worked with? with the other community partners? with the other key players?

Do you recall being uncomfortable at any point?

If you could change anything about your experience, what would you change?

Post Experience

How would you describe the problem you will be working on and is usefulness to your work/experience?

What were you hoping to get out of this project?

What was your favorite part of the experience for you thus far?

Can you describe a way that being involved in this experience has impacted you?

Can you describe a way that being involved in this experience has impacted problem you came here to address?

How would you describe your relationship with the engineers/designers you worked with? with the other community partners? with the other key players?

Is there anything you hoped to see come out of this project but didn't?

What surprised you about your time in this experience?

Do you recall being uncomfortable at any point?

If you could change anything about your experience, what would you change?

Since the experience, what stands out in your memory about your time there?

Describe what you learned during this experience

Do you think you would do something like this again? Why or why not?

Would you recommend an experience like this to other folks in your community? Why or why not? If so, how would you describe the experience?

Table 2. Maturity Levels for Systems Thinking Domains

Mindset	Approaches a system from only one perspective	Actively explores multiple, nonobvious perspectives, some of which might conflict with the thinker's view
Mindset	Does not consider the system holistically	Considers both the "forest" and the "trees" keeping "one eye on each" consistently while approaching systems
Mindset	Stops when faced with uncertainty or ambiguity	Able to make sustainable system decisions despite uncertainties in their outcomes
Mindset	Takes a reactionary approach to issues	Allows time for the complexity of a situation to sink in; rarely, if ever, jumps to conclusions; almost always considers issues appropriately
Mindset	Does not recognize the value of mental modeling; intuitive models are highly inaccurate, overly simple, or overly complex	Devises the simplest mental model that accurately describes the system for a given purpose; recognizes that all models are flawed but some are useful
Content	Does not recognize that a problem is systemic	Recognizes that the problem is systemic and is able to identify associated behaviors or systems in concrete terms
Content	Unable to define the boundary of a system	Able to maintain an accurate boundary of the system that correctly changes over time and context with a high degree of quantitative accuracy
Content	Unable to recognize that elements are different	Able to describe the properties of elements with a high degree of accuracy
Structure	Unable to recognize even those relationships that would be considered obvious by novice systems thinkers	Able to recognize the vast majority of relevant relationships, even obscure, meta-physical, nonobvious, or complex ones
Structure	Unable to characterize the strength of a relationship	Able to create highly accurate characterizations of relationships
Structure	Unable to recognize feedback loops	Able to recognize the vast majority of relevant feedback loops
Structure	Unable to characterize the strength and properties of a feedback loops	Able to create highly accurate characterizations of feedback loops
Behavior	Unable to describe past behavior	Able to describe past system behavior with a high degree of accuracy
Behavior	Unable to predict future behavior	Able to predict future behavior with a high degree of accuracy over a long timescale
Behavior	Does not respond differently to changes in the system over time	Consistently responds to changes over time in highly effective ways

REFERENCES

"Building a Competency Taxonomy to Guide Experience Acceleration of Lead Program Systems Engineers." 9th Annual Conference on Systems Engineering Research (CSER), 1–10. Redondo Beach, US-CA, 14-16 April.

Arnold, R. D., & Wade, J. P. (2017). a Complete Set of Systems Thinking Skills. Insight, 20(3), 9–17. https://doi.org/10.1002/inst.12159

Beer, S. (1989). Viable system model. Viable Systems Model, Wiley, Chicester.

Berry, H. L., Waite, T. D., Dear, K. B., Capon, A. G., & Murray, V. (2018). The case for systems thinking about climate change and mental health. Nature Climate Change, 8(4), 282-290.

Boardman, J., B. Sauser, L. John, and R. Edson. 2009. "The Conceptagon A Framework for Systems Thinking and Systems Practice." IEEE International Conference on Systems, Man, and Cybernetics, 3299–3304. San Antonio, US-TX, 11-14 October

Burandt, S. 2011. "Effects of an Educational Scenario Exercise on Participants' Competencies of Systemic Thinking." Journal of Social Sciences, 7(1), 54–65.

Cabrera, D., Colosi, L., & Lobdell, C. (2008). Systems thinking. Evaluation and program planning, 31(3), 299-310.

Caldwell, B. S. (2009). Perspectives on Systems Engineering and Impacts on SE Education. In 2009 Industrial Engineering Research Conference Perspectives.

Douglas, E. P. (2015). Understanding & Dismantling Privilege. Understanding & Dismantling Privilege, V(1), 36–44.

Eatman, T. K., Cantor, N., & Englot, P. T. (2017). Real Rewards: Publicly Engaged Scholarship, Faculty Agency, and Institutional Aspirations. In C. Dolgon, T. D. Mitchell, & T. K. Eatman (Eds.), The Cambridge Handbook of Service Learning and Community Engagement (pp. 359–369). Cambridge: Cambridge University Press. https://doi.org/10.1017/9781316650011.035

Goodman, M. (2018). Systems Thinking: What, Why, When, Where, and How? Retrieved from https://thesystemsthinker.com/systems-thinking-what-why-when-where-and-how/

Hatfield, G. (2012). Koffka, Köhler, and the "crisis" in psychology. Studies in History and Philosophy of Science Part C :Studies in History and Philosophy of Biological and Biomedical Sciences, 43(2), 483–492. https://doi.org/10.1016/j.shpsc.2011.11.005

Hmelo-Silver, C., Holton, D., & Kolodner, J. (2000). Designing to learn about complex systems. Journal of Learning Sciences, 9(3), 247–298. https://doi.org/10.1207/S15327809JLS0903_2.

International Council on Systems Engineering. 2014. A World in Motion: Systems Engineering Vision 2025. 24th Annual INCOSE International Symposium. Las Vegas, US-NV, 30 June-3

Johnson, N. (2007). Two 's Company, Three is Complexity. In Two's Company, Three is Complexity (pp. 3–18). New York: Oneworld.

Karwat, D. M. A., Eagle, W. E., Wooldridge, M. S., & Princen, T. E. (2014). Activist Engineering: Changing Engineering Practice By Deploying Praxis. Science and Engineering Ethics, 21(1), 227–239. https://doi.org/10.1007/s11948-014-9525-0

Lewis, J. (2009). Redefining qualitative methods: Believability in the fifth moment. International Journal of Qualitative Methods, 8(2), 1-14.

Meadows, D. H. (2009). Thinking in Systems. (Diana Wright, Ed.). Sustainability Institute.

Mendoza Garcia, J. A. (2016). A phenomenographic study of the ability to address complex socio-technical systems via variation theory.

Merriam, S. B., & Tisdell, E. J. (2015). Qualitative research: A guide to design and implementation. John Wiley & Sons.

Midgley, G. (1992). The sacred and profane in critical systems thinking. Systems Practice, 5(1), 5–16. https://doi.org/10.1007/BF01060044

Orgill, M., York, S., & MacKellar, J. (2019). Introduction to systems thinking for the chemistry education community. Journal of Chemical Education, 96(12), 2720-2729.

Plate, R., and M. Monroe. 2014. "A Structure for Assessing Systems Thinking." The 2014 Creative Learning Exchange, 28-30 June.

Puttick, G., Tucker-Raymond, E. Building Systems from Scratch: an Exploratory Study of Students Learning About Climate Change. J Sci Educ Technol 27, 306–321 (2018). https://doi.org/10.1007/s10956-017-9725-x

Richmond, B. 2004. An Introduction to Systems Thinking: STELLA Software. An Introduction to Systems Thinking. Boulder, US-CO:isee systems Inc.

Riess, W., & Mischo, C. (2010). Promoting systems thinking through biology lessons. doi: https://doi.org/10.1080/09500690902769946.

Schieritz. Nadine & Milling, P. M. (2003). Modeling the Forest or Modeling the Trees A Comparison of System Dynamics and Agent-Based Simulation. In 21st international conference of the system dynamics society (pp. 20–24).

Senge, P. M., A. Kleiner, C. Roberts, R. B. Ross, and B. J. Smith. 1994. The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization. New York, US-NY: Doubleday/Currency.

Squires, A., J. Wade, P. Dominick, and D. Gelosh. 2011.

Stave, K. A., and M. Hopper. 2007. "What Constitutes Systems Thinking? A Proposed Taxonomy." In 25th International Conference of the System Dynamics Society. Boston, MA.

Valerdi, R. 2012. "Developing Systems Thinking Competen- cies through Facilitated Simulation Experiences." USC CSSE Annual Research Review.

Waters, J., and F. Waters. 2014. Waters Foundation Systems Thinking in Schools. http://watersfoundation.org/systems- thinking/overview .

VITA

Chanel Beebe

EDUCATION

Purdue University West Lafayette, IN Anticipated Graduation: 2021

Degree: Ph. D. Engineering Education GPA: 3.67

Advisors: Dr. Monica Cardella

Research Question: How do community partners make meaning of community engaged design experiences?

Purdue University West Lafayette, IN Anticipated Graduation: December 2020

Degree: Master's in Industrial Engineering

Advisor: Dr. Bob Kenly

Research Question: What evidence of Systems Thinking present in community engaged design experiences?

University of Michigan Ann Arbor, MI 2014

Degree: B.S.E Industrial and Operations Engineering GPA: 3.066 / 4.0

RESEARCH EXPERIENCE

Purdue University,

Black Cultural Center Fall 2017 – Summer 2019
Scholar in Residence for Black Thought Collective

- Taught and demonstrated qualitative research process
- Facilitated development of 10 student-led research projects
- Developed programming relevant to black students and their experiences
- Managed publication of student findings across various platforms including journals and symposiums

National Association of Multicultural Engineering Programs,

Purdue University Spring 2017 – Summer 2018
Thought Leader for Cultural Hackathon

- Developed a professional development intervention that allows engineering students the chance to interface with corporate representatives on projects designed and led by community members
- Developed and Implemented programming with over 200 students and 20 community partners
- Conducted a pilot study with High School seniors to see if social problems could be addressed with the Engineering design process
- Organized Community partner and student needs into a semester-long course where students collaborated with community partners to solve community problems
- Designed and conducted research around the experiences of the community partners and design ability of the students through surveys and interviews

Purdue University,

Mechanical Engineering Fall 2016 – Fall 2018
Research Advisory Board: TECH-AIDE Grant

- Designed three-phase qualitative study to unpack the values, norms, expectations, and experiences of African Americans across the College of Engineering
- Conducted 12 focus groups, and 25 one-on-one interviews of 54 African American students in Engineering
- Interreacted with multiple University Departments and Centers to implement campus climate change through research and programming

Purdue University,

FACELab Spring/Summer 2015
Research Advisor: Morgan Hynes

- Developed and implemented curriculum for four 9-day Everyday Engineering Camps in which 9 to 17-year-olds engaged with every step of the design process to address problems in their immediate communities
- Developed Make an Engineer Activity in which participants build a model of an engineer using their personal interests and skills to solve global engineering problem
- Conducted research on the impact of informal engineering experiences and activities

Purdue University,

Engineering Explorer's Grant Fall 2014
Research Assistant under Stephen Hoffmann

- Conducted research on the experience of underrepresented and international students in First Year Engineering teams.
- Developed survey to quantify student experiences in teams based on group dynamics frameworks.

Duke University,

Mary Lou Williams Center for Black Culture Fall 2014
Graduate Research Assistant: Durham, NC

- Conducted informal focus groups to understand African American student experience
- Developed outline of needs of African American students
- Began University-wide effort to collect data on African American Student Satisfaction

University of Michigan,

Engaged Advising Learning Grant 2013-2014
Project Coordinator Ann Arbor, MI

- Conducted interviews and focus groups to develop a better understanding of the current state of advisor-student relationships
- Conducted research on student engagement within the classroom
- Developed a comprehensive rubric for faculty to use in evaluating and quantifying student performance
- Helped advisors to see a clearer and more detailed picture of the student's performance

TEACHING EXPERIENCE

Detroit Historical Museum,

1967 Perspectives Project 2017 – Present
Lead Instructor for Detroit Design 2067

- Developed curricula for week-long immersion program for HS Juniors and Seniors
- Conducted research on Detroit History and developed curricula blending historical perspectives with design thinking
- Coordinated with various museum and community stakeholders to book events and activities for students
- Managed an informal learning space of 12 high school students

Purdue University,

Multicultural Engineering Programs Fall 2017 – Summer 2019
Instructor for Multicultural Engineering Program Seminar

- Developed curricula for Cultural Hackathon Co-Curricular Experiences
- Assigned and reviewed student reflections
- Lead various class sessions around design identity and expectations
- Managed a classroom of 35 students for two semesters

Purdue University,

Black Cultural Center Fall 2017 – Summer 2019
Scholar in Residence for Black Thought Collective

- Designed curricula for undergraduate students to investigate gentrification patterns across cities within the African Diaspora
- Facilitated weekly discussions around personal experiences of trauma
- Brought in guest speakers on Urban Planning and Ethnography to prepare students for research project
- Guided students through data collection, analysis and publication process

Beebe Arts LLC,

Detroit based research and design firm 2015-2017
Research, Arts and Teaching Consultant

- Co-Designed and taught Poetry Workshop for Purdue Theatre Class
- Developed and conducted workshops on Freewriting, Painting, and Vision Boarding
- Taught design to 30 high school seniors via summer and spring break programs

Project SEED,

Detroit Branch Fall 2014-Spring 2017
Mathematics Specialist

- Conducted professional development for 50 Detroit Public School Teachers
- Wrote and delivered Socratic lesson plans to 150 3rd – 6th students advanced mathematics

PUBLICATIONS

- In Preparation: Bednar, D., **Beebe, C.** (2021). Socially Engaged Energy Justice and Design: A practical framework for more Inclusive Access, Frontiers Energy
- In Preparation: **Beebe, C.,** Hira, A., Holly, J., Carter, K. (2021). Who gets to engineer?, Countering the Mythology of Inclusion and Wellness in Schooling
- In Print: Secules, McCall, Mejia, **Beebe**, Masters, Sanchez-Peña, Svyantek (2021). Positionality Practices and Dimensions of Impact on Equity Research: A Collaborative Inquiry and Call to the Community, Journal of Engineering Education (In Press).
- **Beebe, C (2020).** Emergence and Compassion: A Reflection on Interpersonal Priorities Strategies Within Collaborative Settings, Purdue Journal of Service Learning, West Lafayette, IN.
- **Beebe, C.** (2018). They Will Ask You. Murmurations, 1(1), 5–7. https://doi.org/https://doi.org/10.31946/meee.v1.i1.19
- Esan, H., **Beebe, C**., Cardella, M. (2017). Promoting Computational Thinking in Children Using Apps, ASEE, Columbus, OH.
- **Beebe, C**., Hynes, M. (2017). Youth Ages 9-15 Perceptions of Mechanical Engineering by Race and Gender, ASEE, Columbus, OH.

- Holly, J., Joslyn, C., Hira, A., Hynes, M., & **Beebe, C.** (2016). What do you like to do? Exploring pre-college students' career aspirations and perceptions of engineering (Work in progress). In ASEE 2016 Annual Conference. New Orleans, LA.
- **Beebe, C.,** Sarwar, U., Jubelt, N., Hira, A., & Hynes, M. (2016). MAKER: A Game to Make Engineering. In ASEE 2016 Annual Conference. New Orleans, LA.

CONFRENCE PRESENTATIONS

- **Beebe, C.,** Holly, Tolbert, Colquitt. "Do You See Me?: Hypervisible Invisibility #EngineeringWhileBlack, American Society of Engineering Education, Virtual, July 2020
- **Beebe, C.,** "Service-learning from the perspective of Community Partners" Poster and Exhibition. Purdue Engagement and Service-Learning Summit, West Lafayette IN, February 2020
- **Beebe, C.,** "Expanding Cultures Part II: Beyond Intersectionality" Women in Engineering ProActive Network, Virtual, October 2019
- **Beebe, C.,** "Researching Socially Engaged Design: Community Partner Narratives of Social Change and Agency Building" Ford Foundation Fellow Annual Conference, San Juan, Puerto Rico, October 2019
- **Beebe, C.,** "Expanding Cultures: How where I come from informs where I am going and how I will get there" Women in Engineering ProActive Network, Virtual, August 2019
- **Beebe, C.,** "Storytelling and Utopia as Resistance to Marginalization of African American Engineers at a PWI" Collaborative Network for Engineering and Computing Diversity, Washington DC, April 2019
- **Beebe, C.,** "Cultural Hackathon: Development and Considerations" Collaborative Network for Engineering and Computing Diversity, Washington DC, April 2019
- **Beebe, C.,** "Inclusive Community-Engaged Design" 45th Annual National Society of Black Engineers National Convention, Detroit, MI, April 2019
- **Beebe, C.,** "Experiences and Learning of Community Partners in Community Engaged Design Settings" 2018 Conference of Ford Fellows: Academic Exchange Session, San Jose, CA, September 2018
- **Beebe, C.,** "Youth Ages 9-15 Perceptions of Mechanical Engineering by Race and Gender." ASEE 2017 Annual Conference, Columbus, OH, June 29, 2017
- **Beebe, C.,** "Promoting Computational Thinking in Children Using Apps." ASEE 2017 Annual Conference, Columbus, OH, June 29, 2017
- **Beebe, C.,** "What do you like to do? Exploring pre-college students' career aspirations and perceptions of engineering." ASEE 2016 Annual Conference, New Orleans, LA, June 24, 2016
- **Beebe, C.,** "MAKER: A Game to Make Engineering." Poster and Exhibition, ASEE 2016 Annual Conference, New Orleans, LA, June 24, 2016

AWARDS AND HONORS

- Humanity in Action Detroit Fellow (2019)
- Ford Foundation Pre-Doctoral Fellowship (2018-2021)
- Leadership in Action Award (Purdue Butler Center – 2017)
- Spirit of Martin Luther King Jr. Leadership Award (College of Engineering – 2014)
- Outstanding Female on Campus (Alpha Phi Alpha Fraternity Incorporated – 2013)
- New Student Achievement Award (College of Engineering - 2009)
- Gates Millennium Scholarship (Bill Gates Foundation-2009)
- Rogel Match Scholarship (U of M-2009)

SERVICE AND LEADERSHIP

Purdue University

- Purdue Black Cultural Center: Black Thought Collective, Scholar in Residence (2017-2019)
- Engineering Education Graduate Student Association, Secretary (2017-2018), President (2017-2018)
- Mentoring at Purdue Program, Peer Mentor (2017-2018)
- Purdue Black Cultural Center: Haraka Writers, Spoken Word Poet, (2015-2017)
- National Society of Black Engineers, Member (2015-2018)
- Black Graduate Student Association, Member (2015-2018)

University of Michigan

- National Society of Black Engineers: Vice President (2012-2013), Finance Chair (2011-2012)
- Office of Academic Multicultural Initiatives: Academic Success Partner to 6 protégés (Present)
- Center for Educational Outreach- Project Inspire: Student Speaker (2009-Present)
- American Association of University Women, National Student Advisory Council (2010-2011)
- Gates Millennium Scholarship (Bill Gates Foundation-2009)
- Rogel Match Scholarship (U of M-2009)

ENTREPRENEURIAL EXPERIENCE

Beebe Arts LLC, *Art & Research Design Solutions* 2017-Present

Founder and CEO: Detroit, MI

- Consultant with Detroit Historical Museum to design and implement a 10-Day Immersion Program for High School Seniors to learn about Detroit History and Co-Develop Community Solutions
- Thought leader with the National Association of Multi-Cultural Engineering Programs Advocates to Design a Cultural Hackathon to develop the skill sets and opportunities of Underrepresented Engineers
- Commissioned Art Projects with community groups and individuals
- Develop and Design Publications such as newsletters, poetry books, presentations and flyers
- Mentoring, Coaching and Advising to students of color
- Poetry Publication Consultation for Young Writers
- Poetic Speaking Engagements for Non-Profit Organizations

PROGRAM CERTIFICATIONS

- Advanced Graduate Teaching Certificate, Purdue University, Center for Instructional Excellence, 2019
- Different Lenses Workshop Series Completion, Purdue University Center for Intercultural Learning, 2019
- Applied Management Principles Program Graduate, Purdue University Krannert School of Business, 2019
- Dissertation Institute Fellow, University of Houston, 2018

PERSONAL PUBLICATIONS

- Beebe, Chanel (2020) Views from the Inside, Beebe Arts LLC, Detroit, MI
- Beebe, Chanel (2019) Proof, Beebe Arts LLC, Detroit, MI
- Beebe, Chanel (2017) Fractal, Beebe Arts LLC, Detroit, MI
- Beebe, Chanel (2017) Now, Go!, Beebe Arts LLC, Detroit, MI
- Beebe, Chanel (2016) Reveal, Beebe Arts & Ahmad Barber Photography, Detroit, MI
- Beebe, Chanel (2015) Now & Then, Beebe Arts, Detroit, MI

WORK EXPERIENCE

The Boeing Company, *Consumer Aviation Services Lean Enterprises* Summer 2013

Industrial Engineering Intern: Renton, WA

- Completed Shingo training and developed a better understanding of perfected business practices
- Designed and developed a visual management system for managing team projects that was eventually implemented to over 200 employees
- Constructed Values Stream Mapping of change request process and completed root cause analysis to eliminate security issues
- Conducted time studies on Kent Distribution Center Receiving Process
- Facilitated and developed accelerated improvement workshop that decreased receiving time by 50%

Dow Chemical Company, *Hydrocarbons Improvement Team* Summer 2012

Supply Chain Intern: Houston, TX

- Facilitated informational discussions with international teams to gather needs of stakeholders and design informational dashboard
- Reevaluated key corporate processes to streamline workflow by building decision trees and flow charts
- Built a balance sheet to manage $500 million in Canadian Ethylene sales

Wal-Mart Stores Inc., *Information Systems Department* Summer 2011

International Department Intern: Bentonville, AR

- Developed strategies to successfully integrate a recently acquired company
- Oversaw budgets of $200 million+
- Interfaced with international groups