THE DESIGN PROCESS OF A COLLABORATIVE ORCHESTRATION TOOL AND ITS IMPLICATIONS FOR INSTRUCTOR UPTAKE

BY

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DISSERTATION

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ABSTRACT

As design-based research becomes a widely used methodology in the Learning Sciences, research is needed to understand how this methodology is applied in practice. The present study responds to calls from the field, for researchers to disseminate the design processes when conducting design-based research studies. In this dissertation, I explored how an interdisciplinary team designed a collaborative orchestration tool and analyzed how it was used in the classroom by engineering instructors. The study broadens our understanding of how design-based research processes are enacted to explore this form of learning among researchers.

This qualitative study explores interactions within a design brainstorm meeting of eight team members from four disciplines using an analytic technique called linkography. This analysis reports on the emergent design discourse and discusses the interplay between collaboration, connectedness of conversations, and critical moves to understand how ideas were generated among the interdisciplinary team. Findings from this identify interactions that lead to high quality discussions and reports outcomes from this process in the form of the final orchestration tool. The findings from the design phase are reported and followed by the investigation of the classroom implementation. While these findings share how the design emerged, it is not enough to solely present conclusions of the design process. Researchers must also articulate how the final design was implemented and how it impacted interactions in the classroom. In the classroom implementation, eight instructors who used the orchestration tool were studied through interviews and video and log file data. This analysis explores how instructors used the orchestration tool to support their interventions with students and report their perceptions from using the tool.

The results of this study suggest that the interdisciplinary team achieved the highest quality collaboration and ideas during intersected, convergent discussions. Using a sociocultural framing, the study describes these collaborative interactions and what lead to different kinds of idea generation. Through this analysis, I present recommendations for future iterations of this tool, as well as suggestions for others engaging with this methodology. The primary finding from the implementation phase was that instructors who used the tool and implemented prompts had productive interventions where the instructor sparked discussion among group members. However, there were few instances where prompts were used, showing that the degree of integration profoundly impacts the use. Outcomes from this study can be used to iterate on this project and lay the groundwork for others doing similar work. Future directions for scaffolding interdisciplinary design processes and designing orchestration tools are discussed.

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CHAPTER 1: INTRODUCTION

The first goal of this dissertation is to study how an interdisciplinary team designed an orchestration tool for engineering, graduate teaching assistants (TAs) and undergraduate course assistants (CAs). The second goal addresses how a real-time supportive orchestration tool was implemented and used by the TAs and CAs in the classroom. The data for this dissertation was drawn from an NSF grant titled Collaborative Support Tools for Engineering Problem Solving (CSTEPS). This dissertation presents the process of iterating on the design of an orchestration technology created for this project called the CSTEPS tool. This iteration of the tool, the second for the project, had embedded prompts to guide TAs and CAs to support collaborative interactions in their classroom.

Teachers use orchestration technology to manage students – often in groups – in real-time, while accounting for various constraints and issues within the classroom (Dillenbourg, Prieto, & Olsen, 2018). While orchestration technologies can enhance the teacher's abilities in a classroom, it is no small feat to design and implement them successfully. Classrooms are complex, and teachers are continually evaluating the tradeoffs between learning and social factors to maintain productivity among students (Barron & Darling-Hammond, 2008). While orchestration tools have the opportunity to support teachers in managing these tradeoffs, they also run the risk of overloading the teacher's orchestration load, the effort needed to facilitate learning activities in a classroom (Prieto, Sharma, Kidzinski, & Dillenbourg, 2018). Therefore, researchers need to ensure that technology does not impede the teacher from doing the necessary actions in their classroom. In order to do this, researchers need to be strategic and attentive during the process of designing.

Design-based research (DBR) methodology, often used in the creation of orchestration technologies (Rodríguez-Triana, Holzer, Vozniuk, & Gillet, 2015; Tissenbaum & Slotta, 2019), emphasizes the design and implementation of educational artifacts that researchers create in real-world contexts with interdisciplinary teams (Wang & Hannafin, 2005). DBR is centered around an iterative design process to create technology with the users (Ormel, Roblin, McKenny, Voogt, & Pieters, 2012). While DBR prioritizes design, researchers in this area typically report the final designed form of technology rather than the process conducted when designing. This has created a gap in the literature, forcing readers to make assumptions about *how* technology was designed and *by whom* (Edelson, 2002).

When an interdisciplinary team is designing a piece of technology, the process and methods used in its creation are particularly relevant to address this gap and document *who* designed the tool and *how*. A final design shows no indication of the complex collaborations, communication of project goals, or prioritization of the components that were determined during its creation. While research shows that interdisciplinary collaborations can lead to innovative solutions, it is challenging to do well as researchers are rarely taught to collaborate across disciplines (Klein, 2008; Leahey, 2018). Research on team science indicates that interdisciplinary teams can solve complex problems by using creative strategies to facilitate idea generation; however, the goals must be clear and well communicated (Hall, Feng, Moser, Stokols, & Taylor, 2008; Read et al., 2016). By nature, interdisciplinary design processes for building educational technology are challenging. Assessing them will contribute to the field by engaging in a discourse about the goals, communication, and planning necessary to do interdisciplinary DBR well. In turn, this will allow insight into what works and how to improve the designed technology and learning. Researchers need to document and assess the design process to identify the relationship between the process and outcomes in the classroom. This relationship can aid in establishing guidelines and best practices which lead to better DBR outcomes.

Through research and shared process, DBR can become a more reliable methodology and improve theories and practices. Therefore, this dissertation aims to document the design process of building the CSTEPS tool for TAs and CAs and address how the use of the designed technology influences their interactions within the classroom. To do so, I will ask the following research questions:

RQ1. How did ideas about the CSTEPS tool emerge during an initial brainstorming meeting among an interdisciplinary team?

RQ2. How did the ideas that emerged during the design process get implemented in the classroom?

RQ3. How did the design decisions embedded in the classroom influence the instructors' interactions in the classroom?

The present study provides insight into the design process and implementation of the CSTEPS orchestration tool. This work responds to calls over the past few decades for researchers to have a more open discourse around the design process in DBR (Easterday, Rees Lewis, & Gerber, 2017; Edelson, 2002; Kolodner, 2016; Phillips, 2006; Sandoval, 2014). Innovative learning takes place during the process of designing educational technology, and researchers are not documenting or assessing this to the same extent as other forms of learning (Kali, 2016). Without this discourse, there is no way to judge the quality of the design process, and researchers may be replicating mistakes that others have already addressed. This study analyzes and reports on this design discourse, and discusses the interplay between collaboration, connectedness of conversations, and critical moves to understand how ideas were generated among an interdisciplinary team. The study broadens our understanding of how DBR processes are enacted in practice in response from calls to study this form of research and learning. Additionally, this study presents findings from classroom implementation to identify the success of the design process and outcomes. It is not enough to solely present on the findings of the design process, but also articulate how they were implemented and how they impacted interactions in the classroom. Through this analysis, I present concrete recommendations for future iterations of this tool, as well as recommendations for others engaging with this methodology. Outcomes from this study can be used to iterate on this project and also lay the groundwork for others doing similar work.

CHAPTER 2: LITERATURE REVIEW

There are various ways in which researchers in education emphasize the design process. Researchers encourage and often examine the design process among learners, for example, frameworks such as Learning by Design (Kolodner et al., 2003) and design thinking (Aflatoony, Wakkary, & Neustaedter, 2018). However, they rarely apply these same approaches and analytic lenses to the design of educational tools and their corresponding technologies. Methodologies, such as design-based research (The Design-Based Research Collective, 2003) and design-based implementation research (Fishman, Penuel, Allen, Cheng, & Sabelli, 2013), value the design process as a way to build educational artifacts that both generate theory and evaluate designs. However, even when using these methodologies, studies are focused on outcomes such as learner interactions or design principles, and rarely discuss the process of designing (Kelly, 2004).

Outcomes in this type of research typically focus on students' processes rather than researchers' processes. Researchers are collaborating and learning during this process to design educational technology (Kali, 2016). When describing ways to assess DBR, Kelly (2006) explained that "*learning from the act of designing an artifact [is] a window into learning*" (p. 109). Researchers collaboratively building educational technology are creating new knowledge in the form of a designed artifact. Researchers need to document the process of designing to the same extent as other forms of learning. Not studying the process can lead to wasted resources and missed opportunities to advance learning.

The design, development, implementation, and assessment of orchestration technology can be uniquely challenging. While there is value in studying the design process to create orchestration technology, there is still a need to assess the final technology in the classroom. A recent review indicated that findings from studies on orchestration technology are most often user perceptions and interactions (Bodily et al., 2018); while these are a valuable step in the design process, usability evaluations alone are not enough to assess a design (Rick et al., 2013). This research indicates a need for more rigorous methods to evaluate the design of a tool in its intended context and through the goals of the design and learning parameters.

Interdisciplinary, collaborative design-based research (DBR) is necessary to design orchestration experiences for teachers. Researchers need to study the design process, in addition to the classroom implementation outcomes, to discover the best strategies and methods to collaborate and generate innovative ideas. To explore this problem space, I will first define orchestration and discuss how teachers use orchestration technologies, followed by a review of how the design of orchestration technology requires an interdisciplinary team. Then I will examine theoretical insights from design and education situated from a sociocultural perspective. I will then describe how design-based research (DBR) is an appropriate methodology for this work and outline its advantages and limitations. After reviewing DBR, I will discuss what the design process is, review examples of it in education, and explore assessment mechanisms for this process. I will close by summarizing this work and discuss how this study addresses these areas.

2.1 Orchestration

The literature on orchestration presents conflicting definitions and perspectives of the term; however, Dillenbourg and colleagues created one of the most common and applied definitions (Dillenbourg, 2013; Dillenbourg et al., 2009). In the most recent issue of the *International Handbook of the Learning Sciences*, they described the definition of orchestration as “the real-time management of multi-plane scenarios under multiple constraints” (Dillenbourg, Prieto, & Olsen, 2018, p. 181). Their definition of orchestration has become more focused in later iterations, putting less emphasis on the metaphor of the teacher as a conductor. However, researchers do not widely agree on this definition. In a special issue on orchestration in Computers & Education, many authors criticized Dillenbourg's work. Within the issue, authors critiqued the definition, which included the narrow view of classroom (Kollar & Fischer, 2013), lack of student perspective (Sharples, 2013), a need for a more theory-driven approach (Dimitriadis, Prieto, & Asensio-Pérez, 2013; Perrotta & Evans, 2013), and emphasis on conducting research in classrooms rather than in a laboratory setting (Chan, 2013).

The term orchestration has been used in various ways over the past few decades to describe how teachers manage learning in the classroom and how technology can support them in doing so (Dillenbourg, 2013; Meyer, 1991; Trouche, 2004). Still, there is considerable variability in how the term is defined and conveyed in research (Prieto, Dlab, Gutiérrez, Abdulwahed, & Balid, 2011). Early uses of the term were focused on the student (Meyer, 1991), the relationship of instruments used in math classrooms (Trouche, 2004), or elements within the classroom to support student learning (e.g., PowerPoint slides) (Chamberlain, Williams, Cowan, & Mistree, 2001). In more recent years the term orchestration has been adopted by the Learning Sciences community, specifically, Computer Supported Collaborative Learning (CSCL) (Dillenbourg, Jarvela, & Fischer, 2009) and emphasized as a "*grand research challenge*" (p. 3) in the field of Technology Enhanced Learning (TEL) (Gillet, Scott, & Sutherland, 2009). Since this work, the definition of the term orchestration has influenced research conducted in CSCL and TEL disciplines.

Though researchers argue about the inclusivity of this definition, one area that continues to spark contention within the field is the use of the metaphor itself. The metaphor of the teacher as the conductor alluded to in the term orchestration, has led to various interpretations. Chamberlain et al. (2001) explained that orchestration served as a better term than teaching, due to the metaphor of conducting information rather than describing the teacher as the source of all knowledge. Later, Rothstein and Trumbull (2008) expressed their dissatisfaction with the term classroom management and explained that the metaphor of orchestration better suits the desired harmony in a classroom like that of a synchronized orchestra. In more recent arguments, Dillenbourg himself explained that the orchestration metaphor is no longer useful “because it generates unproductive debates [and he suggests the field should] use ‘orchestration’ as a concept on its own.” (2013, p. 491). In response to Dillenbourg’s claim, Kollar and Fischer (2013) argue that the metaphor provides significant potential to advance the field methodologically by prompting researchers to analyze the multiple layers of the classroom.

The primary goal of orchestration technology is to support teachers in the messiness of their classrooms. Designers and researchers of orchestration technology need to consider this when creating tools. Teaching is not straightforward; classrooms are complex and take more than merely teaching content to be successful. Darling-Hammond and Bransford (2005) describe this issue as “the problem of complexity” (p. 359); teachers are constantly managing learning and social factors and have to make decisions in the moment to maintain productivity in the classroom. Darling-Hammond and Bransford go on to explain this is a critical part of teacher training, as learning how to make tradeoffs in real-time is a vital part of the job (2005). Some researchers in the orchestration literature defined these complexities using the term extrinsic constraints, including assessment, time, energy, space, and safety (Dillenbourg & Jermann, 2010). Other researchers studying orchestration argue that these constraints provide a narrow view of a complex classroom and have outlined how classroom logistics are essential to consider while designing with these constraints in mind (Nussbaum & Diaz, 2013). They describe how the context, learning objectives, and specific processes in the classroom need to be designed considering both extrinsic constraints and logistics of the classroom. When considering these complexities and designing the orchestration within them, it warrants the questions of how orchestration tools can support teachers without overloading these constraints.

There are pros and cons to the definition of orchestration when describing classrooms and supporting teachers. While some researchers criticize this term for being overly simple, the openness of the definition does allow researchers to include more context in their support tools. In an example of an orchestration tool, Lenton et al. (2018) evaluated the teacher’s movements in the physical classroom environment. Through a general definition, unbound by a specific outcome (e.g., learning outcomes), the broadness of the definition allowed researchers to ask questions and consider all aspects within and outside of the classroom context. Researchers who do this work look for new ways to quantify and describe teachers’ actions and needs; therefore, leading to more inclusive technologies (Holstein, Hong, Tegene, McLaren, & Aleven, 2018; Martinez-Maldonado, Clayphan, Yacef, & Kay, 2015). However, one major disadvantage of the varied definitions, especially when considered with technology, is the challenge of generalizability to make the tool accessible to diverse teachers and contexts. All teachers have different technical skills and practices; teachers are not and will not be dependent on technology or the people that build them (Tchounikine, 2013). To address this obstacle, the designers and researchers of these technologies need to construct versatile tools to accommodate the needs of the teachers using them (Fischer, Goldman, Hmelo-Silver, & Reimann, 2018). Orchestration tools may not be generalizable across contexts and teachers, but the design process, testing, and inclusivity can and should be generalized across projects and designs.

2.2 Teachers and Orchestration

Teachers' voices are incredibly crucial to the creation of orchestration tools, as research shows there is a difference in the perspectives and goals between researchers and teachers (Hofmann & Mercer, 2016). Researchers of orchestration tools can empathize with the complexities of a classroom, but teachers know the method by which they can most effectively engage with students and what they need in their classroom. That being said, the goals of the teachers and researchers are different. Methodologies, such as Design-based Research (The Design-Based Research Collective, 2003; DBR) or participatory design (Könings, Seidel, & van Merriënboer, 2014), begin to bring teachers' voices to the table, but there is still work to be done. Co-design, the method of incorporating the user in the design process (Severance, Penuel, Sumner, & Leary, 2016), is one way to accomplish this and has proved useful in other research building similar tools (Matuk, Gerard, Lim-Breitbart, & Linn, 2015; Severance et al., 2016). Co-design is becoming more common, but the field needs to continue pushing on *how* DBR and participatory design happens.

Teachers' expertise plays a vital role in this work, as expertise can affect the use of orchestration technology. Research indicates that expert teachers notice patterns in their classroom and act on them instinctively, whereas novices have not yet developed a sense to understand these problems and patterns (Hammerness, 2005). Therefore, expert teachers may have less difficulty implementing new technology because they have already perfected their day to day actions within the classroom. However, if an expert teacher has already mastered many of these monitoring and classroom management strategies, what can an orchestration tool do for them? Nussbaum and Diaz's (2013) definition of orchestration explains it "is not about teacher training; it is about giving teachers the tools to structure their classes and empower them beyond the training process" (p. 493). While expert teachers may be skilled in the strategies they have developed over time, researchers need to go beyond anything they would be able to monitor or extract on their own. Orchestration tools are best developed to support teachers with tools that empower them and supply information that will push their abilities further than otherwise possible. This challenges orchestration research to concentrate on specific areas of support to assist expert teachers in exceeding their goals for their classroom.

Orchestration for expert teachers is an exciting area of research; however, more challenging is how to support novice teachers. Novice teachers have not yet perfected skills that experts have but can still benefit from supportive technologies. Rather than supplying novice teachers with sophisticated information about the classroom, support tools should be enhancing the training of new teachers. Similar to methods introduced in job-embedded professional development (National Institute for Excellence in Teaching, 2012) and training through curricular materials (Ball & Cohen, 1996), orchestration technology can provide training and support in the moment to continue educating new teachers in real-time. However, there are limitations to this line of research.

First, no two teachers will implement orchestration technologies in the same way. Research shows teachers do not use the full scope of technology provided, and often find one or two components that are of value to them (Derboven, Geerts, & De Grooff, 2017; Lawrence & Mercier, 2017). What works to train and support a novice teacher in one classroom may not work for another. Another limitation is the training and testing necessary to get a tool in a classroom. Novices may be easily overwhelmed; therefore, introducing a piece of technology needs copious amounts of training to ensure success. Regardless of expertise, but especially for novice teachers, technology needs to be integrated as smoothly as possible with enough training. Finally, when implementing an orchestration tool in the classroom, it forces the teacher to take on multiple roles (Sharples & Anastopoulou, 2011). Introducing technology requires teachers to manage the technology and troubleshoot problems as they may arise. Researchers have begun addressing this through the term orchestration load, meaning the effort needed to facilitate learning in the classroom (Prieto et al., 2018). Researchers need to build technology in a way that maximizes the educator role and minimizes the technology manager role, so they are not conflicting with each other. This tension is especially important for novices who may be struggling with their one role.

It is naïve to assume everyone can agree on one definition of orchestration regarding teachers; it is also unfair to teachers to assume we can address all their day to day and moment to moment tradeoffs and struggles in one term. Developing supportive technology is not enough. In order to come to a definition of orchestration that is inclusive to the needs of teachers, as well as the research and technological goals ahead, there needs to be an integration of interdisciplinarity and co-design to this term. The future of technology and research can provide new paths and trajectories for supporting teachers, and to make sure they work, teachers need to be involved in their development. These are essential issues, guiding research in the pursuit to better understand the variety of content an orchestration tool can provide for a teacher. However, to better implement usable and impactful orchestration technology, design is an overlooked and necessary factor in establishing success advancing this area of research.

2.3 Designing with Interdisciplinary Teams

No one discipline has the knowledge and expertise necessary to design effective orchestration tools for teachers. “It seems obvious that designers need to know what the designs they are creating are intended to produce in terms of processes and outcomes” (Fischer et al., 2018, p. 5). In order to understand this statement, the field needs to address the question, who are the "designers" of orchestration tools? This form of design requires educational researchers, computer scientists, designers, teachers, and many other perspectives. However, a gap remains in the field to understand how interdisciplinary teams come together to design solutions for problems in the field.

Researchers in psychology (De Dreu, 2007), health care (Hall & Weaver, 2001; Leipzig et al., 2002), science disciplines (Sopirala et al., 2014), and others have studied interactions and outcomes of interdisciplinary teams. While most of this work shows that this form of collaboration is challenging, when done successfully, it allows groups to produce more creative and innovative solutions than otherwise possible (Cummings & Kiesler, 2008; Rhoten, Boix-Mansilla, Chun, & Klein, 2000). Nancarrow and colleagues (2013) identified 10 necessary characteristics of successful medical interdisciplinary teams, including having a supportive leader who is both flexible and supportive of team members, a team culture of trust and respect, and consistent communication. A survey conducted on flexibility in teamwork indicated that teams who place too much emphasis on the efficiency of designing a final tool are not allowing themselves the flexibility or time to be as innovative as possible (McComb, Green, & Compton, 2007).

Leahey (2018) discussed the similarities between a large-scale quantitative study and a small-scale qualitative study, to describe that similar issues arise in grossly different projects. She described four challenges of interdisciplinary research, including (1) the requirement of extra time commitments, (2) the toll it takes on productivity, (3) the lack of support from administration and other researchers, and (4) the opposing theoretical and epistemological differences among team members. Similarly, Klein (2008) reiterates similar issues, while adding that social and cognitive collaborations are hard to manage, and group members can have conflicting styles and views of collaboration. She also emphasizes the importance of leadership and management with a team and that the unpredictability of long-term impacts can be challenging to assess – this is especially true when trying to publish results from a study.

Interestingly, reviews on this topic reveal that education fields have the highest number of articles that report results with interdisciplinary work (Jacobs & Frickel, 2009; Spelt, Biemans, Tobi, Luning, & Mulder, 2009). Attempts to teach researchers how to work in interdisciplinary teams have been exploratory (Spelt et al., 2009). While it can be rewarding to teach, it can also be disastrous as some people engage with other perspectives more positively than others (Morse, Nielsen-Pincus, Force, & Wulfhorst, 2007). Morse and colleagues explain one reason for this is that teams are often not explicit about the roles of the different disciplines and, therefore, struggle to integrate their expertise because the team has conflicting perceptions of their roles and integration methods. Researchers who developed training specifically for STEM researchers found that training graduate students on skills such as project management, conflict resolution, and how to share opposing worldviews appropriately, positively influenced their collaborations and perceptions of their work (Read et al., 2016). While education disciplines call for the integration of different disciplines and expertise, there is little evidence of how groups in this space go about collaborating and the issues that they experience.

One problem to be addressed when creating educational technology is that members of the research team often take on multiple roles within the group, posing a challenge to be simultaneously critical of and advocate for their needs (The Design-Based Research Collective 2003). For these reasons, interdisciplinary research is challenging in practice and indicates why there needs to be more assessment and documentation of the design process. There are many reasons projects that take on designing technology with interdisciplinary groups can fail. In order to understand how to better these collaborations, and design more productive and innovative educational technologies, there needs to be a more prominent focus on the design process. With numerous calls from education disciplines such as the Learning Sciences to integrate more interdisciplinary perspectives into educational research (Barab & Squire, 2004b; Fischer et al., 2018; Könings et al., 2014), there needs to be more action and research on these calls to understand how this happens in practice.

2.4 Design-Based Research (DBR)

According to a recent survey, the two most common areas of interest in the Learning Sciences community are “learning environments design” and “learning technologies” (Yoon & Hmelo-Silver, 2017). Additionally, results from a workshop held at the International Conference of the Learning Sciences identified the “design of learning environment and practices” as a key theme in the development of the field (Nathan, Rummel, & Hay, 2016). The Learning Sciences views design as a central theme, and one way in which education researchers in this discipline have addressed design is through design research. However, there are several methodologies that describe this form of research, such as design experiments (Brown, 1992), design research (Collins, Joseph, & Bielaczyc, 2004), design-based research (McKenney & Reeves, 2018), design-based implementation research (Fishman, 2014), among others. While all of these have slightly different ways of addressing design research, they all occur on the underlying assumption that researchers conduct design research through an iterative, user-centered design process. Here, I will focus specifically on design-based research (DBR) methodology.

Beginning with the seminal articles from Brown (1992) and Collins (1992) on design experiments, DBR has formed into a methodology that looks at the relationship between designed artifacts, theory, and practice (The Design-Based Research Collective, 2003). Wang and Hannafi (2005) define DBR as a:

> "systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories" (p. 6)

Researchers conducting DBR often study the longitudinal trajectory of a research project using iterative cycles of design experiments in authentic contexts (Puntambekar, 2018).

DBR is situated in and influenced by the context of the intended implementation (The Design-Based Research Collective, 2003). This emphasis on context is critical when studying interventions and designed artifacts in DBR. Barab and Squire (2004) explain research must "not simply share the designed artifact, but provide rich descriptions of context, guiding and emerging theory, design features of the intervention, and the impact of these features on participation and learning" (p. 8). However, context does not only affect the participants using the designed artifact. Ormel, Roblin, McKenny, Voogt, and Pieters (2012) discuss that context also influences how the researchers and other co-designers perceive and study the intervention. DBR projects are iterative and tend to be conducted over time in collaboration with researchers and co-designers, such as practitioners, so that they can make practical and theoretical contributions (The Design-Based Research Collective, 2003).

The contribution to theory and practice, along with the emphasis of iteration and authentic contexts, are the distinguishing factors that make DBR different from other forms of research (Engeström, 2011). However, one criticism is that researchers are incapable of simultaneously evaluating the practicality of design while also generating new theory (Phillips & Dolle, 2006). Addressing practical and theoretical contributions are challenging, especially considering there is no single criterion to evaluate DBR (Kelly, 2006). This is in part due to the various goals of the methodology, which can include the study of the design process, a specific educational phenomenon, an innovative artifact, or a combination of two or three of these goals (Phillips, 2006). Depending on the goal of the specific study, the deliverables will vary.

One way to bridge this gap and contribute to both theory and practice is through conjecture mapping (Sandoval, 2014). Sandoval (2014) describes conjecture mapping as a technique created for researchers to explicitly define the relationships between theoretical conjectures, features of the designed artifact, and predicted outcomes. He describes how conjecture mapping can be used to articulate causal relationships in a DBR study and can also be aligned to help describe theoretical and practical outcomes over the trajectory of a project. In the most recent iteration of the Handbook of the Learning Sciences, Puntambekar (2018) emphasized the importance of analyzing studies across the entire trajectory of a project to understand the relationships between theory and practice. She suggested that iterations within a study or larger scale project can design for and assess design principles, theoretical perspectives, and issues within practice. Looking at iterations as a whole may attend to some criticisms against DBR, such as lack of alignment of research goal, methods, and theory (Kelly, 2004). When researchers report on their studies and only describe outcomes or findings, the readers are missing the opportunity to understand the full breadth of the work and challenges that they overcame in terms of design, methods, and theory.

While it is valuable to analyze and discuss DBR studies over time, this also contributes to the perception of linearity in DBR (Bannan-Ritland, 2003; Edelson, 2002; Engeström, 2011). Researchers conducting DBR studies over-emphasize the product of a design process rather than the process to design (Sandoval & Bell, 2004), which creates the perception that the process is straightforward rather than messy and iterative (Svihla & Reeve, 2016). With so much weight placed on *design* in the Learning Sciences community (Disalvo & Disalvo, 2014), we still do not see scholars asking, "Who does the design and why?" (Engeström, 2011, p. 600). Engeström (2011) elaborates by explaining that when researchers report the design process, they typically begin with the implementation, with no justification of who made decisions using what principles or theories.

There have been several calls in the past few decades for researchers to have a more open discourse around the design process in DBR (Easterday, Rees Lewis, & Gerber, 2017; Edelson, 2002; Kolodner, 2016; Ormel et al., 2012; Phillips, 2006; Sandoval, 2014; Svihla & Reeves, 2016). Svihla and Reeves (2016) dedicated an entire book to case studies of "design stories" to highlight the importance of the complicated and messy design process in education and why it should be more prominent in research dissemination. Unexpected obstacles and constraints are inevitable in DBR when working with projects that tend to be interdisciplinary and long term; researchers need to describe what constraints arose and how they resolved them in order to allow others to understand the complexity of this methodology (Wang & Hannafin, 2005). For example, Tissenbaum and Slotta (2019) discussed four iterations to develop a smart classroom and showed how through their co-design they were able to reflect on their findings, create design implications, and iterate multiple times. Their work is an example of how research can contribute to both design and learning outcomes as they identified issues and successes in their designs that drove the future iterations.

However, not all research articulates the iterations well. While readers may assume that researchers who are conducting studies using DBR are going through an iterative design process, the assumption is not enough. Anderson and Shattuck (2012) describe the iterative nature of DBR as “research through mistakes” (p. 17). This approach is the perfect description of this form of research–researchers will never develop the perfect solution the first time around. Or the second. Or the third. In order to continue growing as a field, researchers need to document and publish their “mistakes” and create a discourse that is open to the challenges of DBR.

While this idea of openness is of value, it alone is not the only reason for the lack of process in this community. Ormel et al. (2012) explained that the absence of the design process is due to publication bias. Reeves and Shilva (2016) discuss that this bias is not limited to publications; grant proposals often require researchers to present an established plan of procedures and outcomes. They explain, “Our funding and publication mechanisms guide us to say one thing – in the service of giving life to our projects from a funding and promotion point of view – but then do something else to actually accomplish our projects” (Reeves & Svhila, 2016, p. 142). Easterday et al. (2017) suggest making the past and future iterations of a DBR project clear and that providing a concise design plan in publications and grant proposals can address these issues. Others call for alternative systems of publication, although this presents other issues within the field when considering the significance of the work (Ormel et al., 2012). However, even with new strategies or venues for publication, there remains a foundational problem in the mechanisms and success in disseminating the process of DBR.

2.5 Assessing the Design Process

One reason the design process has gone unstudied in DBR is that it is not easy or straightforward. The design process is messy, every iteration is different, and there are no clear indications of what to measure. Goldschmidt (1995) describes this, explaining,

> "We classify design problems as "ill-defined," by which we mean that there are no algorithms for their solution. This is what makes them so fascinating, and their solutions potentially creative, or at least innovative. At the same time, it makes it difficult to model the cognitive processes involved." (p. 2)

Most research on the analysis of the design process is not in education but other disciplines such as engineering, architecture, or psychology; however, there is much to be gained from adopting methods and strategies from other disciplines.

Howard, Culley, and Dekoninck (2011) studied an engineering company and analyzed the creative process during 15, 30-minute brainstorming sessions. They assessed the design process by tracking ideas over time using transcripts and sketches to document how group members analyzed, generated, and evaluated ideas. Shah et al. (2003), also in engineering, developed metrics to assess idea generation among design teams. Their metrics–novelty, variety, quality, and quantity–have been used in various other assessments including a comparison study to understand psychology undergraduate design collaborations (Kohn, Paulus, & Choi, 2011) and a study to understand how engineers use sketching to build ideas (Linsey et al., 2011). These metrics were also used in a meta-analysis to understand how engineering and industrial design students work together to generate ideas collaboratively (Sio, Kotovsky, & Cagan, 2015). Their findings show that groups who generate more ideas tend to have more novel and higher quality ideas, and groups who copy more from examples generate less variety and lower quality ideas.

This is of value to educational researchers because in order to build innovative technology, this process needs to be discussed to understand how this process can be improved.

Another technique to document and analyze the design process is a method called linkography. Goldschmidt (1992) developed the linkography method based on her process focused view of design. Linkography is a method to visualize relationships of "design moves" during collaborative design discussions; Goldschmidt (1992) defines a design move as "an act of reasoning which presents a coherent proposition pertaining to an entity that is being designed" (p. 72). Design moves are connected based on coding for semantic meaning across discussions (Goldschmidt, 1995; 2014).

Linkography has been used to assess the design process in various settings and disciplines because of its flexible level of analysis and ability to include multiple levels of coding within it. Jiang and Gero (2017) used linkography to assess idea connections and inter- and intrapersonal links within an engineering company brainstorming meeting. While traditional linkography is done at the turn level, Jiang and Gero (2017) analyzed links at both the turn level and the conversation level. Other examples of linkography include assessing brainstorming and creative problem solving within groups of industrial design students (Vidal, Mulet, & Gómez-Senent, 2007), comparisons between novice and expert designers creating a building layout (Cai, Do, & Zimring, 2010), and identifying difference between a group designing together versus an individual designer thinking aloud while designing the same task (Goldschmidt & Planning, 1995). One limitation of linkography is that it is very time-consuming. Some researchers have developed tools to build and analyze linkographic representations (Gero, Kan, & Pourmohamadi, 2011; Pourmohamadi & Gero, 2011), but even so only slightly lessens the time commitment to transcribe, code, build and analyze the representations. Another issue is that it is currently not feasible to analyze long term design collaborations, as the logistics and working memory of connecting design moves from multiple meetings over a long period is not possible. However, linkography seems to be a productive way to assess the fine-grain details of a short-term design process.

Other researchers have developed tools to visualize group data in similar ways in the Learning Sciences (Hmelo-Silver, Liu, & Jordan, 2009; Shehab & Mercier, 2019). These focus on student interaction and processes rather than the design processes. In these examples, the researchers visualize interaction data from groups of three or four students; however, in the design process, the members of the team vary and are often more than four members. This makes analyzing the process complex as researchers have to keep track of multiple voices and perspectives. Representing the different voices and perspectives within a design team is invaluable to understand the process and outcomes (Ormel et al., 2012); therefore, adds additional complexity to this analysis.

2.6 Theoretical Framing

There have been various arguments within the design community about the definition and process of design. One common criticism of design research is the lack of scientific rigor (Biggs & Büchler, 2008). Design researchers have called out this issue by suggesting that designers draw upon the research methods and theories of other disciplines as design does not traditionally have an active scholarly culture (Cross, 2001). While there are some discussions in traditional design disciplines about theory, there is generally a lack of theoretical framing in design by researchers and practitioners (Lee, Baskerville, & Pries-Heje, 2015). As argued by Bennett and Heller (2006), without justifiable theory or questions driving the design process, "design is merely an act of faith" (p. 12). Most importantly, this leaves the design community open to question “Are we a science, an art, a craft, a technology, a design field, or some combination of?" (Smith & Boling, 2009). Design lies at the intersection of fine art and social sciences; even so, most designers still side with an atheoretical perspective. However, there is value in situating designs in both pragmatic and theoretical views.

Sociocultural theory highlights the importance of social interaction as a way to create knowledge (Vygotsky, 1978). This theory attends to the process and interactions of learning rather than merely focusing on outcomes; therefore, allowing researchers and designers to understand how people communicate and build ideas (Esmonde, 2017). Designers make decisions about external factors but also consider how interactions with the setting, culture, and people affect learning. Contextual affordances are inseparable from learning, and to design appropriately, they must be taken into consideration during the design process.

More specifically, situated learning theory, a theory positioned within the sociocultural perspective, suggests that learning is embedded within and determined by specific physical and cultural settings (Anderson, Reder, & Simon, 1996). The unit of analysis of this work is typically the relationship between elements. It allows for the exploration of patterns of interactions within the environment that continue to shape and evolve the user’s understanding (Greeno, 1998). Design is always grounded in culture and context. Something cannot be designed, or cannot be designed well, without the considerations of the users and the context. What makes design interesting is the interactions and collaborations that exist while designing an artifact, and also during the implementation of the final form. A design process is a form of learning and one that researchers should document and assess (Kali, 2016).

As described above, Barab and Squire (2004) explain research must “not simply share the designed artifact, but provide rich descriptions of context, guiding and emerging theory, design features of the intervention, and the impact of these features on participation and learning.” (p. 8). This same context also influences how the researchers and other co-designers perceive and study the intervention (Ormel, Roblin, McKenny, Voogt, & Pieters, 2012). The same situated affordances that affect the implementation, also have an impact on the design process. Studying how context is accounted for during the design process, in addition to in the classroom, can have profound effects on future designs and the process by which the designs are created. Leveraging the design and educational perspectives, in this study I employ a socio-cultural theoretical view to analyze the interactions and processes between individuals and artifacts and within groups and communities across both the design process and implementation.

2.7 Conclusion

Classroom orchestration is the real-time management and facilitation of learning that takes place across multiple planes in a classroom. Teachers’ roles in classrooms are complex and require attention at the individual, group, and classroom level at any given time. Orchestration technology is created to support teachers as they facilitate learning across these levels. However, orchestration technology can add to the teacher’s orchestration load; therefore, tools must be designed intentionally to be effective in the classroom. To design technology that is effective for the teacher, their voices must be represented in the design process, because every teacher has diverse expertise and will have different interactions with the tool. By empowering the teachers’ voices in this process, orchestration tools can be impactful to teachers in areas that they need.

One way to incorporate teachers' voices is through the DBR methodology used in the Learning Sciences to design and analyze the use of orchestration technology. By engaging users and other perspectives in an iterative design process and testing designs in an authentic context, DBR is different from traditional methodologies in education, allowing researchers to produce both theoretical and practice outcomes. DBR in education is different from other traditional design perspectives because it is grounded in theoretical assumptions, and researchers systematically analyze the design after implementation. Typically, design work is not positioned in any theoretical stance; however, there is value in situating design in theory rather than designing pragmatically. Sociocultural theory bears the context to the forefront of the design so that designers consider not only the specific decisions about a design but also the local contexts and how the design and users will interact with it. Theory also substantiates learning that takes place during the design process. The design process involves a series of collaborative interactions with an interdisciplinary group to develop new knowledge in the form of educational technology and processes. The success of the final design is highly dependent on a productive collaborative design process in order to come to innovative solutions. However, research tells us that working with interdisciplinary groups is challenging; therefore, more research is necessary to understand what makes a successful interdisciplinary design process.

Research on the design process will improve the field by engaging in a discourse about what it takes to do DBR, allowing insight into what works and how we can make it better. By not describing this process, researchers are missing out on learning opportunities to advance this process. Without these conversations, researchers may repeat bad designs, waste resources, engage in weak collaborations, or miss opportunities to improve the learning outcomes in their studies. Studying the design process can better our methods of collaboration and design, allowing researchers to build more innovative solutions in educational technology. Research shows that successful interdisciplinary collaboration can lead to creative and innovative solutions. Studying the design process and improving the methods to do this work will only improve outcomes and build better technology. To do so, researchers need to begin documenting the design process and finding ways to disseminate findings and solutions. There is no straightforward answer to these problems, but through research and shared insight DBR can become a better methodology and produce more robust theories and practices for researchers, designers, and practitioners.

In order to address these areas, this dissertation aims to document the design process to build an orchestration tool with an interdisciplinary team. While describing this process would be valuable to design orchestration technology, this dissertation goes one step further and analyzes the full design process. Additionally, while the arguments presented above advocate for the documentation of the design process, there is also value in understanding how a design is implemented in the classroom. Both components are highly beneficial to determine the impact of a tool and analyzing a full iteration of a DBR study; therefore, the second goal for this dissertation is to test how users interact with the CSTEPS tool in the classroom. By assessing the design process and implementation, I aim to describe how the CSTEPS tool was built, how instructors used it, and how the research team can improve the CSTEPS tool based on findings from both of these proposed phases.

CHAPTER 3: DESIGN METHODS

3.1 Study Design

This study is part of an NSF funded project at the University of Illinois Urbana-Champaign called Collaborative Support Tools for Engineering Problem Solving (CSTEPS). The project is on the fourth implementation of a design-based research project. Past implementations have focused on creating and studying a student whiteboard tool, and an orchestration tool for instructors called the CSTEPS tool. The current implementation presented in this dissertation will apply an iteration of the CSTEPS tool with embedding prompts to support TAs and CAs (henceforth, instructors) as they learn about collaboration and simultaneously aid groups' collaborative processes. In this dissertation, I will analyze a full iteration of this DBR project. I will study the process of iterating on the design of the CSTEPS orchestration tool, investigate how it was implemented in the classroom by the instructors, and close with the findings and future directions for the next iteration of the tool.

3.2 Phase 1: Design

The goal in analyzing the initial brainstorming meeting for this iteration of the CSTEPS tool is not to provide a definitive plan how meetings like this should be structured but to explore the process and discuss the complexity of developing an orchestration tool in an interdisciplinary, DBR project. To explore this specific process, I will address the following research questions:

RQ1. How did ideas about the CSTEPS tool emerge during an initial brainstorming meeting among an interdisciplinary team?

RQ1.1. What were the critical ideas that influence their discussions?

RQ1.2. How interconnected were the ideas?

RQ1.3. How did the team members build on each other's ideas?

RQ2. How did the ideas that emerged during the design process get implemented in the classroom?

3.2.1 Context

The analysis of this phase of the project was completed on the most recent iteration of a five-year project. Below I will provide a brief overview of the research completed before this study. However, the remainder of this dissertation, I will focus on the most recent design iteration, which was collected Fall 2018 through Spring 2019.

This project has been funded through two NSF grants; see Table 3.1 for a timeline of the two grants (CSTEPS 1 and CSTEPS 2). The two grants were written in succession to build collaborative experiences in required introductory engineering courses. The first grant worked with a 210-level course in engineering, and the second grant worked with a 250 level course. The two courses were in a series; students took them in a sequence. These courses were foundational courses; all engineering students were required to take them. Students in these courses attended a 50-minute lecture three times a week with the faculty member teaching the course, as well as a discussion section once a week led by one TAs and two CAs. At the beginning of the first grant, the engineering department was transitioning their discussion section classes from their traditional lecture format to a group-based discussion format where groups of students worked on collaborative worksheets. Members of the research team, two of whom participated in this current study, worked with faculty members to understand what was happening in discussion sections, and developed strategies to improve collaborative interactions among students. The primary goals in CSTEPS 1 were to develop tools to support collaborative sketching and understand how groups of students interacted with them. In CSTEPS 2, the goals were to create and study the use of an orchestration tool used to teach instructors to support collaboration.

Table 3.1
Timeline of the CSTEPs projects

Semester	**Grants**	**Phases of the project**
Fall 2014	CSTEPS 1	*Data collection (paper only)*
Spring 2015	CSTEPS 1	Analysis, design, & development
Summer 2015	CSTEPS 1	Analysis, design, & development
Fall 2015	CSTEPS 1	*Data collection (student CSTEPS tool comparison: paper vs. tablets vs. multitouch tables)*
Spring 2016	CSTEPS 1	Analysis, design, & development
Summer 2016	CSTEPS 1	Analysis, design, & development
Fall 2016	CSTEPS 1	*Data collection (student tool comparison: unsynced tablets vs. synced tablets vs. multitouch tables)*
Fall 2016	CSTEPS 2	Design & development
Spring 2017	CSTEPS 1	Analysis
Spring 2017	CSTEPS 2	Design & development
Summer 2017	CSTEPS 2	Design & development
Fall 2017	CSTEPS 2	*Data collection (synced student tablet; first CSTEPS tool)*
Spring 2018	CSTEPS 2	Analysis, design, & development
Summer 2018	CSTEPS 2	Analysis, design, & development
Fall 2018	CSTEPS 2	Analysis, design, & development
Spring 2019	CSTEPS 2	*Data collection (synced student tablet; second CSTEPS tool)*

Over five years, there have been many changes to and analyses of the discussion sections. While describing the full project in detail is beyond the scope of this proposal, I want to highlight some decisions to rationalize and contextualize the current study. To do so, as described in the 4T model for understanding collaborative technologies (Mercier & Higgins, 2015), I will provide a brief description of the changes to the task, teams, teachers, and technology over time.

Task. At the start of CSTEPS 1, the tasks for the discussion sections were a series of worksheets that contained problems for groups to solve. These problems were straightforward, structured problems that could be solved by each member of the group individually because there was one right answer for each problem. Through an iterative process, members of the research team worked with the faculty and instructors to create worksheets specifically for collaborative problem solving (Shehab & Mercier, 2017). The redesigned worksheets were ill-structured and open-ended tasks containing a real-world problem, requiring students to discuss among their group to solve the task. The development of these tasks was iterative with the course instructors and faculty, with small changes or full redesigns happening after each semester.

Teachers. From the beginning of the project, the Principal Investigator, Erica, developed relationships with the engineering faculty to build a successful collaborative rapport. While the faculty sometimes changed semester to semester, one faculty member became a member of the team. Marisa, the faculty member, worked with the team during the first grant and was the faculty member who initiated the changes from the traditional lecture-style discussion section to collaborative discussion sections in engineering.

The relationship with the instructors of the discussion sections have varied throughout the project. There is often turnover of instructors; TAs and CAs graduate, get new jobs or are assigned to different sections. However, two TAs chose to stay with the team and work on the research project for two consecutive data collections each; the remaining instructors were new to the project. In addition to changes in instructors, there has been variability in the training of the instructors. During the first two data collections in CSTEPS 1, the research team was able to hold two semester-long courses for the instructors of all discussion sections on the importance of collaboration and ways to monitor and intervene with groups effectively (Mercier & Shehab, 2018). However, this course was not sustainable due to lack of funding to continue teaching the course past the grant, and due to restrictions from the College of Engineering, as it could not be offered for all TAs and CAs in this series of courses. Although, the team put forth other efforts to engage the instructors in discourse around collaboration. In one iteration, several members of the team provided a small lecture about collaboration to the instructors during training on the CSTEPS tool; in another iteration, the TAs were hired as members of the research team to engage them more in the project goals.

Teams. In discussion sections, groups of four students worked to solve worksheets. These teams were created based on criteria developed by faculty using CATME software so that groups were evenly distributed by various factors such as academic status, sex, or race. Groups of students were held constant across the semester, per the suggestion and influence of the research team, so that students could become familiar with their groups. Findings from CSTEPS 1 indicated that students in discussion sections struggled to collaborate (Mercier, Shehab, Sun, & Capell, 2015). When comparing different forms of collaborative sketch tools, including paper, multitouch tables, synced tablets, and unsynced tablets, students using multitouch tables had more collaborative interactions than tablet versions (Mercier, Kelly, Shehab, & Jung, 2019). Analysis of CSTEPS 2 on students' interactions is ongoing.

Technology. There were two main technology components to this project: the student tool and the CSTEPS teacher tool. The student tool was a shared drawing space to encourage collaboration among group members. The student tool design has had three iterations, see Figure 3.1; students used the final design in the study presented below. As discussed above, in CSTEPS 1, the researchers made comparisons between the screen size and collaborative interactions (Mercier, Ferguson, Kessler, & Shehab, 2016). Findings from this analysis indicated that the multitouch tables were more effective at supporting collaboration. However, the team chose the synced tablets to move forward within the second CSTEPS project due to the scalability of the technology and the opportunity to collect individual interaction data from students. While CSTEPS 1 focused on the student tool, CSTEPS 2 refined the student tool and developed a tool to support instructors during discussion sections.

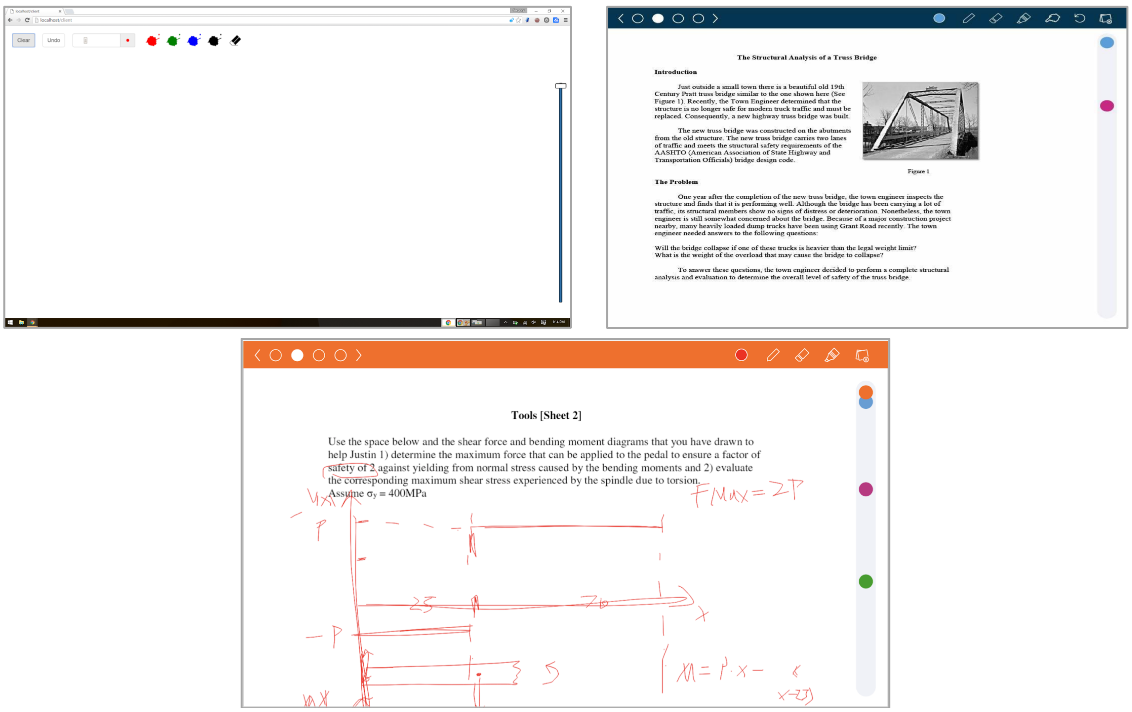

Figure 3.1: The first iteration of student tool (top left); second iteration (top right); third iteration (bottom middle).

During CSTEPS 2, I, and members of the research team, incorporated the instructors' voices into the design of the CSTEPS tool. Through focus groups and interviews, we gathered insights from instructors using low fidelity prototypes and scenarios to address what their needs were in their classrooms (Lawrence & Mercier, 2017; 2019). The first iteration of the CSTEPS tool, presented in Figure 3.2, visualized live data collected from the students' tablets to the instructors. These data required the instructors to interpret and act on the data in real-time. Findings from interview data of the instructors reflecting on the CSTEPS tool found that each instructor used the tool differently and valued different components of the software (Lawrence & Mercier, 2017; 2019). In the implementation phase, I will describe the next iteration of the CSTEPS tool based on findings from the first iteration.

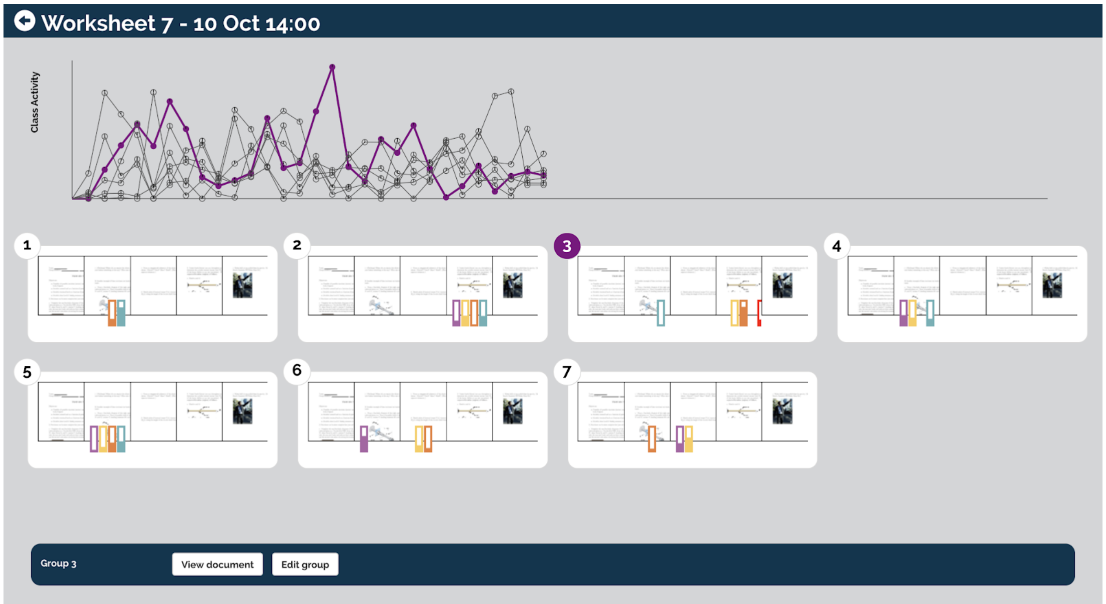

Figure 3.2: First iteration of the CSTEPS tool.

By briefly reviewing the task, teams, teachers, and technology of the project, my goal is to shed light on the complexity of this project in order to give context for the analysis I will present. The past design phases were not documented, and as a result, I cannot provide concrete details about how the team made decisions. From this point, I will present data that was collected Spring of 2018, where I am leaving off in the context section, through the implementation in the Spring of 2019. By analyzing this process, I aim to understand more clearly what this process looked like, how ideas were generated and implemented in the classroom, and how these decisions were taken up by the teachers.

3.2.2 Participants

The creation of collaborative technology, such as the CSTEPS tool, requires the perspectives from different backgrounds and the contribution of varying skill sets.

Interdisciplinary nature is critical to building a tool that can achieve the goals of supporting instructors as they enact collaborative interventions. Participants in the lab group were from a range of disciplines, including education, design, computer science, and engineering. They focused on different areas of research to gain a diverse perspective of the issues addressed in this project. Bringing together this group of people allowed the project to generate innovative ideas and learn from the views and expertise of others.

Twelve participants, who were members of the research team, took part in the design process to create the CSTEPS tool. Eight of the 12 members of the research team were able to attend the brainstorming meeting (see Table 3.2). Of the eight participants, three were faculty, Erica was the Principal Investigator, Levi was the Co-Principal Investigator, and Marianna was a faculty in engineering and computer science. Noah was a post-doctoral researcher. Three participants were education graduate students funded on the project, Sami, Sarah, and myself. Peter was an undergraduate developer working on the project.

Table 3.2
Participant information.

Participant name	Position	Background
Erica	Faculty; PI	Learning Sciences
Levi	Faculty; Co-PI	Learning Analytics
Marisa	Faculty	Engineering
Noah	Post-Doctoral researcher	Learning Analytics
Sami	Graduate researcher	Learning Sciences
Sarah	Graduate researcher	Learning Sciences
Lu	Graduate researcher	Design and Learning Sciences
Peter	Software developer	Engineering

3.2.3 Positioning the Researcher

The positionality of a researcher influences the framing, interpretations, and conclusions of a study (Malterud, 2001). Acknowledging my subjectivities as the researcher allows me to use my experiences and perceptions to gain depth and meaning when I collected and analyzed the data (Bresler, 1996). My role in the CSTEPS projects and with the participants varied over the last five years. I began working as a designer on the first CSTEPS project in the Fall of 2015. I was brought on the team as a graduate student in graphic design to provide feedback on the design of the first student whiteboard application and mockups for the CSTEPS tools to be included in the grant proposal for the second grant. After a few months of working on the team, I soon decided to transition to a graduate student position in the College of Education, advised by Dr. Mercier.

During the spring of 2016, after transitioning to Dr. Mercier's lab, my responsibilities on the grant was primarily designing interfaces. The following semester, NSF awarded the second grant, and I designed the first CSTEPS interface through a series of interviews with instructors. Through this phase of the project, my role transitioned from designer to designer and researcher, as myself and members of the research team began analyzing findings from the interviews and brainstorming designs for the software. After the implementation of the first CSTEPS tool, I facilitated the conversation on the design of the second iteration.

It was in my facilitation of the design process, and later analysis of it, that formed the duality of my role as a researcher–both insider and outsider. In this dissertation, I will analyze the design process of the CSTEPS tool's second iteration, where I led many discussions and meetings about the design process and the implementation where I interacted with instructors weekly over a year (one instructor, two years). At this point, my interest in the project was beyond facilitating the design process and creating the software. I was deeply embedded in the goals of the project and developed relationships with the research team and instructors.

As is true with most DBR studies where technology and interventions are co-designed, my relationship with the research team and instructors who used the tools influenced my research and findings. I recognize, as a participant observer, I need to be clear about my role and address limitations of this work due to my positionality. However, my closeness with the research team and instructors afforded collaborations to build the CSTEPS tool and explore how it was used, not through assumptions but based on my understanding and rapport with this group of people. While I cannot be objective in my dissertation analysis, through reflection of my subjectivities during data collection and analysis, I aim to be transparent about my role and my interpretation of this research as much as possible.

3.2.4 Data Collection

During the fall semester of 2018 and the spring semester of 2019, data were collected from 29 meetings about the design of the CSTEPS tool. Of the 29 meetings, 12 were lab group meetings where all group members were asked to be present, although there were several absences throughout the semester due to illness or schedule conflicts. Eleven of those meetings were one hour long, and one was three hours. The remaining 17 meetings were between subgroups that pertained to the design of the prompts or interface and ranged in length.

Audio data and notes were collected from the majority of meetings. This form of data was not collected at the beginning of the project before I decided to analyze this process, during impromptu meetings, or when conducting user testing with participants that did not consent. Other data sources were collected when applicable. These data sources were documents that members used to present information to the group and artifacts the group created during the meeting or after the meetings to synthesize content. These artifacts included slides and shared documents, photographs, notes, sketches, in-progress screenshots of the software, and paper artifacts.

I collected photographs of meetings in progress, notes on a whiteboard, or physical arrangements of papers on a table. Sketches were photographed and uploaded in the folder for the relevant week; physical papers were also kept for future analysis. Screenshots that were taken of the software as new iterations emerged. Finally, any documentation that a member of the team created to synthesize meetings were collected (e.g., mockups, sketches, notes).

3.2.5 Coding and Analysis Procedures

The goal of the first phase was to understand and document the design process with an interdisciplinary research team. I used a case study methodology (Stake, 1995) to dive into an initial brainstorming meeting that took place toward the beginning of the design process. I analyzed what ideas the team generated and how they connected them across this meeting using a method called linkography (Goldschmidt, 1994). The following steps describe how I analyzed data during this process.

Step 1. The analysis of the design process began by transcribing the meeting. The transcript was completed in a playscript form to document verbal interactions of group members (Forrester & Sullivan, 2018). Long monologues by a member were separated by pauses so that coding could identify ideas and content accurately. Transcripts were checked by a second person to ensure quality.

Step 2. Linkography was used to look in-depth at the meeting to identify ideas that emerged and the quality of collaboration among the group members. Linkography is a method used in traditional design disciplines to assess the design process at a fine-grained level by visualizing relationships of “design moves” during collaborative design discussions (Goldschmidt, 1992). Goldschmidt (1992) defines a design move as reasoning that adds to or relates to the ideas that progress the design forward. Design moves are connected based on semantic meaning across discussions to build linkographic representations (Goldschmidt, 1995). Figure 3.3 shows an example of this form of representation. Along the horizontal axis is each turn, or design move over time. Each design move is related to each other by the content of that design move. For example, the ninth turn may be related to the sixth turn because the ninth turn elaborated on an idea that was proposed during the sixth turn. Lines were used to connect ideas that linked by a similar context visually.

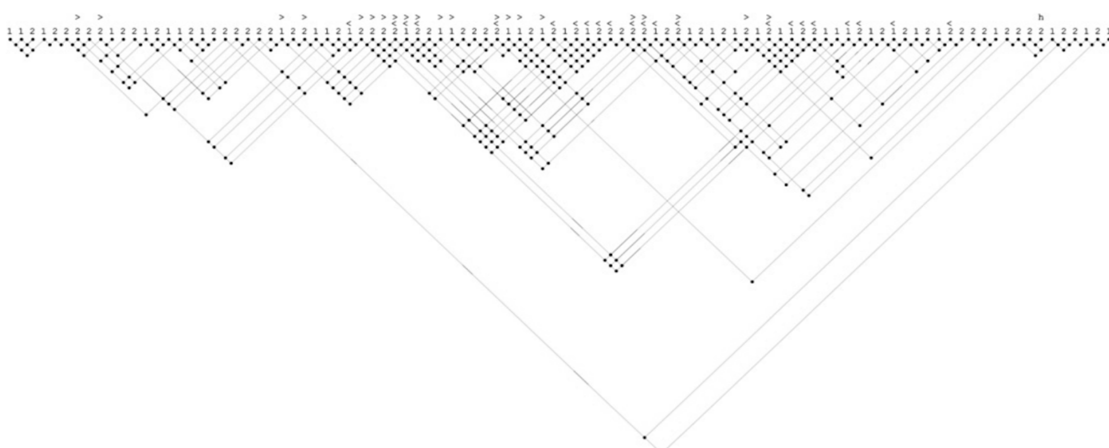

Figure 3.3: Linkographic representation from Kan, Gero, & Mason, 2008 (p. 322).

In this analysis I used all turns of talk as design moves. Design moves were connected using guidelines by Hatcher et al. (2018). They built their guidelines from the literature on linkography as well as their experience coding and linking design moves. Their guidelines identify that links between codes can be connected if one or more of the following criteria were met: “Participants relate directly to earlier ideas when verbalizing their ideas. There are functional, behavioral or structural similarities (van der Lugt, 2000). The same basic idea is applied in a different context." (p.136)

> They also describe three tips for making connections between design moves, including "Repeated words alone do not necessarily mean there is a link. Links between design moves that have a large number of intervening moves can be coded if the related idea has not occurred between these moves. Where elements of an idea reoccurred multiple times within the transcript, segments were only linked back to the first time the idea was presented, unless a new element was introduced in a subsequent move that would produce a new link." (p.136)

I used these guidelines to connect design moves. My role in the project provided me with insider knowledge about the group, their dynamics, and the overall context. Therefore, I did not achieve reliability because of my insider knowledge; my subjectivities could not be replicated in the form of a second coder (Bresler, 1996).

The brainstorming meeting was segmented into three scenarios. These three sections were analyzed individually using linkography because conversations had precise introductions and wrap-ups. Therefore, steps three through six were repeated for each scenario.

Step 3. To answer research question 1.1–what are the critical ideas that influence the discussions that emerged–the distribution of link generation was analyzed. Link generation explores what percentage of moves generate a certain number of links. This shows the number of links per turn of talk as well as orphan moves and critical moves. Orphan moves were turns of talk that were not linked to any other move. This could indicate that the turn was ignored or perhaps was enveloped in a conversation where people were talking over each other. Critical moves were moves with at least ten links to other moves. Highlighting critical moves in the linkography identifies which turns of talk were highly linked back to during the brainstorming session. The analysis illustrates which turns were highly referenced back to, showing it had some importance to the discussion.

Critical moves were identified by determining a threshold based on the grain size of the analysis. Research recommends using a percentage of the 10% to 12% of turns when analyzing design discussion with less than 100 turns. Ten percent of the total turns in the first scenario was 76 links; however, the highest number of links achieved by one turn was 63 links. Therefore, since this linkographic analysis has a high number of total turns, the threshold for a critical move was adjusted to represent the influential turns in the dataset. After the critical moves were identified, they were visually mapped onto the linkographic matrix representations, and frequencies were analyzed by the speaker.

Step 4. To further understand what the critical moves were and why they may have been turns of talk that were highly linked to, next, I applied a coding scheme to all critical moves to identify what components of the design process each critical move built onto. As described above, researchers who have developed strategies for completing linkographic analysis use the Function Behavior Structure (FBS) framework to understand how the design process emerged within conversations (see Table 3.3). The FBS framework has been used by researchers using linkography (Kan & Gero, 2009; Pourmohamadi & Gero, 2011) and in the Learning Sciences to understand the design process (Hmelo-Silver, Liu, & Jordan, 2009).

Table 3.3.
Coding scheme for FBS framework.

Code	Definition	*Example*
Function (F)	The intention, goals, hypotheses, or past data about the artifact or concerns or observations about how the users behave without the artifact.	*“So here, it's very interesting to watch because they don't talk at all. They're just writing on the tablets.”* *“Because this is, this is the intervention piece [of the research].”*
Expected Behavior (Be)	The analysis, explanation, evaluation, or integration of how the artifact exists and concerns or ideas about the human-artifact interaction derived from the project goals and the expected/desired interaction.	*“So, if you’re asking them to monitor how do you actually ask that?”* *“I think we need to have classifications of things that they are monitoring for.”*
Behavior from Structure (Bs)	The analysis, explanation, evaluation, or integration of how the artifact exists and concerns or ideas about the human-artifact interaction derived from the physical or virtual features of the design.	*“We need to find a way to hit monitor, right? To make it like, there needs to be uh alert that says?”* *“But if I'm with a different group and then this changes, then it should dismiss itself, right?”*
Structure (S)	The physical or virtual features of the designed artifact, such as size, color, or word length or style.	*“Every minute, the font should get darker.”* *“Do you want something that’s only going to be a few words?”*

Step 5. In order to answer research question 1.2—how interconnected the ideas were during the brainstorming meeting—I analyzed link density and vertical and lateral areas. First, I calculated the link index, which shows how interconnected ideas were over time (Goldschmidt, 2016). Link density was calculated by dividing the number of links in an area by the total number of ideas in that same area. Research shows that this proportion represents the level of synthesis the group achieves. Meaning, the higher the link index, the higher the amount of

synthesis across the group; the typical range is from 0 (low synthesis) to 2.5 (high synthesis) (Goldschmidt & Tatsa, 2005).

In order to compare interconnectedness within and across the scenarios, two types of areas were identified in the data, vertical and lateral. Vertical areas are areas where one link sparks an area of high density linking back to itself (El-Khouly & Penn, 2013). These areas were identified using the linkographic representation as areas of patterns where one turn is highly linked back to repeatedly. While vertical areas have the potential to develop good ideas, they also have limitations. Goel (1995) explains that vertical areas make up higher interconnected discussions; however, they can sometimes mean that the team's discussion is fixated on one idea which reduces the opportunities for creative insights.

I identified vertical areas as a sequence of turns that are highly linked back to one turn. This means that the turn sustained a high number of links for a duration of time immediately after being proposed. Vertical areas were a sequence of turns where 40% of the possible links in the area were connected to the initial idea, validating that the turn of talk was highly influential within the discussion. Forty percent on turns were selected using a trial and error method to identify what percentage captured conversations; this metric captured conversations while also accounting for backchanneling turns of talk (e.g., um, yeah, ok, mhm). The duration of the vertical areas varied because some links had high linking for a few turns compared to others who were built on consistently for upwards of 50 turns but had to be at least 10 turns long.

These turns were identified visually by identifying dense lines of linking in the linkography representations (see turn 670 in Figure 3.4 for example of visual marker in linkography). Next, the end of each area was determined after a gap in links occurred for more than 10 turns (see figure 3.4 in blue). Ten turns were decided from inspecting the video and identifying how long it took for new ideas to emerge. Because these conversations include so many people, conversations are quick; a block of 10 turns typically included backchanneling (e.g., “mhmm”, “yeah”) and a few turns of talk between ideas. Finally, the area was validated as a vertical area, meaning it was 10 turns or longer and at least 20% of turns were linked to the first turn. In Figure 3.4 nine out of 16 turns are linked back to turn 670, exceeding 40% of turns.

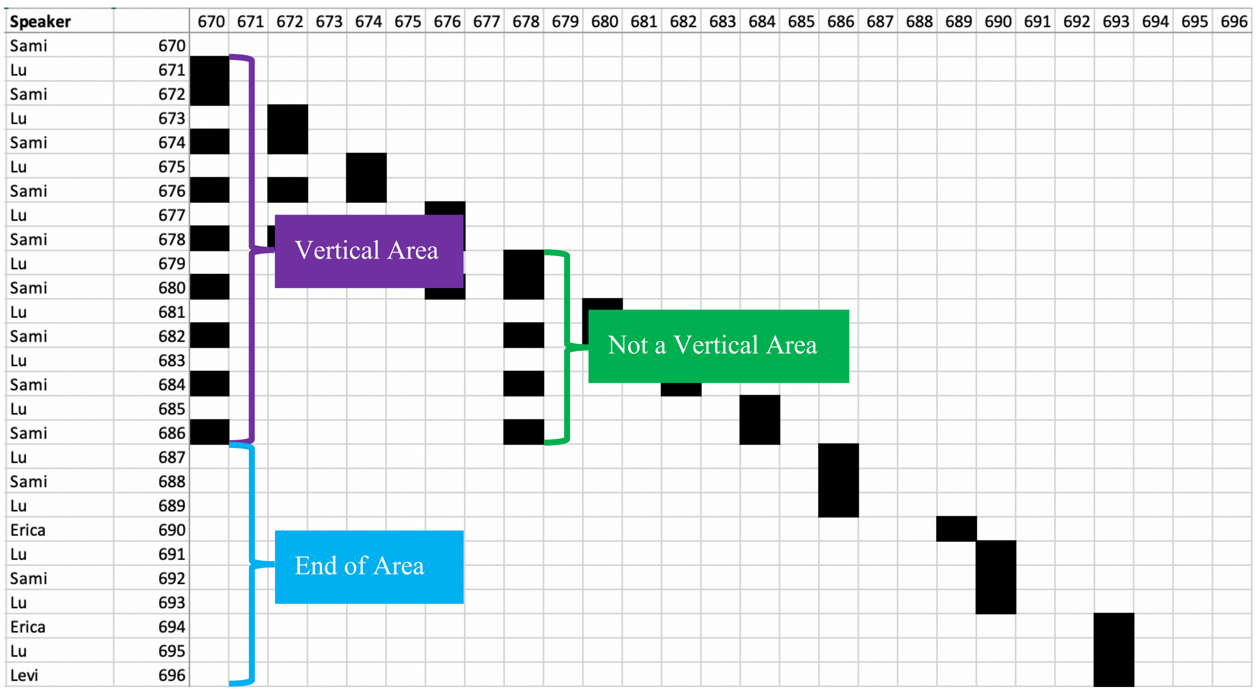

Figure 3.4: Linkography excerpt from scenario 3, turns 670 – 696.

Rather than fixating on one idea like vertical areas, during lateral areas, the groups’ links are more dispersed. Lateral areas change the concept to different, less fixated ideas, which in turn creates more divergent thinking and potentially more ideas (El-Khouly & Penn, 2013). Lateral areas were identified in between areas of vertical areas. Meaning the links were not building back to one idea but were dispersed across each other. This area illustrated discussions that were not heavily influenced by one idea but were linked across multiple turns. Lateral areas can lead to more diverse ideas but may have more shallow insights where the ideas can get lost if not brought back up by a member of the discussion.

Step 6. To answer research question 1.2, self-link index was run to determine the amount team members built on the ideas of others versus their own (van der Lugt, 2000). This analysis identifies how much the group was building ideas together versus building on their own ideas. Self-link index was calculated by dividing the number of links a person built on their ideas divided by the total number of links in that area. Additionally, the self-link index was also completed by discipline to assess cross-disciplinary collaborations.

Step 7. In order to answer the overarching–how do ideas about the CSTEPS tool emerge during an initial brainstorming meeting among an interdisciplinary team–I analyzed the interplay between critical moves, interconnectedness, and collaboration across the entire brainstorming meeting. Themes were extracted to suggest ways to brainstorm concepts in the future.

Step 8. Finally, the second research question–how do the critical ideas that emerged during the design process get implemented in the classroom–was answered by describing what ideas that were extracted from the brainstorming meeting were implemented in the classroom and the form they took. To do so, I describe the final design of the CSTEPS tool, and outline ideas from the meeting that were and were not implemented in the classroom.

CHAPTER 4: DESIGN RESULTS

In order to answer the first research question, how did ideas about the CSTEPS tool emerge during an initial brainstorming meeting among an interdisciplinary team, linkographic analysis was used to understand how ideas were generated and to explore the group's collaboration. First, I describe the brainstorming meeting format and who contributed to this discussion. The brainstorming meeting was broken into three distinct sections that were designed into the meeting. The group discussed two scenarios that were pulled from the previous year's data and wrapped up with a discussion about findings from past implementations to make decisions about the software. These three sections were analyzed individually using a form of interaction analysis called linkography because conversations had precise introductions and wrap ups. I dissect these three sections individually, discuss how the conversations were linked, describe critical moves that emerged, and outline the group's collaboration. Finally, I describe relationships of factors across the data and overarching takeaways.

4.1 Description of Brainstorming Meeting

The goal of the brainstorm design meeting was to develop concrete prompts for the CSTEPS tool and make decisions about changes to the software. The meeting was structured with scenarios from the previous year's data to scaffold the conversation and give real examples from the classroom to build prompts. Scenarios were used to structure the discussions and give the group a joint problem space to brainstorm together (Rosson, Carroll & Hill, 2002). The team developed prompts around these scenarios by answering a series of questions about what the TAs should do if the identified scenario presented itself in the classroom.

Sami and I chose the scenarios using in-progress features from four group behaviors, which Levi and Noah developed using log file analysis (see Table 4.1). Using log file analysis, they developed models to predict group behaviors. The models were built using video coding of collaborative interactions in the classroom and related actions on the tablets. The video and interaction data were collected from the implementation the previous year, where the context, classroom, and group format were the same. The goal of the prediction models was to understand which actions on the tablet predicted types of collaborative behaviors among groups (for details about prediction model see Paquette, Bosch, Mercier, Jung, Shehab, & Tong, 2018). The tool used those predictions to provide prompts to TAs and CAs in real time about groups' collaborative processes. The relationship between actions and group behaviors were still being developed at the time of this meeting; however, the preliminary results were used for brainstorming purposes. In collaboration with the researchers building the models, Sami and I pulled video clips that best portrayed those features in the data. We found two videos of each kind of feature that represented the possible group behaviors. We developed six scenarios to be used to brainstorm during the meeting.

Table 4.1
Features and possible group behaviors used in scenarios for the brainstorm meeting.

Features **[Interaction data]**	**Possible Related Group Behaviors** **[Video description]**
Number of actions of the 2nd most active person divided by the number of actions of the most active person	Solo on task [One person is working by themselves while the other group members are working together

Table 4.1 (Continued).

Features **[Interaction data]**	**Possible Related Group Behaviors** **[Video description]**
Maximum proportion of students concurrently on different pages	Group division [The group is working on different pages of the worksheet indicating they may not be working together]
Total number of actions (e.g., writing, scrolling, erasing, etc.; not including accelerometer events)	More actions = less talking Less actions = more talking, not present, or TA/CA at the table

While six scenarios were developed, during the meeting, only two scenarios were discussed. The group discussed the two in-depth and did not leave enough time for the remaining four. I presented both scenarios in the same format. First, I described the feature in the scenario, then provided context for the clip that the group was about to watch (see Figure 4.1). I read the questions the group would respond to, and the group watched a video of this scenario in the classroom (see Figure 4.2). The group then engaged in a discussion to answer the proposed questions about the scenario.

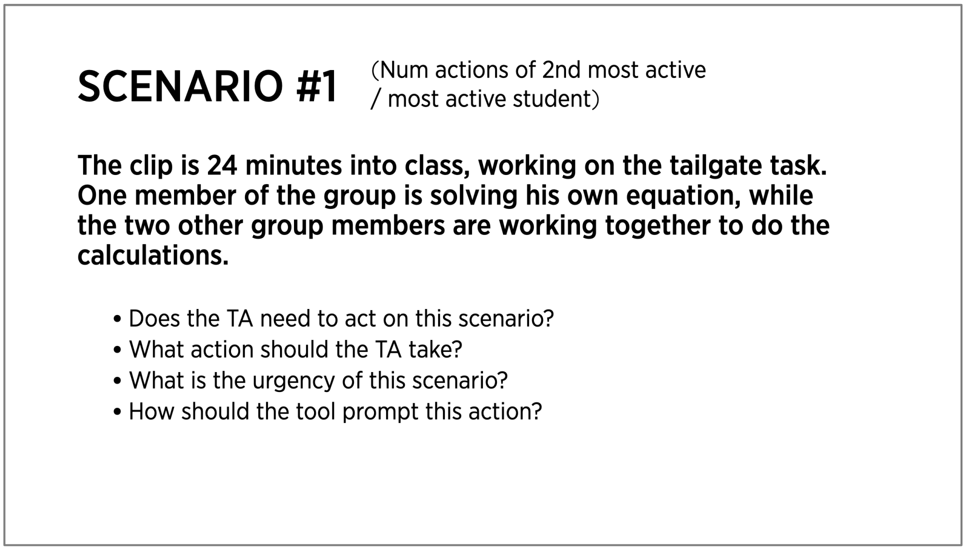

Figure 4.1. Example of context provided about the scenario.

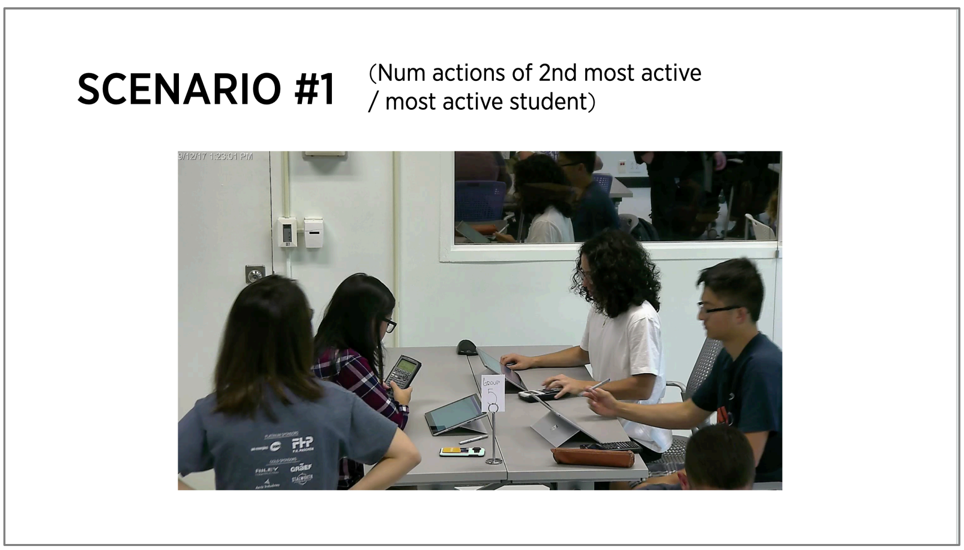

Figure 4.2. Example of the video format of the scenario.

The first scenario showed a clip that was 24 minutes into a class, where a group of three students was working together on the worksheet. In the video, one group member was solving his equation and the other two group members were working together. This video indicated a solo on task scenario, where one person was not working with the group. After watching the video, we engaged in discussions during this scenario for 38 minutes and 57 seconds (see Table 4.2). Eight group members participated in the first scenario and resulted in 766 turns of talk.

Table 4.2
Time and turns per scenario.

Scenario	Time	Turns of Talk
1	38 min 57 sec	766
2	26 min 32 sec	495
3	33 min 21 sec	723

After the discussion of the first scenario, the group took a break for 10 minutes and returned to finish the meeting. After the break, we discussed the second scenario. The second scenario showed a group of four students seven minutes into class. This scenario illustrated an example of a feature where the total number of actions were high, but the students were not talking. The same eight group members again watched a video clip and then engaged in discussion for 26 minutes and 32 seconds, resulting in 495 turns.

Finally, after the last scenario, seven members of the group discussed feedback from the last implementation of the CSTEPS tool. One group member had to leave because of another commitment during that time. In this last discussion, I recapped all the functions of the existing tool, feedback from interviews with instructors at the end of the last implementation, and observations and reflections from the group. This section of the meeting lasted 33 minutes and 21 seconds and resulted in 723 turns of talk.

4.2 Scenario Descriptive Statistics

The three scenarios lasted an average of 32 minutes and 56 seconds (*SD* = 6 minutes and 13 seconds). All turns of talk were considered design moves for the linkographic analysis; therefore, all 1,984 turns were included in three separate linkographic analyses. The three separate linkographic matrices are shown below in Figure 4.3 (enlarged versions of each scenario can be found in Appendix C).

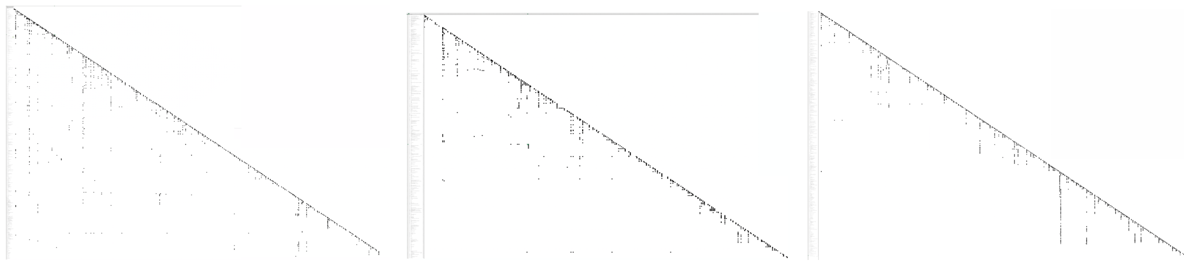

Figure 4.3. Linkographic matrix for scenario one (left), two (middle), and three (right).

4.2.1 Participant Turns

Eight participants took part in this meeting; Table 4.3 shows turns of talk by the group members. I was the most active member of the group; this, in part, was because I facilitated the discussions. The next most active member was Erica. The remaining participants, Levi, Sami, Marisa, Sarah, and Noah engaged in less conversation than the highest contributors (me and Erica) combined. Peter had the fewest turns.

Table 4.3
Turns, total number of links, and link density of by scenario.

Individuals	Individual Turns	Scenario 1	Scenario 2	Scenario 3
Erica	439	175	77	187
Sami	204	75	58	71
Sarah	128	71	57	0
Levi	249	101	59	89
Noah	92	46	22	24
Lu	715	237	191	287
Marisa	139	57	32	50
Peter	18	4	0	14

Analyzed by position on the team, the three faculty contributed 827 turns of talk across all three scenarios, while the three graduate students had 1,047 turns of talk. Noah, the only post doc in this meeting, had 92 turns of talk; Peter was the only undergraduate in this meeting and contributed 18 turns of talk.

These descriptive statistics show that while there is variability in who talks, some of these findings could be the result of the individuals' role on the project. For example, as the facilitator, I contributed the most turns of talk, meaning my role influenced the amount I contributed to the discussion, as the remaining two graduate students on the project had far fewer turns of talk. Additionally, looking at the faculty, Erica contributed the most to the discussions. As the Principle Investigator, this is not surprising based on her role and knowledge of the project. Peter, who had the fewest contributions among the group, was the developer, the most recent addition to the team, and the only undergraduate that participated in this meeting. His position within the group may have affected his comfort level in the conversation. The remaining group members were interweaved as to the number of turns they had and their position on the team. Indicating that graduate students contributed similarly to faculty and post docs with a variety of talk.

4.2.2 Linking

In each of the three scenarios, turns of talk were linked together based on semantic meaning using an analytic technique called linkography (Goldschmidt, 1992). Using audio data and transcripts, ideas were connected based on the content of each turn. Links were not connected when similar words or phrases were used, but when they referenced an idea previously proposed. To illustrate linking in the data, I have pulled one excerpt from the second scenario, where Levi introduces a new piece of information that scaffolds a short discussion (see Table 4.4).

Table 4.4
Transcript of turns 105 - 122 in the second scenario.

Turn #	Speaker	Transcript	*Notes about linking*
105	Levi	Sami and I sat down yesterday and looked at his graphs, and this is one thing that we haven't looked into quantitatively right now, but one thing we noticed is it seemed like TAs are less likely to make an intervention as if, if the students are not talking.	*Sami's graphs show different qualities of collaboration over time*
106	Sami	That's right.	*Agreeing with Levi's comment (#105)*
107	Noah	Mm.	*Acknowledging Levi's comment (#105)*
108	Lu	Yeah.	*Acknowledging Levi's comment (#105)*
109	Levi	That when you look the graph it seems like when the, the TA actually go to talk to the student is because is when they're already talking.	*Levi continues his thought (#105)*
110	Lu	When they're already talking? Interesting.	*Lu reiterates parts of Levi's turns (#105 + 109)*
111	Levi	And then when they're not talking, probably the TA have no idea what to say, so they don't go to talk to people that are not talking.	*Levi continues to build on his comments in both turns (#105 + 109)*
112	Lu	So that's an interesting place to start, like that could be… what would be a prompt for a [group that's not talking]?	*Lu poses a question based on the information that Levi provided (#105 + 111)*
113	Erica	Mhm. [long pause]	*Acknowledging Lu's comment (#112)*

Table 4.4 (Continued).

Turn #	**Speaker**	**Transcript**	***Notes about linking***
114	Erica	Er, yeah, I think this is one of those situations where five, six minutes after reading the thing you should be talking to each- like, the first early on they should be talking to each other if they're fiddling around doing other stuff then maybe they launched into solving the problem without planning it, or, they're just like, don't, they don't know how to get started. And I think early on in the semester we may see more than other times, where they don't actual- no one has the...	*Erica is responding to Lu's question and building on the information Levi provided (#105 and #112)*
115	Noah	Yeah, they could just be aimlessly scrolling or like...	*Noah gives an example of Erica's comment "if they're fiddling around doing other stuff" (#114)*
116	Erica	Yeah and- well no one has language for like how- okay, how do we get them to start [collaborating]?	*Erica builds on the information presented by Levi (#105), answering Lu's question (#112), and continues her thought (#114)*
117	Levi	Mhm	*Acknowledging Erica's comment (#116)*
118	Erica	Ah the…	*Starts a turn, but ends it when Levi starts speaking (no link, because not enough context)*
119	Levi	Well, if you expect them to collaborate at some point, they have to talk to each other	*Levi is referencing part of Erica's turns (#114 and #116) regarding student talking and how to get them to collaborate*
120	Lu	Yeah	*Acknowledging Levi's comment (#119)*
121	Erica	Yeah, but they don't know- like, if you don't know how to do that…	*Erica reiterates her question (#116) while also building on Levi's point (#119)*
122	Marisa	Don't know how to start.	*Marisa finishes Erica's sentence in turn (#121) and is building on her question in (#116)*

This example, and others throughout this chapter, illustrate how links were determined and coded. Through rigorous documentation of the data, turns of talk were connected using the context of each turn through the transcript and audio recordings of talk and the flow of conversations.

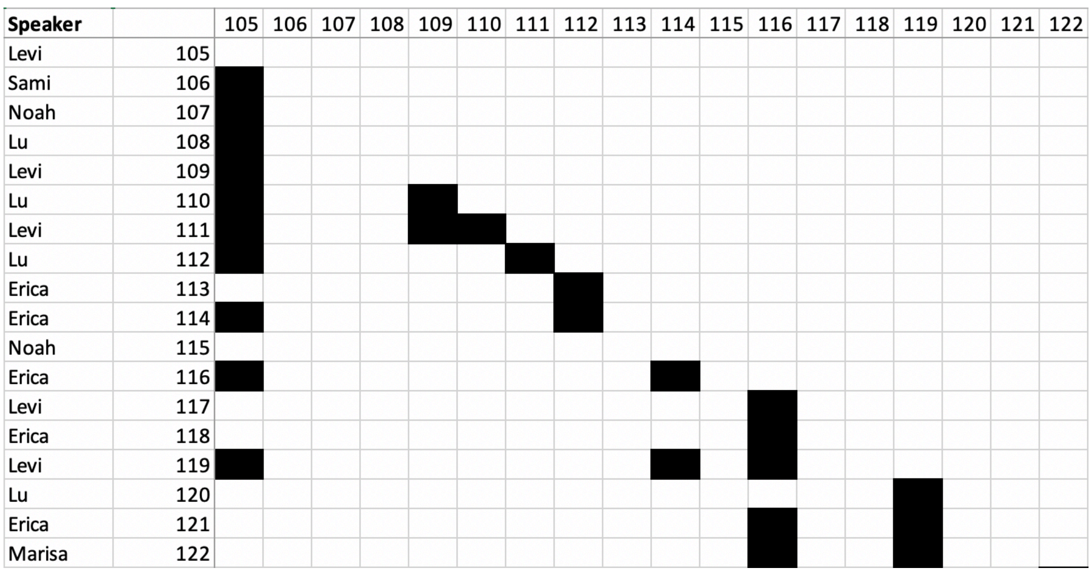

Figure 4.4. Linkographic representation matric turns 105 – 122.

Table 4.4 outlines turns of talk and describe what turns they are linked back to in the conversation. In Figure 4.4, I show the matrix linkographic representation of those links. Each black box in the matrix represents a link between turns. As an analytic tool, this representation allows for the exploration of patterns and areas of interest to understand how the team developed ideas. This example shows turns of talk that have multiple links, one link, and no links. Turn number 105 was linked to nine turns of talk, where people acknowledged the idea (#107 and #108), reiterated it (#110), asked questions based on it (#112 and #116), and added more information to it (#114). Several turns had only one link in this example, such as turn numbers 107, 108, and 113, where the turn was simply acknowledging that something was said with no other connection to the discussion. Finally, turn number 118 was a turn where Erica started to say something, but Levi cut her off, therefore, not giving enough context to link it to a previous turn. Turns like this, as well as the number of links per turn, will be described in the analysis below.

The frequency of links per turn was calculated to understand how connected turns of talk were across the three scenarios (Table 4.5). The distribution of turns of talk to links highlights the number of turns that have no links to other moves (orphan moves), moves with more than ten links to other moves (critical moves), and everything in between. According to linkography methods, the distribution should be asymmetrical, with most turns only having one or two links and fewer turns with more than 10 links (Goldschmidt, 2014). Comparisons across the three scenarios show that there was a similar percentage of links by turn across each category. This indicates that the group sustained similar connections across the entire brainstorming meeting.

Table 4.5
Turns, total number of links, and link density of by scenario.

Link per turn	Scenario 1	Scenario 2	Scenario 3
Turns with zero links (Orphan Moves)	39 (5%)	30 (6%)	41 (6%)
Turns with one link	297 (40%)	204 (41%)	246 (34%)
Turns with two links	103 (13%)	52 (10%)	100 (14%)
Turns with three or more links	307 (40%)	194 (40%)	312 (43%)
Turns with ten or more links (Critical Moves)	20 (2%)	15 (3%)	24 (3%)
Total number of turns	766	495	723

One hundred ten of the total 1,984 turns across all three scenarios were orphan moves or moves with no links. Because this is a brainstorming meeting with eight group members, discussions were often quick, with overlapping turns of talk. Orphan moves from all three scenarios were pooled and coded from a grounded theory perspective (Strauss & Corbin, 1997) to understand why some moves had no links. 58% of orphan moves (*n* = 64) were cut off turns, where there was not enough context in the move to connect it to another turn. 35% of turns (*n* = 38) were ones where someone responded to something with a simple response, and because of multiple people talking, there was not have enough context to connect it to the previous turns. One turn (1%) was inaudible, and seven turns (6%) were off topic turns that were not related to anything else.

4.2.3 Critical Moves

Critical moves in linkography are telling of the ideas or contributions of group members that were influential during the brainstorming. Using a threshold of 10 links, which included about 3% of the turns (see table 4.5), 59 turns were identified as critical moves across the three scenarios. Across scenarios, scenario three had the most critical moves, followed by scenario one. Comparatively, scenario one had the most turns with 766, compared to 495 in scenario two and 723 in scenario 3. The increase in critical moves could be due to the change of the format; the first two scenarios were brainstorming around specific data, whereas scenario three had a set of slides that brought up a larger variety of topics. The two formats of the scenarios were different, but both served specific purposes for the brainstorming.

To answer the research question, what are the critical ideas that influence the discussions that emerged, I analyzed who contributed critical moves, when they emerged, and the contents of these turns. Across team members, I had the most critical moves, which is consistent with the fact that I also had the most turns of talk across the scenarios (see Table 4.6). Erica had the next most critical moves, followed by Sami and Levi. Sarah and Marisa both had four critical moves.

Peter did not contribute any critical moves, which can be explained by the overall lack of turns from him, as in scenario one, he only had four turns of talk. All other members of the group had at least one critical move.

Table 4.6
Critical moves by speaker and scenario.

Individuals	Scenario 1	Scenario 2	Scenario 3
Erica	5	3	7
Sami	1	3	3
Sarah	4	0	0
Levi	2	2	3
Noah	1	1	0
Lu	6	5	9
Marisa	1	1	2
Peter	0	0	0
Total	20	15	24

A coding scheme was applied to identify the format of each critical move using the Function, Behavior, Structure design theory (Pourmohamadi & Gero, 2011; see Table 3.3 for the coding scheme). One key assumption of the FBS framework is that in a well-structured design brainstorm, designs start with functions (e.g., goals and requirements), build upon them with behavioral discussion (e.g., interactions with the artifact or experience). Once the behavior decisions have been made, the group starts discussing structural choices (e.g., physical or virtual features of the artifact). This process is not intended to be linear but provides scaffolding as most designing should not make structural decisions without being based on functional and behavioral intentions.

The most critical moves emerged during the third scenario ($n = 24$), followed by scenario one ($n = 20$) and scenario two ($n = 15$). Overall, there were differences regarding what kind of critical moves emerged in the three scenarios. Five or fewer functional critical moves emerged in each of the three scenarios (see Figure 4.5). The 12 functional critical moves that emerged were analyzed to understand what kind of goals and requirements emerged. Table 4.7 outlines the three themes that were extracted from the 12 functional critical moves and examples of each.

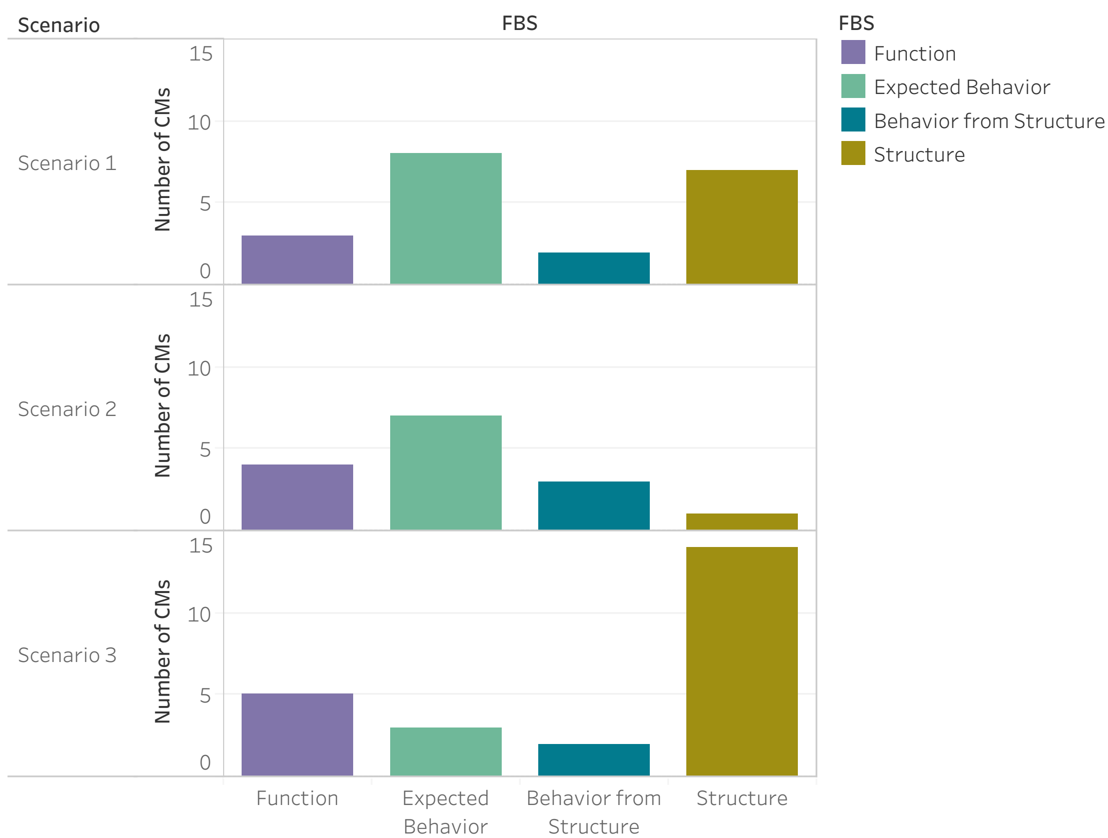

Figure 4.5. Frequency of FBS codes by critical moves.

Table 4.7
Themes of functional critical moves.

Code	Definition	*Example*
Scenarios	Existing data used to define the brainstorming activity for the group.	*"Alright and so this person is just kind of sitting here, ya know, working on his own solving his own equation on his own screen."*
Research goals	Referencing the goals or intentions of the research project.	*"This is the intervention piece [of the project]."*
Past research outcomes	Describing or referencing findings from past research related to this project.	*"Sami and I sat down yesterday and looked at his graphs … but one thing we noticed is it seemed like TAs are less likely to make an intervention if the students are not talking."*

Expected behavior critical moves included turns that talked about what the desired or hypothesized behaviors of the instructors. This did not include the design of the tool but the expected instructors' interactions in the classroom. Eighteen expected behavior critical moves emerged over the three meetings. Scenario one had the most, while scenario three had the least. These critical moves included turns that discussed monitoring, goals for interactions, the structure of the classroom, and desired collaborative behaviors.

Behavior from structure had the least of the four codes with seven critical moves. The lack of critical moves identified as behavior derived from structure can be explained by the preliminary state of the brainstorming because the team was still in the process of designing the structural elements. Therefore, the discussion did not progress to the level of how the instructors would engage with structures, but more focused on what those structure might be. Some of the critical moves that did emerge included turns covering how to notify the system that monitoring had taken place, how instructors would interact with prompts in the software over time, and how the instructors might provide feedback.

Structural critical moves were turns of talk that cover physical or virtual features of the design. In this case, critical moves were coded as structural when they referenced concrete design decisions about the CSTEPS tool. Structural critical moves were the most references in the brainstorming meeting with 22 total turns of talk. The majority of these critical moves emerged in the third scenario, with only one in the second scenario and seven in the first. Themes were analyzed across these structure critical moves to understand what kind of topics were discussed. Table 4.8 shows the six themes that emerged and examples of each.

Table 4.8
Structural critical moves.

Code	Definition	*Example*
Color	Discussions about color representations in the technology.	*"So, it might be like a pale yellow."*
Organization	Referencing the organizational structure of data or information in the tool.	*"We could change the way the data is displayed here."*
		"Well, and also it will take a little less space."
Functionality	Explicit functions or tools that could be added to the technology.	*"So, projection has to come back into this at some point."*
		"You know, if we can add whatever the Apple TV, thing is for these things and make it easier to run."
Development	Describing components of the back end data or coding.	*"We are using more localized events in the prompts."*
		"Depending on what the prompts are, what I was thinking is we could play with [the data] to align better."

Table 4.8 (Continued).

Code	Definition	*Example*
Word style or length	Specificity of the style, length, or design of the content. Must be about the design of the text, not the content of the text.	*"how long do you want the prompts to be? Do you want something that's only going to be a few words or do you want an actual?"* *"The font should get darker"*
Tool logistics	Logistics around the technology, such as how to run things or what is needed to use the technology in the classroom.	*"What is the work around? It didn't- he didn't use it? Right?"* *"It's not that great, because, um, it really requires good Wifi."*

To further understand how influential ideas emerged, critical moves were analyzed over time to identify patterns and differences across scenarios. As discussed above, one assumption of the FBS framework is that while there is no set trajectory through these spaces, ideally, design processes would start with goals, which would lead to behaviors, and end with structural discussions. While this is the ideal process, design processes are iterative and will go through several rounds of each space leading to many possible trajectories.

In this design process, I analyzed the temporal relationship between critical moves and the FBS framework (see Figure 4.6). The first scenario began with functional and expected behavior critical moves; however, there was a quick jump to structural critical moves. The structural moves eventually lessened as the first scenario went on. Diving further into the data to understand why structural critical moves emerged from the beginning, a few influential interactions took place. Erica presented the first structural critical move (see Figure 4.6, A). This critical move shifted the conversations from discussions about the instructors' anticipated behaviors to concrete ideas about how the CSTEPS tool would flag these possible behaviors (e.g., color of the prompt). From here, several critical moves about structural components of the tool emerged, possibly indicating that Erica's critical move shifted the discussion.

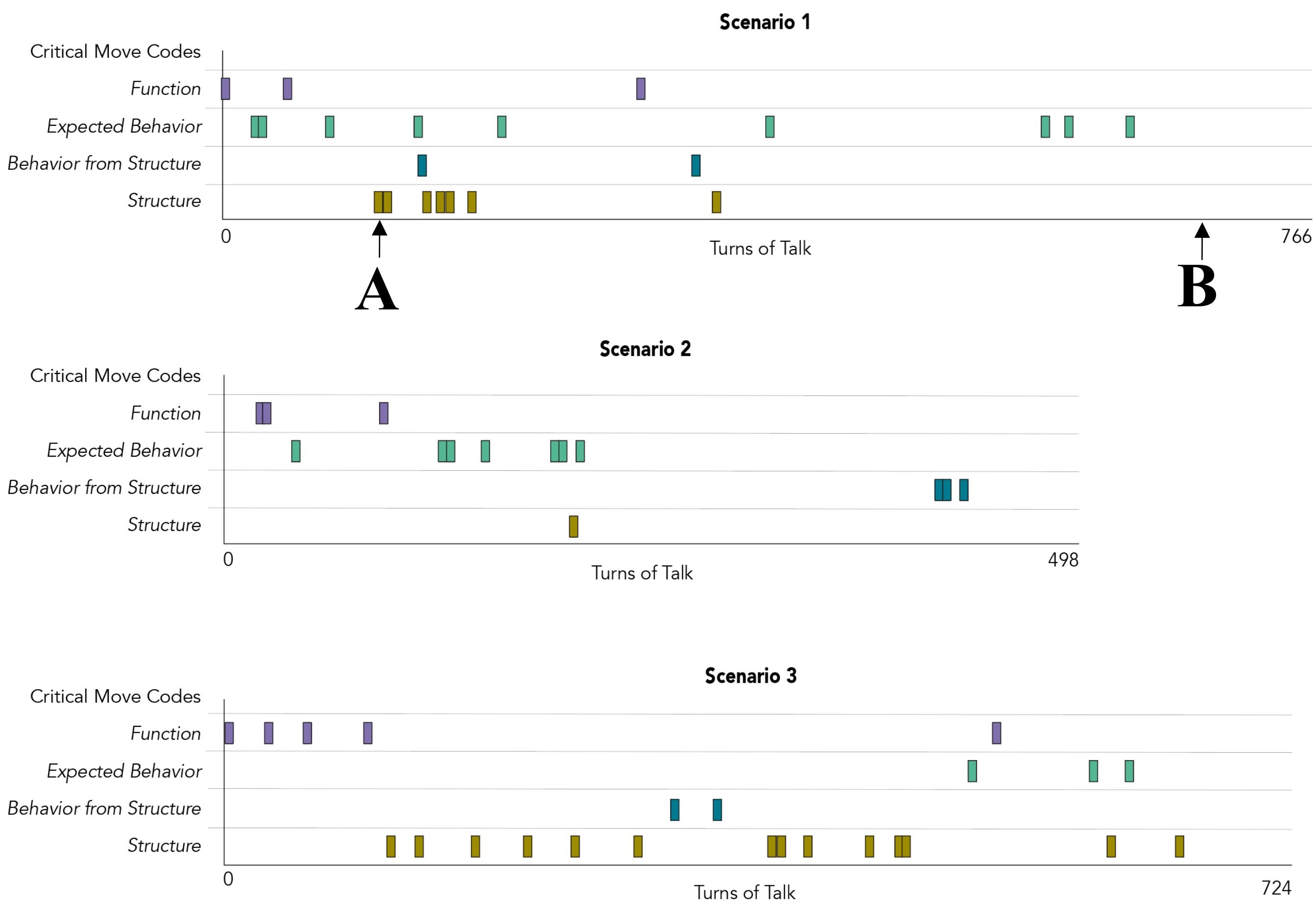

Figure 4.6: FBS codes over time (turns) across all three scenarios.

However, another critical interaction took place toward the end of the first scenario that changed the discussion in scenario two (see Figure 4.6, B). Erica and Noah expressed concerns about the lack of specific prompt creation (e.g., expected behavior turns). During this discussion, they pointed out that most of the discussion had been about software design decisions (e.g., structural turns) and that as a group, we had not gone deep enough into specific prompts to support interactions (e.g., expected behavior turns). After this realization, three expected behavior critical moves emerged before the end of the first scenario.

In scenario two, the majority of the critical moves were expected behaviors, and there was a drop in structural critical moves with only one critical move coded as structural. This is likely due to the discussion in the first scenario for more specific prompt creation and less structural conversations. In scenario three, there is a sharp spike in structural codes. This increase can be explained by the distinct change in the format of the discussion. The first two scenarios were open ended brainstorming using scenarios from the past implementation. During the third scenario, the group reflected on the past iteration of the software and proposed suggestions and feedback to change the software–prompting structural responses. The change of the goals of the brainstorming lent itself to more structural ideas because of this change in format. This analysis shows that the team was able to be reflective of their progress throughout the brainstorming meeting to identify when conversations may need to transition and that the critical moves that emerged align with the FBS framework (Kan & Gero, 2009).

4.3 Interconnectedness of Turns

4.3.1 Link index

In order to answer the research question, how interconnected are the ideas among the team, the links within each scenario were analyzed. Table 4.9 shows the total number of turns, the total number of links, and link index of each scenario.

Table 4.9
Turns, total number of links, and link density of by scenario.

Scenario	Number of Turns	Number of Links	Link Index
1	766	1,308	1.71
2	495	798	1.60
3	723	1,292	1.78

Link index is a metric used in linkography to asses interconnectedness of turns (Goldschmidt, 2014). Link index was calculated as a proportion between the number of links and the number of turns of talk. Research shows that the higher the link index, the higher the amount of synthesis across the group, and the typical range is from 0 (low synthesis) to 2.5 (high synthesis) (Goldschmidt & Tatsa, 2005). Across the three scenarios, the third scenario, where the group engaged in a more structured discussion, had the highest link index. However, all three scenarios had similar link indexes, meaning our conversations were similarly linked across the entire meeting. While the link index has been associated with high synthesis, this metric alone does not conclude design quality (Goldschmidt, 2014); therefore, further analyses were applied to smaller areas of the data to understand how the group synthesized together.

4.3.2 Vertical Areas

In order to compare interconnectedness within and across the scenarios, two types of areas were identified in the data–vertical and lateral. Vertical areas are areas where one link sparks an area of high density linking back to itself (El-Khouly & Penn, 2013). These areas were identified using the linkographic representation. Areas of patterns were visually identified where one turn is highly linked back to repeatedly. While vertical areas have the potential to develop good ideas, they also have limitations. Goel (1995) explains that vertical areas make up higher interconnected discussions; however, it can sometimes mean that the team's discussion is fixated on one idea, which could reduce the opportunity for creative insights.

I identified vertical areas as a sequence of turns that are highly linked back to one. This means that the turn sustained a high number of links for a duration of time immediately after being proposed. Vertical areas were a sequence of turns where 40% of the possible links in the area were connected to the initial idea, validating that the turn of talk was highly influential within the discussion. The duration varied because some links had high linking for a few turns compared to others who were built on consistently for upwards of 50 turns but had to be at least 10 turns long (see Figure 3.4 For example).

To illustrate what a vertical area looks like, below is an example from scenario two (Table 4.10). In this scenario, Sami proposed an idea about how an instructor could interact with a group.

Table 4.10
Vertical area from scenario two turns 133 through 157.

Turn #	**Speaker**	**Transcript**	***Notes***
133	Sami	They leave the group with something controversial. A controversial issue. Like let.. let me, let me expand of.. on what I am saying.	*Sami proposes an idea, to leave the group with a controversial issue.*
134	Lu	Yeah	*Acknowledging Sami's idea (#133)*
135	Sami	So one of the, um, episodes that I'm so interested in in other data is like, the groups..	*Sami continues to build on his idea (#133)*
136	Lu	Mhm.	*Acknowledging Sami's turn (#135)*
137	Sami	Uh, three members group. And they're not saying a word. Then the.. a TA comes in, and he asks them what are you guys doing? And it's a very early, like, five or six minutes afterwards…	*Sami elaborates on his idea with an example (#133)*
138	Lu	Mhm	*Acknowledging Sami's turn (#137)*
139	Sami	And then it seems, as Erica is saying, like, they don't know what to do. So…	*Sami continues to build on his idea (#133) and builds on an idea Erica previously had*
140	Lu	Yeah	*Acknowledging Sami's turn (#139)*

Table 4.10 (Continued).

Turn #	Speaker	Transcript	*Notes*
141	Sami	[The TA] was like, "Okay. Can you listen to me?" He addressed them all, and he kind of like just walked them through kind of like the task. "What's the purpose of the task?" What they wanna do.	*Sami elaborates on his idea (#133) and continues with the example he proposed (#137)*
142	Lu	Mhm	*Acknowledging Sami's turn (#140)*
143	Sami	And then someone suggested, "Okay so then we have to put the books and whatever in the middle," and then some- another person was, like, "No no, we should put them on the side." And then he was like, "No, let me tell you why we should them in the middle." And I was like, leave them! Now you just leave.	*Sami elaborates on his idea (#133) and continues with the example he proposed (#137)*
144	Lu	Mhm	*Acknowledging Sami's turn (#143)*
145	Sami	You just- you- you did your part, which is, like, you made them come start talking and kind of like start discussing the alternative solutions. Just leave now, right? So, that's kind of the prompt that I'm thinking about.	*Sami elaborates on his idea (#133) and describes the example he proposed (#137)*
146	Lu	How on earth do you do that?	*Responds to Sami's idea (#133) and his explanation (#145)*
147	Sami	No, how- how do you this? Now that's- that's the question. So-	*Responds to Lu's question (#146) about his idea (#133 and #145)*
148	Lu	What do you even say about that? How- what?	*Reiterates her question (#146) about Sami's idea (#133) and his explanation (#145)*
149	Sami	Yeah, so-	*Not enough context to develop a link*
150	Lu	That's- I get it, yeah	*Refers to understanding the idea (#133 and #145)*
151	Sami	So that's what I meant by controvers…	*Reiterates his first idea (#133)*
152	Lu	Yeah	*Acknowledging Sami's turn (#151)*

Table 4.10 (Continued).

Turn #	Speaker	Transcript	*Notes*
153	Sami	Like, something to talk about-	*Proposes the group talk about the idea (#133 and #145)*
154	Lu	At least the groups-	*Not enough context to develop a link*
155	Sami	-right?	*Sami finishes his thought (#153)*
156	Lu	-not arguing about something, but, like, um…	*Clarifies Sami's idea (#133 and #145)*
157	Levi	An open question. Some- but that's gonna be very task specific, right?	*Levi builds on Lu's clarification (#156) about Sami's idea (#133 and #145)*

In this example, Sami's idea (turn #133; see Figure 4.7) starts the vertical area, which lasts for 25 turns, of which 15 turns link to it. While future turns link back to turn 133, this vertical area shows how proposed ideas can heavily influence a short conversation. Vertical areas were long and short in length, and the amount they overlapped varied. In total, 71 vertical areas emerged in the brainstorm meeting, with the majority in the third scenario (see Table 4.11). This shows that conversations were more interconnected to single ideas compared to the first and second scenarios. The third scenario was scaffolded with specific talking points and feedback from previous implementations; this may have influenced the variety of topics that came up and turned into vertical areas. Additionally, the discussion in scenario three were focused on refining existing ideas rather than generating new ones.

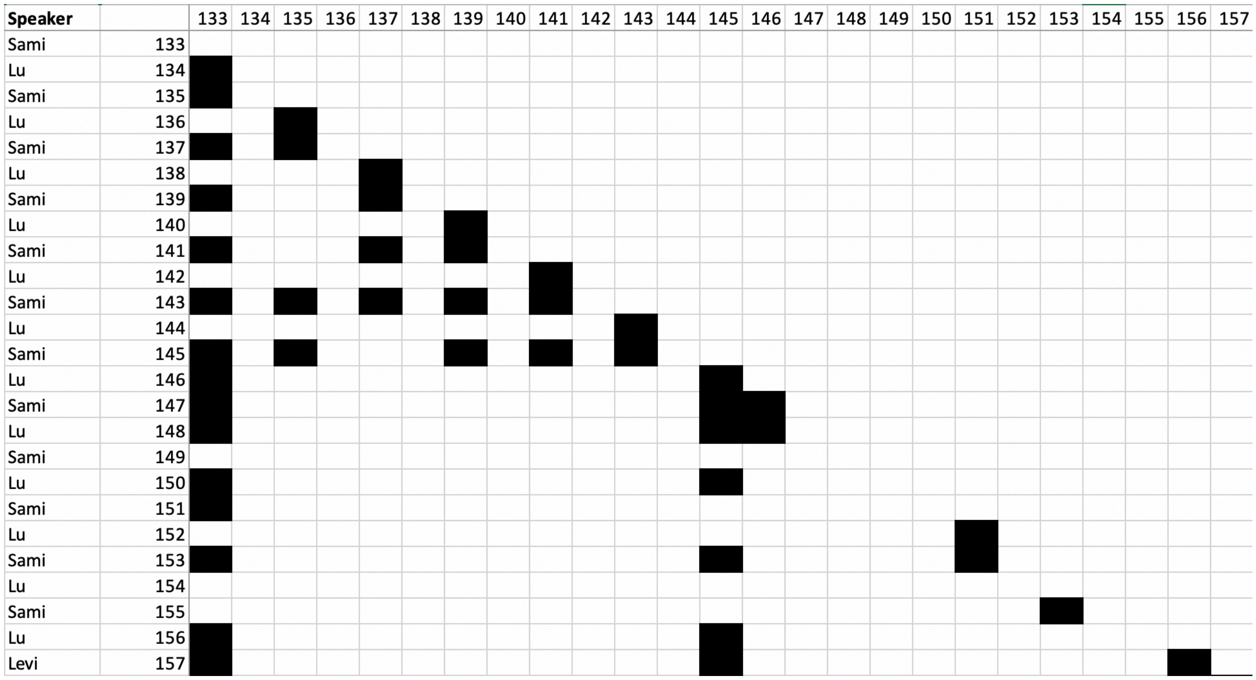

Figure 4.7. Vertical area from scenario two turns 133 through 157.

Table 4.11
Number of vertical areas by scenario.

Scenario	Vertical Areas
1	18
2	17
3	36

To understand the results of the vertical areas, I analyzed relationships over time across the three scenarios. Figure 4.8 shows the relationship of vertical areas over time by the length of the area by turns of talk. Besides scenario three having more than double the vertical areas, it also has different patterns of interaction compared to the first two.

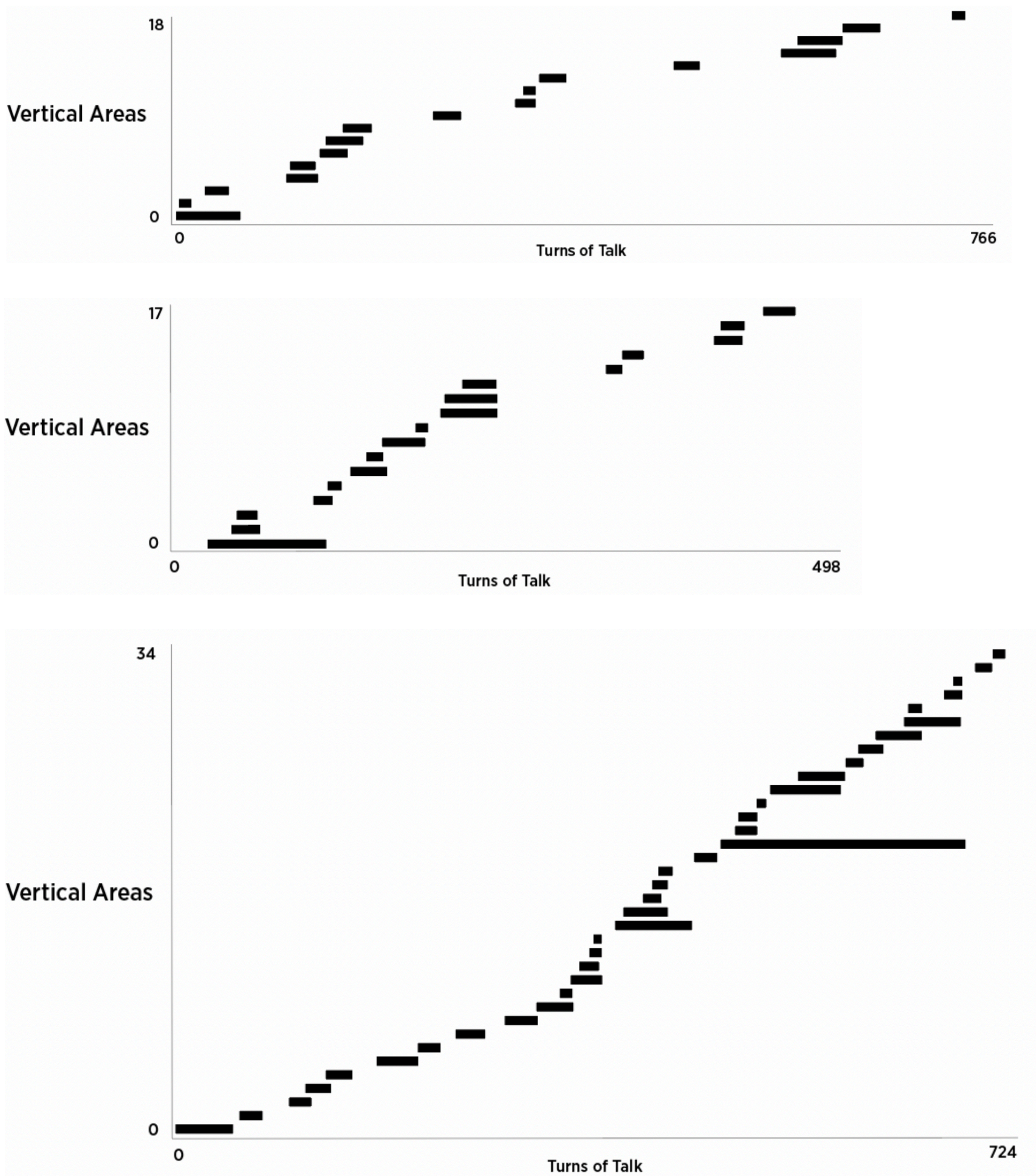

Figure 4.8. Vertical areas identified in the first (top), second (middle), and third (bottom) scenario

The first and second scenarios had similar patterns of interactions. Both scenarios had more overlapping vertical areas in the beginning, with gaps in the middle and fewer, shorter areas at the end. Overlapping vertical areas showed instances where ideas were converging across topics. For example, in scenario two, vertical areas 10, 11, and 12 overlapped (see Figure

4.9). Vertical area 10 included turns 201 through 244 is started when I proposed, “I mean, or like- what do you need to say to… can you give the TA a goal to accomplish? Like, do you wanna get the group to do something?” This vertical area encompassed the entirety of 11 and 12 vertical areas, meaning both are connected to the idea of providing the instructors with a goal. Vertical area 11, turns 204 through 244, was linked from Erica’s initial turn,

> “I think we need to play with this. I don't really know. Um, like we know that sentence starters are really helpful in group work. Um, that a lot of the time people don't- like, I can say, you know, your goal is to get the students on the same page…”

Erica’s proposal of sentence starters was linked to my comment about setting a goal. Her turn started another vertical area, where the group discussed possibilities of sentence starters, while also elaborating on goals that could be set. Finally, a smaller vertical area emerged within areas 10 and 11. Vertical area 12 spanned turns 217 through 244. In turn 217 Sami said, “Because there is the what to do part, and the how to do it, right?” Sami proposed this format of what and how in response to Erica’s suggestion about using topics and questions to scaffold goals and sentence starters. In this smaller vertical area, the team continued to discuss how setting goals and using sentence starts could be used in the prompts, but now including the format *what the instructors should be doing* and *how they should do it*.

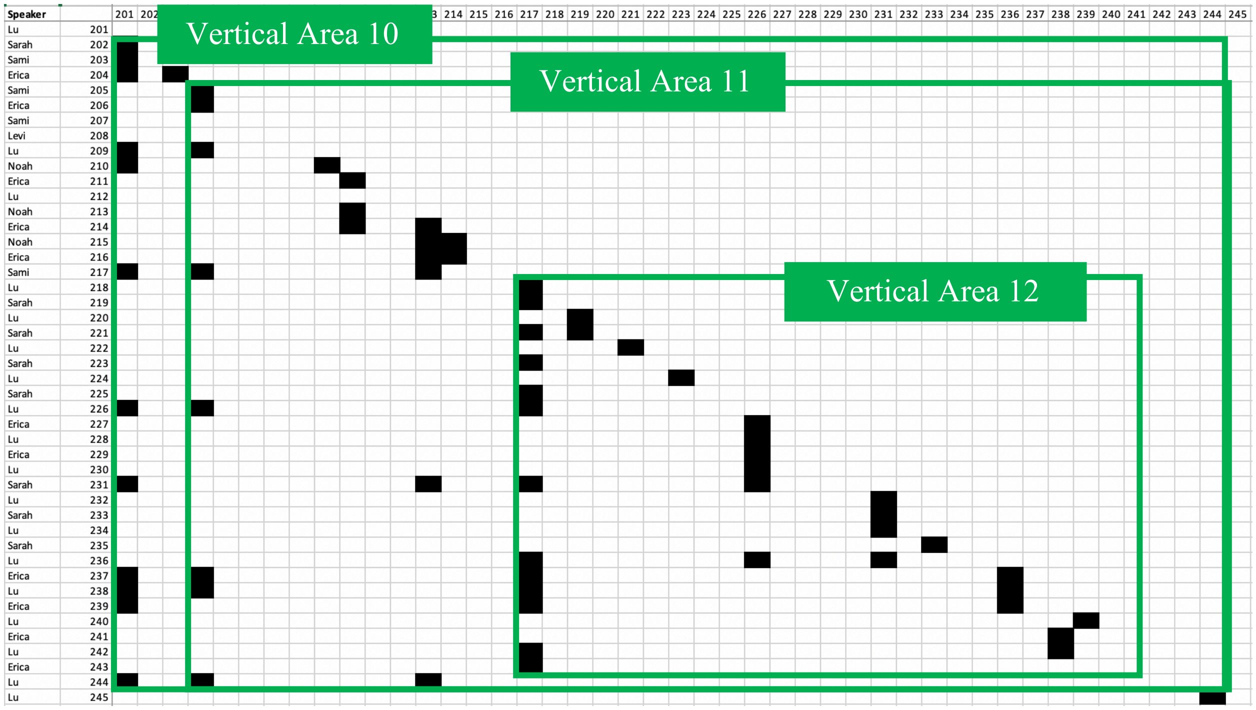

Figure 4.9. Vertical areas 10, 11, and 12 visualized in the linkographic matrix.

While the first and second scenarios have similar patterns, scenario three was entirely different. Since the third scenario had an entirely different format, this is to be expected. Scenario three was a more structured conversation, whereas the first two scenarios were open brainstorming about two scenarios of data. The beginning of the third scenario had more spread out areas with some overlap. During the first half of the discussion, I spent the first ten minutes presenting on the findings from the past iteration and going over the tool design in depth. Therefore, there were fewer discussions overall and more presenting. In the remaining 20 minutes of this scenario the group had conversations about specific components of the CSTEPS tool and what may need to be changed.

The additional change to the last scenario was the number of overlapping vertical areas. The third scenario had significantly more overlapping areas than the previous two scenarios. Two of these vertical areas spanned more than half of the discussion. The longest of the two vertical areas, number 23, spanned 12 other vertical areas. Vertical area 23 covered turns 477 to 689. In turn 477, I proposed adding scaffolding to existing data visualizations. This turn had 89 links to other turns of talk. Some other vertical areas that emerged during this section included topics such as, what the visualizations mean, how the visualizations could be more descriptive, how instructors used them in the past, and how to scaffold collaboration within visualizations. This area had many converging ideas that all stemmed from turn number 477. The vertical area ended after the group transitioned their conversations from how to scaffold instructors' experience to what the group's next steps needed to be.

These vertical areas show that dense linking can lead to high idea generation from the team. This data also indicates that overlapping vertical areas lead to more converging ideas. Below, I will discuss the relationship of vertical areas to other data sources within this brainstorming meeting.

4.3.3 Lateral Areas

Rather than fixating on one idea like vertical areas, during lateral areas, the groups' links are more dispersed. Lateral areas change the concept to different, less fixated ideas, which in turn creates more divergent thinking and potentially more ideas (El-Khouly & Penn, 2013). Lateral areas were identified in-between sections of vertical areas. Meaning the links were not building back to one idea but were dispersed across each other. This area illustrated discussions that were not heavily influenced by one idea but were linked across multiple turns. Lateral areas can lead to more diverse ideas but may have more shallow insights where the ideas can get lost if not brought back up by a member of the discussion.

One example of a lateral area is described below. In scenario three, after a vertical area talking about students consenting to share their work to a class, the conversations lulled and transitioned to logistics of projecting student work. Table 4.12 outlines with transcript of turns 274 through 290 with description of links.

Table 4.12
Lateral area from scenario three turns 235 through 248.

Turn #	Speaker	Transcript	*Notes*
274	Marisa	Yeah.	*Marisa acknowledges a previous turn*
275	Erica	Um…	*Not enough context to develop a link*
276	Noah	Well technically… to go back to the airplay question, uh, even if we… even if airplay doesn't work, or air parrot, because of the wifi, we can plug in a computer and get people off the TA tool website.	*Noah proposes an idea to a question proposed earlier in the conversations*
277	Lu	Tool website…	*Lu starts to build on something Noah says but Marisa starts talking (#276)*
278	Erica	Yeah.	*Erica acknowledges Noah's idea (#276)*
279	Marisa	I was gonna say that. Like why not just plug it into the projector directly?	*Marisa proposes a question based on Noah's idea (#276)*
280	Lu	Yeah, yeah. Cause that's what we tried last year, and it didn't get used. Right?	*Lu responds to Marisa's question (#279)about Noah's comment (#276)*
281	Erica	Right. They found it really annoying. Um…	*Erica builds on Lu's response (#280)*
282	Lu	Yeah, because it's not as easy...	*Lu builds on Erica's response (#281)*
283	Erica	As holding it and walking around the room.	*Erica finishes Lu's thought (#282)*
284	Lu	Yeah.	*Lu acknowledges Lu's comment (#283)*
285	Erica	So, um…	*Not enough context to develop a link*
286	Lu	Takes one other step… [group chuckles]	*Lu makes a joke about Erica's previous comment (#283)*
287	Erica	Yeah. I mean…	*Not enough context to develop a link*

Table 4.12 (Continued).

Turn #	**Speaker**	**Transcript**	***Notes***
288	Lu	Oh.	*Not enough context to develop a link*
289	Sami	Can I ask a question about…	*Not enough context to develop a link*
290	Lu	Yes.	*Lu acknowledges Sami's turn (#289)*

Opposed to the vertical areas, there was no indication of one turn being highly linked, and the links are more distributed across the turns rather than being clustered within one turn (see Figure 4.10). Across all three scenarios, there were 20 lateral areas across the brainstorming meeting, and an even distribution across scenarios (see table 4.13).

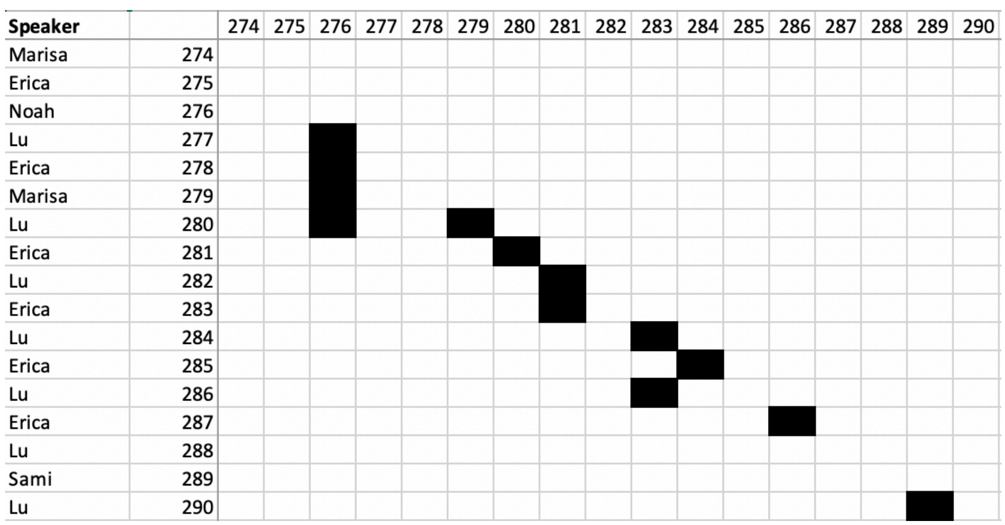

Figure 4.10: Linkographic representation of scenario three, turns 274 – 290.

Table 4.13
Number of lateral areas by scenario.

Scenario	**Lateral Areas**
1	6
2	7
3	7

To understand the results of the lateral areas, I analyzed relationships over time across the three scenarios. Figure 4.11 shows the relationship of lateral areas over time by the length of the area by turns of talk. All three scenarios had different lateral areas emerge. Scenario one had long areas, spread throughout the entire 766 turns. Scenario two had both long and short areas; scenario three's vertical areas were very short. All of these areas held conversations that were scattered and did not generate fully formed ideas, but quick turns that quickly transitioned to other topics. Further analysis of these areas will be discussed below. This data shows that early on in the discussion, scenario one and two, there were a lot of new ideas generated and these areas were longer in length. In scenario three, during the wrap up, the design gets tighter and the conversations were more structured meaning the areas were more connected.

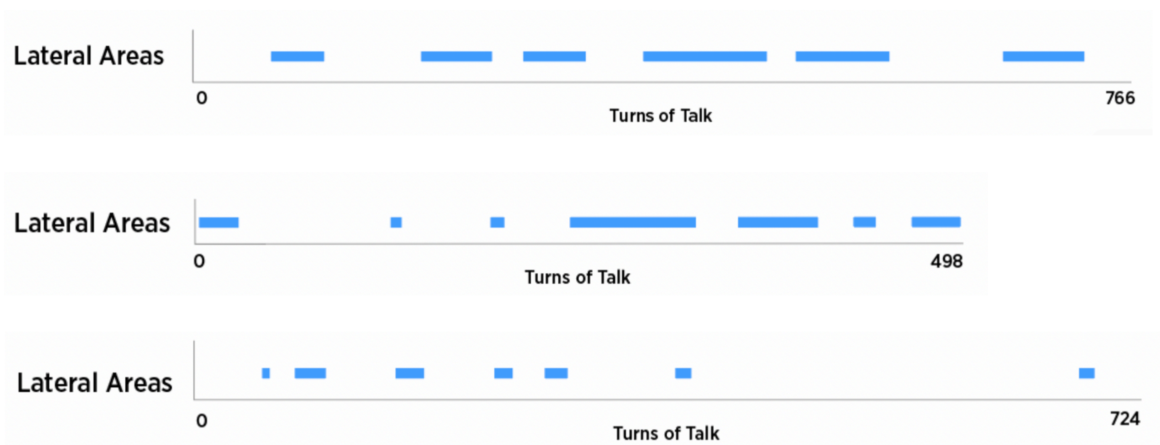

Figure 4.11. Chunks identified in the first (top), second (middle), and third (bottom) scenario.

4.4 Collaboration

In order to answer the second research question, how do the team members build on each other's ideas to design the CSTEPS tool, collaboration was assessed. Goldschmidt (2014) analyzes collaboration as identifying who is building on whose turns, meaning, the more individuals within the group are building on ideas of others, the better the collaboration. Whereas if one member of the group is only building on their ideas, they are not contributing to the overall collaborative idea generation. Of the total 3,398 links across all three scenarios, 1,012 links were self-links, where one member of the group linked to something that they had previously said. 2,386 links were collaborative, meaning a group member linked back to something that another group member had said rather than themselves (see Table 4.14 for collaboration by scenario). This shows that 70% of links were collaborative across the meeting. This shows a high percentage of collaboration among the group. Especially considering not all turns can be a collaborative link, natural conversations have a mixture of both, meaning some percentage of self-collaborative links are inevitable.

Table 4.14
Links and percent collaboration by scenario.

Scenario	Self-Links	Collaborative-Links	Percentage Collaborative
1	292	1,016	78%
2	270	528	66%
3	450	842	65%

To further understand the quality of the collaboration, links were also assessed by discipline to understand if the quality of collaborative links remains the same for individuals within their discipline. Table 4.15 shows the frequency of turns based on individuals and disciplinary backgrounds. Three members of the research team, Erica, Sami, and Sarah identified most as education researchers, specifically Learning Scientists. I identified most as a designer, while my position on the project is both a Learning Scientists and a designer, during this brainstorming session, I was primarily acting as the facilitator and design expert. Marisa and

Peter both identified as engineers; Levi and Noah identified most as the learning analytics or machine learning experts. While this is not an exact definition of each of these individuals' roles and positions, it best represents their perspectives on the project during this brainstorming session and which perspective contributed to most during the discussion. Across all turns, I, as the designer, contributed 36% of turns, the Learning Scientists (Erica, Sami, and Sarah) contributed 39% of turns, Engineering (Marisa and Peter) contributed 8% of turns, and Learning Analytics contributed 17% turns.

Table 4.15
Turns, total number of links, and link density of by scenario.

Discipline	Individuals	Individual Turns	Discipline turns
Learning Sciences	Erica	439	771
	Sami	204	
	Sarah	128	
Learning Analytics	Levi	249	341
	Noah	92	
Design	Lu	715	715
Engineering	Marisa	139	157
	Peter	18	

The disciplinary collaboration was analyzed in the same way as overall group collaboration (see Table 4.16). Collaborative linking is when someone from one discipline is building on someone else from a different discipline, and self-linking is when someone of one discipline is either building on them self or someone else from their discipline. Of the total 3,398, 1,242 links were self-links, where someone from one discipline linked to something that they had previously said or someone within their discipline had previously said. 2,156 links were collaborative, meaning someone from one group member built on someone from another discipline. 63% of all links were cross-disciplinary during the first scenario. This shows a high rate of collaboration across disciplines, however, not as high as the general collaboration among team members.

Table 4.16
Links and percent collaboration of each discipline by scenario.

Scenario	Self-Link	Collaborative-Link	Percentage Collaborative
1	402	907	69%
2	345	453	57%
3	495	797	62%

4.5 Relationships Across Variables

To further understand how ideas emerged, I analyzed the relationships between critical moves (see Section 4.2.3), link index (see Section 4.3.1), and collaboration (see Section 4.4) that emerged during vertical and lateral areas (see Appendix D). Collaboration, link index, and the number of critical moves were calculated for each individual lateral and vertical area. Then, correlation statistics were run for the 91 areas to understand the relationship between variables. Across the areas identified in the three scenarios, there was a correlation between the link index and the number of critical moves, $r(91) = .28$, $p < .001$. In other words, the higher the link density, or proportion of links to moves, the more critical moves emerge.

Contrary to the literature, there was no relationship between collaboration and the number of critical moves within vertical and lateral areas, $r(91) = .02$, $p = .18$. While there is no relationship, overall three scenarios, there is a high percentage of collaborative links (M = 67%, SD = 14%). The range of collaboration across areas was 30% to 93%, indicating there is a wide range of collaboration across all three scenarios. Finally, across vertical and lateral areas identified in the three scenarios, there was no relationship between collaboration and the number of critical moves, $r(91) = .01$, $p = .45$. This means that the higher the collaboration does not lead to more ideas that are highly linked in the discussion.

Another way that lateral and vertical areas were analyzed was by looking at the visual relationships of variables. Appendix D shows vertical and lateral areas over time with collaboration and link index values and critical moves laid over the top of them. This visual analysis allows seeing patterns that emerged overtime between variables. Three themes were identified across scenarios regarding vertical and lateral areas. Areas were either *segmented* areas, where vertical or lateral areas are separate and did not overlap, *intersected*, where two vertical areas were connected by one turn of talk, or *integrated*, where multiple vertical areas were overlaid and therefore integrated together. Below I will describe each theme.

Segmented areas were ones that were not connected to any other areas. These included all lateral areas and some vertical areas. Seven vertical areas were segmented areas where there was one turn that initiated an area of discussion; however, it did not connect to multiple areas. Across all three scenarios, segmented areas had lower level of collaboration and link index, as well as fewer critical moves compared to intersected and integrated areas. These areas may not be as productive as others; however, further analysis of these areas shows that they do allow for transitions between conversations and topics. While they are necessary, the longer segmented areas in the first and second scenarios are not productive and often had intermittent off topic conversations. However, in the third scenario, segmented areas were often short transition conversations between new ideas or topic, showing the evolution of collaboration as the design solidified.

Intersected areas were ones where vertical areas we are connected but not overlapping. This often indicated a transition between topics that had overlapping themes but were not necessarily converged together. Critical moves still emerged during intersected areas; however, compared to integrated areas, intersected areas had mid to low link index and collaboration values. These conversations were often productive, where one idea fed into another conversation allowing ideas to transition between different topics. While these conversations intersect across one or two turns of talk, these overlaps are not as incorporated as integrated areas.

Finally, *integrated* areas were identified in the data as vertical areas that were overlaid with highly convergent turns. Integrated areas had higher link index, more critical moves, and higher values of collaborative linking. Integrated areas were the ideal state for this interdisciplinary team generating innovative ideas as a group. While each scenario had integrated areas, the third scenario had the longest areas of overlap. This indicating that the structured discussions were possibly a productive end to the meeting.

4.6 Takeaways

While there are several findings from this work, the main takeaways for this chapter are suggestions for other researchers engaged in DBR with interdisciplinary teams.

4.6.1 Takeaway #1

Make goals explicit. In this analysis, goals came up several times. First, in the inquiry of functional critical moves captured all turns that had to do with research goals and scenarios. Research has shown that constructing ideas requires a common ground to build collaboratively. Our common ground was in the form of the scenarios themselves, as well as the group reflecting on the goals of the overarching project. Establishing goals during brainstorming allowed everyone to be on the same page and reflect on if the group was achieving our desired outcomes. This included short term goals for the brainstorming and long term project level goals.

4.6.2 Takeaway #2

Add methods for reflection. Our team had a moment when two members reflected on their own on the lack of progress made toward our goal. It is not enough to have goals, but teams need to reflect on the progress toward achieving them. This was a productive turning point for our discussions but was not planned. Groups should reflect on how they are doing at achieving their goals as they are designing. While our group naturally did this once, more reflection throughout may have been beneficial to identify if we were meeting our design goals. I recommend findings ways to embed reflection in design processes to identify problems and progress along the way. These reflections can also extend beyond in progress check-ins and become a point of documentation for the process and development.

4.6.3 Takeaway #3

Use a variety of methods to generate ideas. Using two scenarios and one more structured discussion led to diverse ideas and discussions. The findings above show that different kinds of ideas and patterns of interactions emerged during the first two scenarios compared to the structured scenario. Embedding variety into brainstorming allowed team members to brainstorm in different ways and develop ideas without getting sucked into conversations that were too open ended and not productive. In this process, this variety took place in one meeting, but should be extended across several meetings within a design process.

4.6.4 Takeaways #4

Document ideas and changes. This analysis was a fine-grain analysis of the conversations that led to the final CSTEPS tool. While this analysis is necessary to understand how these collaborations take place, documenting ideas and designs in DBR are highly valuable. There are many ways to share design processes with DBR, and researchers must continue documenting and disseminating these processes in a variety of ways – both at the fine grain and large scale levels. As discussed in Takeaway #2, this can happen through reflection or other methods, but as a whole, researchers need to continue developing methods to document this process more rigorously.

CHAPTER 5: IMPLEMENTATION METHODS

Through a mixed methods design (Creswell, Clark, Gutmann, & Hanson, 2003), I aimed to understand how ideas that emerged during the design process, influenced the instructors' interactions in the classroom. To do so, I answered the following research questions:

RQ3. How did the design decisions embedded in the classroom influence the instructors' interactions in the classroom?

5.1 Implementation

5.1.1 Context

Five, 50-minute engineering discussion sections were taught in a lab classroom during the 16-week semester in the spring of 2019. Each class had a maximum capacity of 32 students in total. Students attended a 50-minute lecture three times a week in addition to a discussion section once a week. In the discussion sections, students worked on tasks related to content covered in the lecture. The tasks were ill-structured problems that had been designed by members of the research team to support collaboration (Shehab & Mercier, 2017). Students worked on the task in groups of three or four on synched tablets that provided them with a joint space to solve the task.

A student tool and the CSTEPS teacher tool were implemented in the five discussion sections. The final design of both of these tools will be described and discussed in chapter 6.

5.1.2 Participants

Each of the five discussion sections had one graduate student teaching assistant (TA) instructor and two undergraduate course assistant (CA) instructors who had previously taken and excelled in the course. This study was conducted with five discussion sections, that were taught by two TAs and five CAs (see Table 5.1 for class break down by instructor). The instructors attended weekly meetings with the faculty who ran the courses, in addition to their time in discussion sections with students. All instructors were consented during the first week of the semester for video and audio data, log file interaction data, and interviews. While the focus of this study was on the instructors, students working in the discussion sections also consented so that video and audio data could be collected from them of their interactions with the instructors.

Table 5.1
TAs and CAs by class.

	Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**
Number of Students	18	22	10	22	14
Number of Groups in Class	8	7	5	6	5
Number of Groups Analyzed	5	6	3	6	4
TA	Adam	Adam	Adam	Lisa	Lisa
CA 1	Zain	Jason	Jason	Casey	Raj
CA 2	Santu	Jenn	Jenn	Santu	Santu

Our prior work with instructors in this engineering context indicates that they typically had little to no teaching experience (Shehab & Mercier, 2019). While students were placed into groups during discussion sections and asked to work together, instructors often do not have the expertise to support groups appropriately. Therefore, to supplement the CSTEPS tool, the TAs participated in an hour-long training. Two members of the research team familiarized instructors with the importance of collaboration and the overall structure of the information that was presented to them in the tool.

5.1.3 Data Collection

I collected video and audio data of students and TAs in the classroom. Log data provided detailed traces of the TAs interaction with the CSTEPS tool from the five, 50-minute classes. The five classes that data was collected from were during the eighth week of the 16-week semester. Students had been using the student tool since week two, and the instructors had been using the CSTEPS tool since week five.

Audio and video data were collected from all consenting participants in the lab classroom. Six overhead cameras and either a hanging microphone or wireless microphone collected data from each table in the classroom to document all interactions that happen with the groups of students, including interactions with the instructors. A fishbowl camera was positioned in the middle of the classroom to collect interactions that occur within the room. The instructors wore lapel microphones to collect their discussions during the class period.

Log data were collected from the instructors' interactions with the CSTEPS tool. The log files were collected when a prompt became visible, disappears, or was selected, and when a TA confirmed an issue, dismissed the prompt, or viewed the students' work. The log data recorded who was interacting with the CSTEPS tool with a timestamp for every action. Interactions were logged and time stamped so that they could be aligned with the video and audio data.

To get a full picture of how the instructors used the tool, I conducted pre and post interviews with each instructor individually. Two semi-structured interview protocols were used (see Appendix B). The first interview was held during week four, before the instructors received training on the CSTEPS tool. I asked instructors to describe their role as TA or CA, why they took the position and several questions about what they thought the value of discussion sections were. In the post-interview, I asked instructors how they used different functions of the software during class. Interviews were audio and video recorded for analysis.

5.1.4 Coding and Analysis Procedures

Analysis for this phase of the project was completed in a series of steps. I started by analyzing pre-interview data, followed by log file and video data analysis, and finally, the post-interview data. I then triangulated findings between all data sources to understand better how the instructors used the technology.

Step 1. The first step in the analysis of the implementation phase was to analyze pre-interview data. Content logging was completed for each instructors' pre-interview. Using narrative analysis (Riessman, 1993), each instructors' responses were described to contextualize how long they have been in their position, what drew them to the position, and what they value about discussion sections.

Step 2. To analyze the video data, two members of the research team identified intervention episodes in the video data. All video data were watched and timestamped to documented instances where an instructor or student prompted an intervention. All videos were watched by a second researcher to confirm that all intervention episodes were identified.

Step 3. Next, the interventions episodes were transcribed. Using the timestamps of interventions, all interventions with groups were transcribed at the turn level in playscript form (Forrester & Sullivan, 2018). Interventions began where the timestamp was identified and completed until the instructor left the group of students.

Step 4. I did an initial round of documentation of each intervention to identify what was happening. First each intervention episode was coded to indicate which instructor was involved and who initiated it (e.g., student or instructor). Then timestamps were documented for if/when an instructor started monitoring the group, followed by when the monitoring ended, and also the timestamp for when the intervention started and ended. Timestamps were used to calculate how long the instructors monitored or intervened with groups.

Step 5. By adapting a coding scheme from Shehab & Mercier (2019), I coded the instructors' interactions with the groups (see Table 5.2). Each turn of talk from an instructor was either coded as explicit collaborative, implicit collaborative or not collaborative. Reliability was completed for 20% of the interventions with a second coder with a Cohen's Kappa of .87.

Table 5.2
Coding scheme for types of collaborative interventions.

Type of Turns	Definition	Example
Explicit collaborative prompt (EC)	The TA or CA prompts the group with an explicit collaborative intervention that asked the group to work together.	*"But now that you've gotten that make sure that everyone in the table does."* *"Talk to your group – what do they think?"*
Implicit collaborative prompt (IC)	The TA or CA asks questions or probes the group to invites student to present their reasoning, explore their understanding, or challenges their ideas.	*"How do you calculate for the shear force generated by a moment?"* *"Like what is it doing- if you apply that moment to this?"*
Absence of a collaborative prompt (NC)	The TA or CA provides the group with no prompts to talk to each other or share ideas. All prompts from the TA or CA are content related, responding to questions, instructing them of what to do, or asking clarifying questions.	*"Sorry are you talking about for the contributions of MY?"* *"And so the shear stress due to MY is gonna be positive, the shear stress due to VW is gonna be negative. Does that make sense?"*

Step 6. To further analyze how the instructors engaged in different kinds of interventions, each intervention was categorized by how instructor's initiation and follow up moves with groups. In this analysis, I include only interventions where the instructor initiated the intervention. When students initiate an intervention, the overall focus of the interactions was different. In my analysis the focus of the study is on the tool's effect on instructors; therefore, I excluded student initiated interventions.

Using the above coding scheme to identify the instructors' turns of talk as non-collaborative, implicit collaborative, or explicit collaborative during interventions, I analyze both the initiation move and follow up moves of interventions. First, I will compare initiation moves across instructors. Initiation moves were the turn of talk that the instructors started the intervention. Initiation moves have been identified by past research as setting the tone for the quality of the intervention (Shehab, 2019). Then I identify the follow up turns after each initiation moves as including or not including implicit or explicit collaborative turns. I included all turns of talk that came after the initiation move, a follow up move. According to the design of the CSTEPS tool and results of past analysis (Shehab, 2019), we want instructors to initiate interventions using implicit or explicit collaborative prompts (supplied from the tool and in training), as well as use implicit and explicit forms of collaborative talk in their follow up moves. Shehab (2019) showed that interventions that involved no collaborative turns, including explaining content, providing answers, or describing procedural steps of the problem, led to less productive conversations within groups after the intervention ended. Initiation and follow up moves were compared by instructors across all classes and intervention episodes.

Step 6. Next, the frequencies of log file interactions were calculated. Frequencies included how many prompts were presented in the tool, what kind of prompt they were (e.g., silent on task or off task), and how many were opened, confirmed, and denied. Each frequency was calculated by class and instructors to show differences between classes of students and how TAs and CAs used the tool.

Step 7. Timestamps were extracted for all prompts that were opened by an instructor to identify when the instructors used the tool. These timestamps were cross-referenced with the video data transcripts. By aligning the log file data with the video data, I identified instances where the instructor used the tool and initiated an intervention.

Step 8. Using the log file and video data alignment, I developed emergent themes that portray how the tool was used in the classroom. While the team developed the prompts with a desired interaction, technology is rarely implemented as expected. While there were several instances where instructors used the tool as designed, there was a variety of other factors that came into play. I outlined emergent themes that illustrate other ways the CSTEPS tool was used by instructors that include external factors as well as errors by the instructors. These findings are not negative depictions of the classroom, somewhat realistic reflections of what took place. Classrooms are complex and continuously changing, and these findings can be used to inform design modifications that may be needed to better support instructors in the future. To explain these examples, I described exemplars of these themes.

Step 9. After documenting the log file data, aligning it with the video data, and describing how instructors used the CSTEPS tool, I compared intervention episodes where the instructors used the CSTEPS tool and where they did not. These comparisons demonstrated how the tool affected monitoring and intervention. First, I compared monitoring and intervention times with and without the CSTEPS tool. Then, I compared initiation and follow up moves with and without the tool.

Step 10. To answer the research question–how the design decisions embedded in the classroom influence the instructors' interactions in the classroom–I took the instances where an instructor used the CSTEPS tool before or during an intervention and described these narratives using the data analyzed above (e.g., coded instructor turns, monitoring times, etc.). To describe these 12 examples, I chunked them into categories to illustrate the variety of ways the instructors used the CSTEPS tool.

Step 11. Finally, to understand how instructors reflected on these experiences, I used the same process to analyze the post-interviews as I did with the pre-interviews. I developed content logs for each instructors' post-interview. Using narrative analysis (Riessman, 1993), I describe each instructors' responses to depict how they used different functions of the tool to monitor and intervene.

Step 12. Finally, to triangulate the data, I describe overall trends and findings across all data sources and make design recommendations based on findings from the implementation.

CHAPTER 6: DESIGN TO IMPLEMENTATION

6.1 Introduction

As described in Chapter 3, the CSTEPS tool has gone through multiple iterations within this DBR project. In this chapter, I will describe how we implemented findings from the design process into the classroom. I will explain the final student and instructor CSTEPS tools and define ideas that made it into the final design and those that did not. Describing these ideas was essential to identify ideas that may be useful but were not implemented during this iteration and also reflect on ideas that were generated to gauge their effectiveness in the implementation phase. In this section, I posit the research question, how did the ideas that emerged during the design process get implemented in the classroom?

6.2 Final Design

The team implemented two pieces of technology, the student tool and the CSTEPS teacher tool. The student tool remained the same as the last iteration of the project, while the CSTEPS teacher tool changed significantly. The student tool, as described in Chapter 3, provided students with a drawing space to work collaboratively on the assigned worksheets. The tool represented each student with a color related to the color shown on the teacher tool. The tool segmented worksheets into a series of pages (Figure 6.1, A); the white dot indicated the page the student was on, and colored dots were shown for other group members, in this case, the student represented by the green dot, who was on a different page. The student tool included a series of drawing tools (Figure 6.1, B), including color change, pen, eraser, highlighter, and clear. The worksheet contents, a PDF inserted into the system, were presented at the center of the page (Figure 6.1, C), where the students were able to draw (Figure 6.1, D). The dots on the scrollbar indicated the location of students on the page so that they can see where their group members were if they were on the same page (Figure 6.1, E). In Figure 6.1, the student using this tablet, represented by the blue dot, was at the top of the page, as was the student represented by the orange dot. The student represented by the purple dot has scrolled a little further down the page (and as noted above, the student in 6.1 A, the fourth student, represented by the green dot, was on a different page).

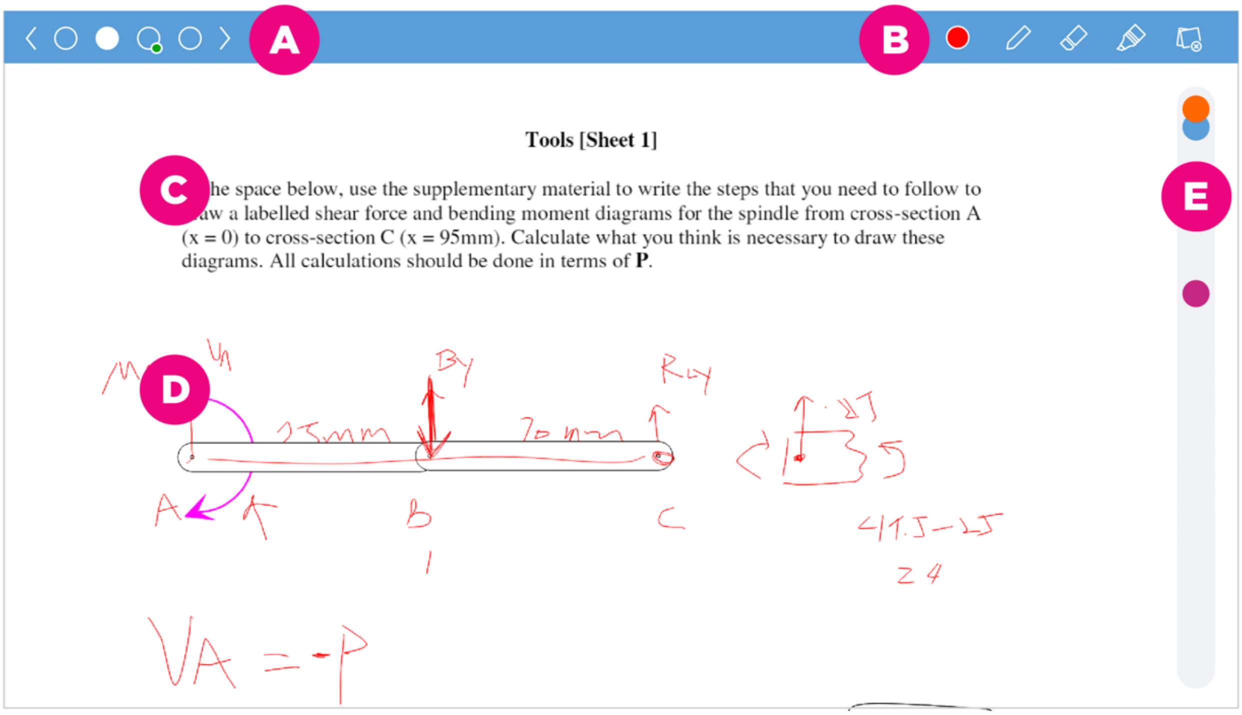

Figure 6.1. Student tool implemented in the classroom.

After a yearlong process to redesign the CSTEPS teacher tool, following an initial semester-long implementation, the final design, was implemented in the classroom. The CSTEPS tool displayed all groups in the class (see Figure 6.2), presented in a card format. All groups appeared with a color on top of their card. Yellow appeared when there was no prompt, meaning the prediction models had not identified a potential issue for the group (Figure 6.2, A). When an alert appeared, it changed to orange (Figure 6.2, B). When another TA in the classroom had selected a prompt, it turned grey so that no other instructor could click on the same prompt (Figure 6.2, C).

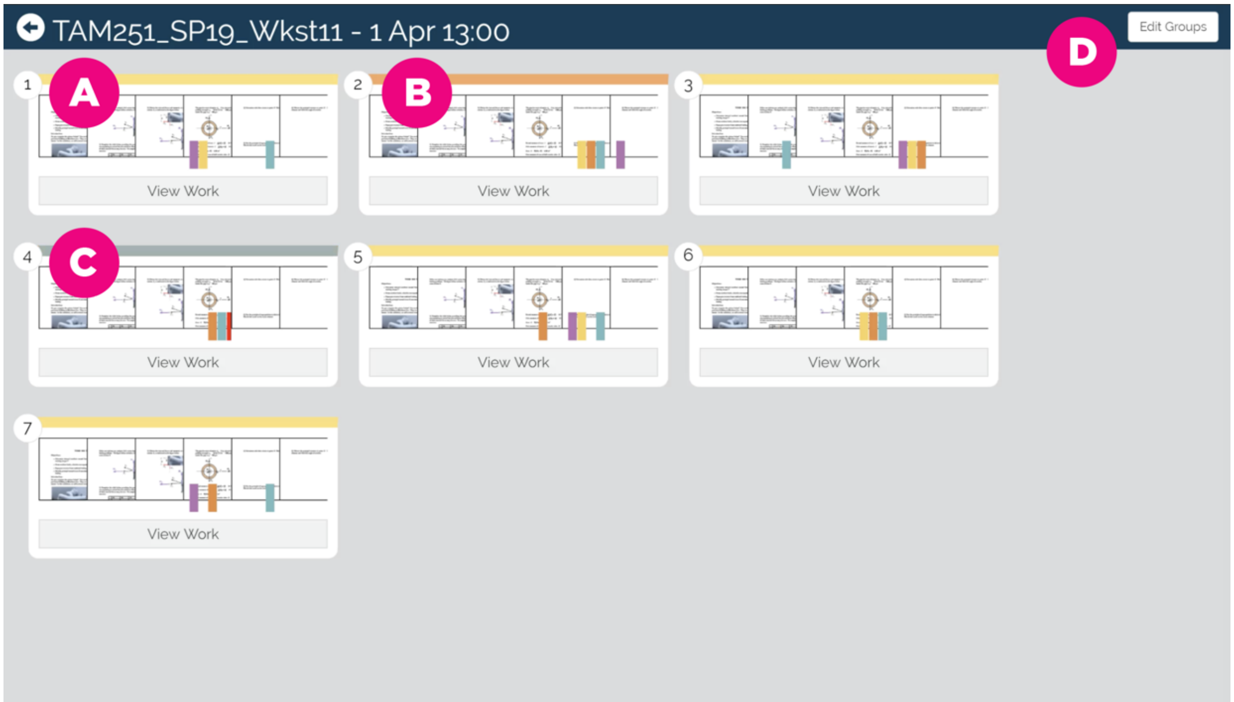

Figure 6.2: CSTEPS teacher tool.

In addition to the prompts, the CSTEPS tool had some of the same functionality as the past iteration. The team decided to remove the data visualizations about group progress and student progress because of some misalignment with the prompts (to be discussed below; see Lawrence & Mercier, 2019 for examples of the earlier iteration of this tool). However, instructors could still edit the groups in real-time (Figure 6.3, D). Editing a group allowed instructors to move students if there was a problem with a group or if only one student was present. Instructors could also see the thumbnail of the worksheet (Figure 6.3, E) and the students' location by page (Figure 6.3, F). Finally, the instructors could view a group's work (Figure 6.3, G), allowing them to join the group's worksheet to view and write with the students on the shared drawing space.

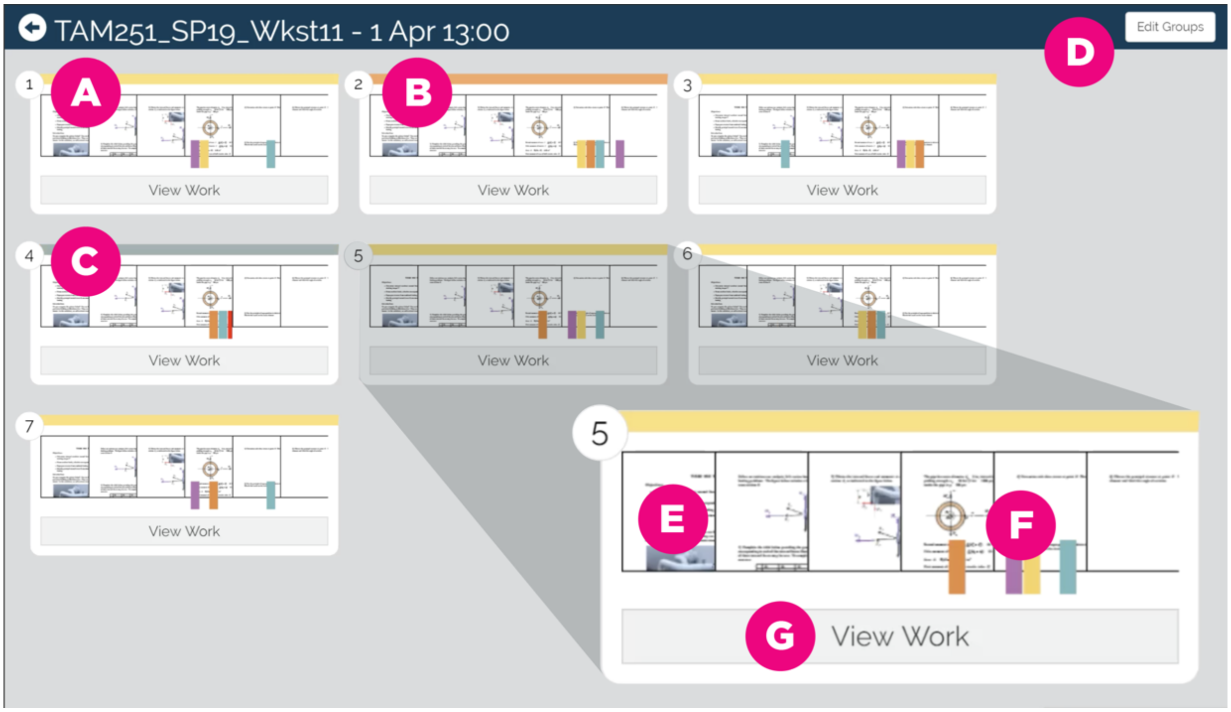

Figure 6.3: CSTEPS teacher tool, close up of a group.

When selecting a prompt in the CSTEPS tool, the instructor clicked on an orange group, which indicated the prediction models had identified a potential problem. When selecting a prompt, a pop up appeared on the screen (see Figure 6.4). This prompt showed which group it was for and two panels. On the left panel, the tool prompted the instructor to monitor the group for the behavior that the prediction models had identified, and the right panel remained blank. When prompted to monitor, the tool provided the instructor with a title; in this case, the prompt was to monitor for silent on task behavior within group one. The panel included a drop-down for more information about what this prompt meant and buttons to confirm or deny if the behavior accurately represented the actions of the group. In this case, if the instructor denied the issue, the pop up disappeared. If they confirmed the issue, the tool presented strategies with tips on how to intervene.

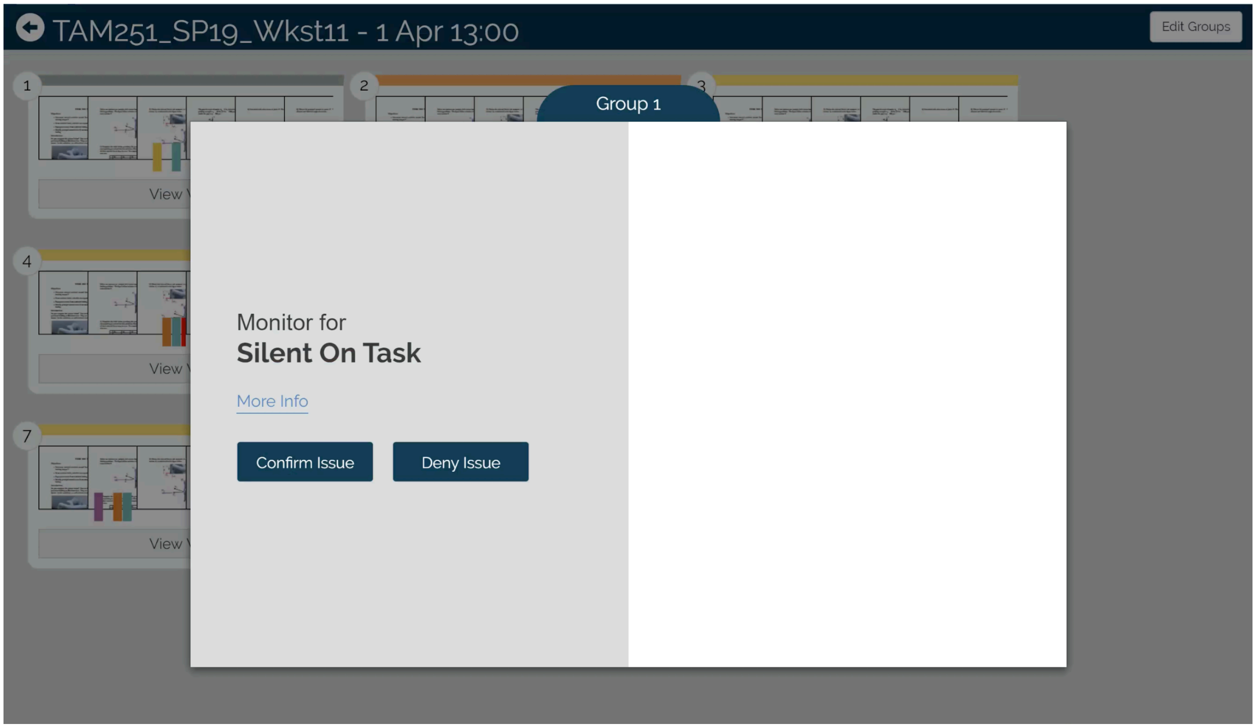

Figure 6.4: CSTEPS teacher tool, prompt to monitor.

Figure 6.5 shows what the strategies look like after confirming the predicted issue in the group. Tips were sectioned into two components, first an overarching goal that identified a strategy for approaching the group, followed by a few sentence starters or phrases to use when talking to the students. After reading the strategies, the instructor could exit the prompt by hitting the done button.

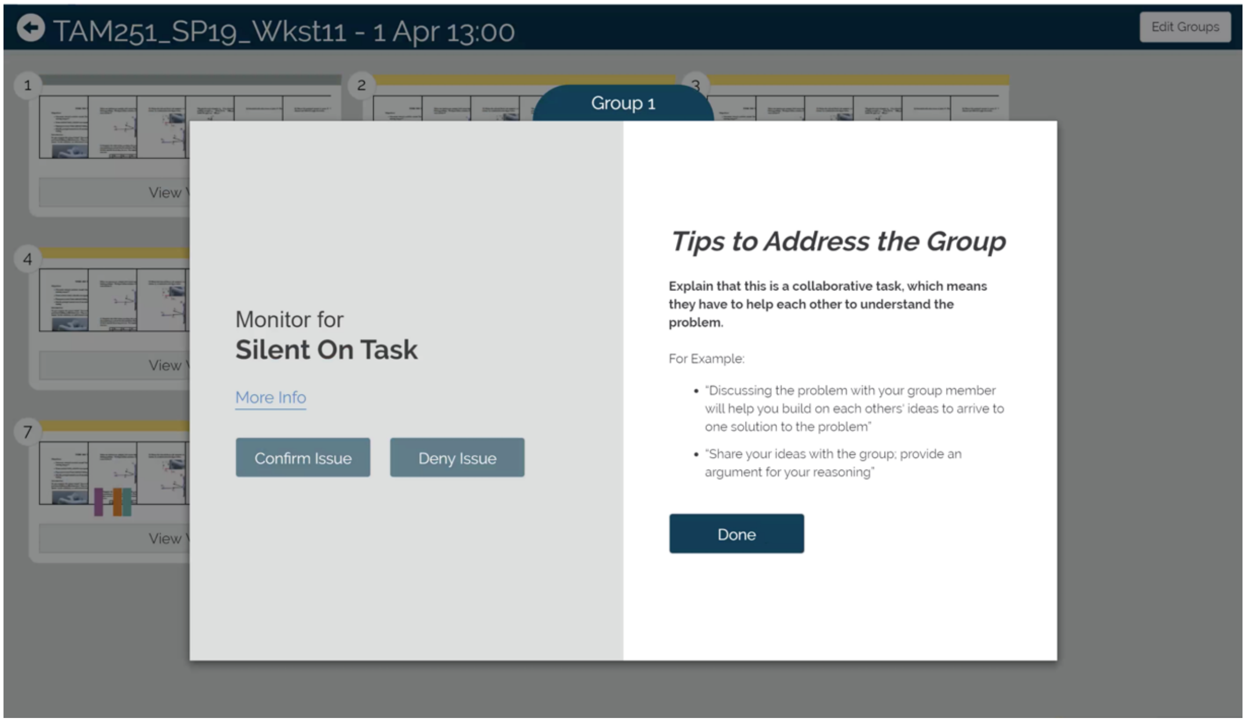

Figure 6.5: CSTEPS teacher tool, monitoring confirmed, 'tips to address the group.'

6.3 Design Ideas: What Made it, and What Did Not?

In the design phase of this project, I extracted ideas that came about during the brainstorming meeting. Findings from Chapter 4 show that ideas about the CSTEPS tool came out of several types of conversations, including critical moves and lateral areas. Analyzing the ideas that emerged, I discuss themes that surfaced from this data about what elements got implemented in the classroom and what did not.

6.3.1 Design Ideas: What Made it?

The team discussed several ideas in the brainstorming meeting that we implemented in the CSTEPS software. Three themes emerged that were implemented in the final tool: monitoring, intervention, and interface choices.

6.3.1.1 Monitoring

The team identified monitoring as a clear goal of this iteration from the very beginning of the brainstorming meeting. Within the first 10 minutes, monitoring was characterized as a critical move and vertical area. Sarah first proposed this idea after I probed the group to explain what they would do as an instructor in the first scenario,

Lu	Alright so what should the TA actually do [in this scenario]? [Long pause] What would you have the TA go do it they were going to intervene in this group?
Sarah	I would have them monitor
Sami	I think definitely there should be a monitoring phase, in this…
Peter	Yeah
Lu	Monitoring? [As I write it down on the board]
Sami	Like, in my opinion, he or she needs to know first, um like what sort of… remember that the TA has kind of, assuming that he or she has the content expertise, right? So at least standing next to the group for a little bit will allow him or her to know what type of equations are we working on, right?

As Sami described how the instructors might interact in the classroom, the discussion transitioned to exploring what the instructors should be monitoring for in these situations. These discussions included some disagreement regarding the description of what monitoring might be to the instructors. Noah discussed including more information in the tool to purposely outline what to monitor for, while Sarah and Marisa held to the idea that less information was better than more. Sarah elaborated that a short monitoring prompt would be better because, ideally, we had trained the instructors on what to monitor for. She explained that if simply told to do so, the instructors would monitor for content-related issues like we had seen in past analysis. Marisa built on this idea by presenting the option to use a title to show that monitoring was necessary and including a drop-down to share more information if the instructors needed it. She elaborated that in her experience overseeing engineering instructors, they were not going to read long descriptions during class.

Noah described his reasoning for more information was to provide scaffolding for instructors the first few times they received a prompt so that they were not overwhelmed and had a clear idea of what to do. Shortly after, Erica suggested the idea of creating a classification of monitoring to help instructors identify what kind of social behaviors they should monitor for. These conversations about how to support the instructors to identify what they should be monitoring recurred through our discussions. Other proposed ideas included presenting an icon that identifies what to monitor for, a short description of specific behaviors, and colors to indicate categories of behaviors. These conversations slowly transitioned into discussing how to signify that the behavior was happening or not happening.

This transition started when Erica asked if the instructors needed to report if the behaviors were accurate or not. There was a consensus that the instructors needed to acknowledge if the behavior they monitored for was correct. Levi described that this was necessary to understand if the models were accurately identifying the predicted behaviors. Overall, this was agreed upon by the research team as being an important aspect of the research. Sami elaborated from a teaching perspective that we needed some kind of confirmation because the goal was for the instructors to monitor and identify if an intervention was necessary. As past analysis has shown, we do not want instructors interrupting groups; instead, monitoring to ensure an intervention was necessary.

About 30 minutes into the first scenario the group seemed to be wrapping up when Levi asked to summarize what we had so far,

> "So, for this scenario, I guess, there was a lot of discussion, I kind of want to kind to summarize. So it seems like the way we're going right now, what we're thinking, is, having something that's easy to read, that's just like, monitoring and then maybe, what they're monitoring for, that's really easy to read. But then with options to get more information about what behavior to look into. And then, if they see something, is there another layer where the tool tries to help them intervene? So then it's like, it opens up and then they can ask for more information, and then it'd say yes or no. And then if they click yes it gives them a, uh, possible intervention?"

At this point, the group agreed on Levi's summary, which led to discussions about what it looked like to support interventions.

Over the next few months, the design team took the ideas described above and made final decisions about the tool. The tool prompted the instructors to monitor by giving a short title identifying two categories of behaviors that they should monitor for, followed by a drop-down to provide them with more information. Monitoring was separated from the intervention strategies by requiring the instructors to confirm or deny the prompt.

6.3.1.2 Interventions

After monitoring, how to support instructors as they engage in interventions with groups of students was the most discussed topic during the brainstorming session. It was clear that the research team wanted instructors to monitor groups before intervening because past analysis showed that instructors did not monitor and often interrupted collaborative interactions (Shehab, 2019). However, the intervention component was more challenging to design.

During the second scenario, Sami suggested two forms of strategies for the tool. Explicit sentence starters that could help the instructors tell the groups that they need to work together and implicit strategies that provided suggestions to get the groups talking. He continued, explaining that for the implicit strategies to be effective, the instructors needed to "leave the group with a controversial idea." Meaning the instructor would prompt the group to talk about alternative ways to solve the problem and leave the group without providing more information. Using this context, the group came up with some strategies, such as asking the entire group a question, probing the group to engage everyone in conversation, asking students to explain their process or goals for the worksheet, and explicitly asking students to respond to each other. While multiple members were contributing to these ideas, the idea of complexity came into the discussion.

Sarah	Those [strategies] are pretty hard. Those are pretty advanced.
Lu	Mhm
Sami	Yeah, this is…
Sarah	I dunno if that would be very realistic. I mean, this doesn't hurt to write it down.
Lu	Yeah, yeah, yeah. I think these are the questions to ask, but how do you get – I mean, you can't just put these on the tablet, right? And say, say this exactly.
Levi	Mhm
Sami	So Erica, when you talk about prompts, do you have in mind, like, ah again, do you have in mind something like what you suggested? It looks like you are working on something like this should pop up or a goal that we want the TA to…
Erica	I think we need to play with this. I don't really know.

Erica explained that this was the exploratory part of the project. There were not many examples of instructors receiving prompts in real-time, especially for novice instructors. Designing supports to get instructors to engage, became more complex as Levi pointed out that the data from the last iteration showed that instructors were less likely to intervene with a group that was not talking (Shehab & Mercier, 2019). Meaning instructors may not be comfortable engaging with a silent group.

Noah spoke to comfort several times throughout the brainstorm meeting. In one instance, Noah explained that instructors might not be comfortable intervening explicitly about collaboration because it can feel confrontational. In this discussion Sami was using his experience has a high school teacher to explain how he would intervene, he again reiterated the explicit collaborative route, "I would [ask] the student why aren't you participating? Or [explain] that this is a collaborative, uh discussion section, why aren't you saying anything?" While the explicit route seems helpful, the team pushed back on it. Our goal for the project was to help instructors who had never done this before, and explicit prompts may be challenging to articulate to students as Noah and several members explained.

The tension between providing support that will engage students in discussion while also considering that instructors were novice instructors, often with little to no collaboration experience, was a big challenge with this design. Some ideas the team generated during the discussion about interventions, included providing instructors with a goal to accomplish during an intervention, sentence starters, ideas for probing questions, and distinct collaborative phrases. All of these ideas eventually made it into the strategies provided in the tool. In the final design, the team decided to use how and what format for strategies. The first section of the strategy provided a general summary of what instructors could do to get the group talking. Below this goal was sentence starters for the instructors to use to initiate or follow up during an intervention.

The team designed a final set of strategies (see Appendix A) after this meeting using ideas that emerged. Over several months, members of the team used these ideas as a starting point, in conjunction with past data from this course series and literature on teacher interventions and teacher noticing, to develop a series of strategies for the CSTEPS tool. These strategies went through several rounds of revisions with members of the research team, including instructors from discussion sections, before a final list of developed and implemented.

6.3.1.3 Interface decisions

The final theme that came through during the brainstorming session was ideas about the design of the CSTEPS tool interface. These ideas came out of the third scenario, where the goal was to review the last iteration and make decisions about the software moving forward. Because this was an iterative project, we used video and interview analysis from past years of data collection to understand what worked and what did not in the previous CSTEPS tool. During these discussions, two ideas were implemented in the teacher tool, projection, and changing the data visualization to align better with the goals of the prompts.

In the past iteration, the projection tool had functioned through the *view work*, where instructors could view a group's worksheet and choose to project it to a large screen in the classroom. This function was designed during a co-design process with expert teachers and instructors, for them to use during wrap-ups, but also throughout the class as needed (Lawrence & Mercier, 2019). In past iterations, interview data indicated that instructors often used this to identify if the students had the correct or incorrect answer (Lawrence & Mercier, 2017). During the brainstorming meeting, I proposed the idea of cutting the *view work*, and therefore the projection, to eliminate the possibility of checking the students' work. I argued that this function contradicted the goals of the project to support students' collaboration, not the correct answer, especially considering there is never one right answer in the ill-structured tasks. However, several members of the team disagreed, explaining that the projection tool was potentially beneficial because past instructors used it for wrap-ups and introductions (Shehab, 2019). While many members of the group understood my argument for removing the function, eventually, the group came to a consensus to include the *view work* function in this iteration.

The last idea implemented in the CSTEPS tool that emerged as a critical move and a lateral area was the possible misalignment between the data visualized in the tool and the prompts. In the past iteration, we visualized raw data about students' and groups' activity that accumulated over the class. Sami and Levi both expressed concern about the mismatch. Sami initially brought up that the tool may cause confusion if it appeared that one student was doing all the work, and all students were on different pages, but there were no prompts from the prediction models. This confusion could cause the instructors to question the tool. Later in the third scenario, Levi linked back to Sami's point and elaborated that the visualizations were cumulative data.

In contrast, the prompts were more localized events, which again could contradict each other. Eventually, the group agreed to get rid of the student activity and impose changes to the group activity, which were later not implemented, which will be described below. In the final design, the team removed student activity and group activity because of this misalignment.

6.3.2 Design Ideas: What Did Not Make it?

Several ideas emerged during the brainstorming meeting as critical moves and lateral areas that the team did not implement in the final design. Here, I briefly outline why ideas about the interface, technology, and teaching that we generated were not integrated.

6.3.2.1 Interface Decisions

There were a few interface design choices that we did not use in the final tool, including changing font darkness for prompts, integrating icons for monitoring or intervention types, and creating two pages of the tool (one for prompts and one for the visualizations). We revised and iterated on the design over four weeks after the initial brainstorm meeting. We decided in later meetings that subtle design choices, like icons or fonts changes, required too much thought process and memorization on the instructors' behalf. We decided to use more explicit phrases and titles that were presented as ideas during this meeting so that instructors could easily extract and use information in the tool.

One idea presented when discussing the mismatch between the data and prompts was to create two separate screens that the instructors could swipe between. One had the data visualizations, and the other had the prompts. However, we excluded this as an option with the worry that instructors could miss the prompts. The focus for this project was on the prompts rather than the data presented in the previous iteration.

6.3.2.2 Technology Decisions

Two suggestions emerged from the brainstorming meeting about the technology that we did not implement. The first was to identify if an instructor was at a table. In the discussion, Levi clarified that one limitation of the software in its current design was that it could not identify if another instructor was already at a tablet with a group. Therefore, a prompt may present itself while another instructor was already engaged in an intervention with a group. While we discussed this limitation during the meeting, we decided that since the prediction models could not account for talking or the location of the instructors, it was not possible to identify during this iteration. While this was an issue to be discussed in future iterations, there was no way to identify in the current iteration.

The second idea was to ask the instructors to reflect on the tool if the prediction models were correct. In the implemented version, the tool asked instructors if an issue that the prediction models identified were correct or not after monitoring. From a data standpoint, this idea was presented as a way to identify if the prediction models were accurate when there was not a prompt, which means that instructors would confirm if a group was really working on-task or talking together. Others pushed against it from the perspective of the instructor. Asking instructors to do this would be an unnecessary overload during class. Additionally, this was something that the research team could do from the video data after it was collected. By not adding this, we intended to keep the tool as close to a classroom tool (not a research tool) as possible–so not overloading instructors with additional research tasks during data collection.

6.3.2.3 Teaching Decisions

The final category of ideas that the team did not implement in the classroom were decisions about teaching. This category had the most of the previous two because the goal of the brainstorming session was to find ways to support instructors better. Four main ideas emerged either as critical moves, lateral moves, or both during the meeting.

The first idea was to add student names to the dashboard. The team, especially those who had worked in discussion sections for many years, discussed that one way to support collaboration would be for instructors to know the students' names. The group agreed that this would be ideal; however, it was beyond the scope of the classroom and could overload the interface. Therefore, it was not enacted in the design.

As discussed above, one of the issues with this design was the misalignment between the visualizations and the prompts. One proposed idea was to redesign the way the group activity presented the data. The team proposed two suggestions, imposing structure to the class and presenting a timeline of expected events. In our past research, the team has had many conversations about collaborative frameworks to structure discussion sections (Kaendler, Wiedmann, Rummel, & Spada, 2015). The first idea was to change the group activity so that it imposed structure on the group activity data. The structure would add scaffolding to support instructors' understanding of how much activity students had (e.g., lower activity at the beginning when students should be reading and discussing the problem). This idea sparked discussions on the validity of the relationship between activity and possible frameworks. When we identified there was no data or research to back up this hypothesis, we moved to set up the structure with no data. We discussed providing the instructors with a timeline that showcases a framework to organize the class. This idea linked to ideas about including a timer to help instructors identify how far into the task the students should be and identify times that may be good to start a wrap-up. While the group had conversations about these decisions and eventually reached a conclusion to include a framework without the data, we never implemented it into the classroom. DBR can be beneficial in many ways to design useful tools for instructors; however, one limitation is time. In this case, the intervention strategies in the tool took several iterations to design a reliable set. Since the prompts were the focus of the tool, due to time, we did not return to other design choices after this meeting to meet implementation deadlines.

The final idea that was generated during the brainstorming meeting was about the sequence of prompts. In the second scenario, conversations arose about sequencing the strategies throughout the semester. Sequencing would allow time for instructors to practice and master some strategies and build up to ones that were more complex as the semester went on. This idea had consensus across the group; everyone thought it would be useful to train the instructors over time. However, again a limitation of DBR, due to time, it was challenging to design strategies. We decided to include fewer more polished strategies rather than potentially less useful prompts to the instructors. This meant that only ten polished strategies were put into a pool and randomly selected by the software.

6.4 Takeaways

The goal of Chapter 5 was to answer the research question, how did the ideas that emerged during the design process get implemented in the classroom? In answering this question, I outline two major takeaways.

6.4.1 Takeaway #1

All major changes made to the CSTEPS tool emerged during the initial brainstorm meeting. Decisions about monitoring, interventions, and interface changes were discussed by the team and iterated on over the course of the following months preceding the implementation.

6.4.2 Takeaway #2

While several decisions were ultimately decided they were not feasible for the software (e.g., icon designs), others were excluded because of limitations of the design process. As a DBR study, one major limitation to this kind of research is the time constraints that arise when working within the constraints of a grant. Several ideas, including adding structure and findings ways to identify where instructors are in the classroom, were not integrated because there was not enough time. Since the priority of the grant was to explore how prompts may be implemented into the software, the focus of the design process was put on that goal, leaving other potentially useful changes to the wayside. This is a realistic limitation of DBR. Documenting what was not implemented and how it may be useful in future iterations helps to identify gaps in this research and other methods to improve this software in the future.

CHAPTER 7: IMPLEMENTATION RESULTS

7.1 Introduction

To understand the impact of the design process, this chapter describes the analysis of the implementation of the design outcomes in the classroom to answer the research question,

RQ3. How did the design decisions influence the instructors' interactions in the classroom?

In this chapter, I will first provide context of this analysis and reiterate findings from past studies. I will follow this by outlining the classes and the instructors in each discussion section using analysis of pre-interviews. Then, I will describe what the predictive models prompted during each class time and how the instructors interacted with these prompts. To describe how the tool affected the instructors, I will then describe how the instructors monitored and intervened with groups and compare their interactions with and without the technology. Finally, I will close with vignettes that illustrate how the instructors used the tool in their classrooms and summarize findings from the overall implementation phase.

To preface this analysis, I want to outline that the CSTEPS tool was a supportive tool intended to inform instructors about what was happening in the classroom to support their interactions. This analysis looks at how instructors used strategies based on how the team expected them to be implemented. There was no one "right way" to implement these strategies in the classroom. In reality, the implementation of how this software was used was informed by training, teaching philosophies, student needs, and a myriad of other factors in the classroom. As the research team, we have goals for how we hope to see this tool implemented, but the point of this study was to learn from how instructors use the prompts and strategies to learn how to better support instructors in the future.

The design and analysis of the implementation phase of this project were heavily influenced by past research. Specifically, my analysis primarily builds on the findings of Shehab (2019), who analyzed the instructors' monitoring and intervention strategies in a previous iteration of this project. In the classroom data he analyzed, students used the student version of the CSTEPS tool, but the instructors did not have any technology. This research was important to understand how instructors monitored and intervened without any additional scaffolding or support. His findings show that instructors engage in monitoring before 28% of interventions and that there were no instances of monitoring when an instructor engaged in a content related intervention. Additionally, interventions with monitoring were significantly shorter compared to interventions without monitoring, showing that when instructors monitored they took up less of the potential collaborative interactions among group members. Finally, Shehab's findings reveal that the instructors did not explicitly prompt collaboration. Meaning, the instructors were focused on the task and asking questions but were not prompting groups to engage with their group collaboratively. These findings were influential in designing the technology and prompts in this iteration; they gave insight into what kinds of scaffolds could be used to better their monitoring and interactions with groups.

7.2 Classroom Context

This analysis drew on five discussion sections that used the CSTEPS technology in the classroom. Each discussion section had one TA, who was a graduate student teaching assistant, and two CAs, who were undergraduate course assistants who previously excelled in the course (see Table 7.1). The number of students and groups included only students who consented to be in the study. There were more groups of students in the class; however, if one member of the group did not consent, data was not collected from the entire group.

Table 7.1
TAs and CAs by class.

	Class 1	Class 2	Class 3	Class 4	Class 5
Number of Students	18	22	10	22	14
Number of Groups in the Class	8	7	5	6	5
Number of Groups Analyzed	5	6	3	6	4
TA	Adam	Adam	Adam	Lisa	Lisa
CA 1	Zain	Jason	Jason	Casey	Raj
CA 2	Santu	Jenn	Jenn	Santu	Santu

Each TA and CA approached the job with different reasons for taking on the position and perspectives about the courses. Using narrative analysis of pre-interviews, I will describe how long each instructor was in their position, what drew them to the position, and what they valued about discussion sections. While all instructors were interviewed with the same interview protocol, Adam and Lisa's interviews were almost an hour each, whereas, on average, the CAs' interviews lasted 21 minutes, with shorter, less elaborated answers.

7.2.1 Pre-Interview Analysis: Teaching Assistants

Adam was the lead TA for the first three classes in this data set. He had been teaching as a TA for five semesters in the same course; two of which were part of the CSTEPS project. Adam was the only instructor who had previously worked on the CSTEPS grant. When asked about why he chose to become a TA, Adam first discussed his need for funding in his master's program. However, he described that while it was an option for funding, he also saw the potential for personal growth within the position. He described that beginning his program, he did not feel he had the best social skills but enjoyed explaining things to others. When the opportunity to be a TA presented itself, he reflected on why he decided to take the position, explaining:

> "[Teaching is a] novel form of social interaction – helping a class and working with students. I find that having those types of social experiences helps me be more comfortable in other interactions in my life. So as a matter of personal development, it appealed to me there."

He elaborated that in addition to the potential of improving his social skills, as an undergrad in the same program, he had served as a student consultant when the faculty began redesigning the courses. While he enjoyed the courses, he also felt attached to the program, which motivated him to help improve them.

When asked about what he valued in the discussion sections, Adam described that his opinions about the course changed during his time working with the CSTEPS team. He explained that while he was biased because he was aware that collaborative learning was the motivation behind discussion sections, he explained why he found value in collaboration for his students' sake. He explained,

> "[With my experience] I'm kind of predisposed to view [discussion sections] in that way, but at the same time, I do see students... when students are having discussion as they are working through these worksheets, [the discussions] are entirely unlike discussions they would be having with a TA or a professor. It's not that they won't tell course staff that they don't understand something, but the interactions that they have with each other are much more characterized by

> thinking they understand something or trying to explain something or kind of being… rather than either being 'ok I understand this' or 'I don't understand this', they are kind of more in this middle ground where they are willing to say 'well… I think I maybe need to do this' or 'I think this is maybe how this works.' And I see students challenging each other... and I think this is a space where students are actually able to figure out a lot and get a better understanding of where they're at. When [collaboration] works, I think that it is the greatest value of the discussion section."

With several semesters of experience, Adam had copious examples of ways students interacted with each other. However, he also discussed the challenges that accompany this kind of learning. While he has seen several groups naturally develop a collaborative rapport, some groups never get to that point. With groups that do not want to talk, he explained tactics like trying to start conversations that often end immediately after leaving or reminding groups that it was part of their grade to work together. In these cases, he explained if a group is not talking, telling them it will affect their grade has never motivated them. He wrapped up by saying that while it was challenging to prompt this kind of learning in groups that will not work together, collaboration does work enough for him to be encouraged because he wants to see improvements in his classroom.

Similar to Adam, Lisa had been a TA for several semesters. The semester of the interview was her fourth time being a TA for this course, having chosen it over other courses in its series. This was her first semester working on the CSTEPS grant, and she volunteered to be a part of it after learning about Adam's experiences in previous years. When asked to describe why she chose to be a TA, Lisa responded that it was her only option for funding in her program. She went on to explain that while she enjoyed teaching, she had hoped to get a research appointment but there was no funding in the area she was pursing. She became more involved in the course series in the college of engineering throughout her degree. She ran the course websites, of which she got paid to do, and built guides for other TAs, which she did voluntarily. She leveraged her experience in the classroom to create guides, where she outlined each worksheet week by week and provided insight into problems students might experience, reoccurring questions, and tips and tricks for explaining solutions.

When Lisa was asked about what she valued about discussion sections, she responded that they were helpful for students to work through examples with colleagues. She felt that she learned more through teaching the content, compared to her experiences as a student; she described that allowing the students to explain content helped them learn. This conversation transitioned to ways she supports groups. She passionately explained that the point of the instructor's interactions was to help students with the problems without providing them with an answer. Her strategy was to guide students to the solution by probing questions rather than explaining specific details about the problem. In this response, she stopped herself suddenly and altered her framing,

> "But I guess in terms of this research project… another important part I feel is making sure they uh, that you don't interrupt them. I've definitely felt like I come check on a table and they're working and I'm trying to just check that they're at a good spot, but it can do more harm than good. Because you interrupt someone who's mid-sentence explaining something."

She explained that she was excited about the opportunity to work on this project and for her students to use the tablet application because it forces them to work together. Lisa elaborated that it can be a struggle to get students to work together and that she thought that leveraging the affordances of the technology could alleviate some of those problems she had experienced.

7.2.2 Pre-Interview Analysis: Course Assistants

Zain was a CA in Class 1 with Adam and Santu. This class was Zain's third time being a course assistant and his second time in this course. Zain explained that he had chosen to be a CA because the previous semester, one of his friends had had the position. He expressed excitement that it seemed like it would be a good way to make money because he enjoyed the course. In our discussion, he reflected on what he valued about the discussion section format. He described that discussion sections allowed students to apply what they were learning in lectures and homework to real world applications. Getting students to think about the material in other ways helped them to solidify their understanding of the content. He went on to say that he also values the team component of the course. He explained that some students could come in and complete the worksheets on their own, but having groups allowed students to explain and ask questions. However, this was challenging for him because it was always challenging to get a group to start talking to each other.

Santu was a CA with Zain in Class 1, as well as two other sections in Class 4 and 5. This was Santu's second semester as a CA for this course. Of all the CAs' interviews, Santu's was the longest as he reflected on his experiences with groups that led him to this position as well as his values for the course. As soon as the interview started, he was eager to share his group experience when he took the course the year before with Adam as his TA. He was in a group where all of the members were engaged and had productive conversations about the course content. Their group was comfortable around each other and voiced problems and confusions openly so that someone could help explain what was going on. Santu explained that this was only one of the reasons he chose to be a CA. He described that he had always enjoyed teaching and explaining things to others. He described his transition from his position as a tutor on campus to his CA position, where he worked in three courses and also helped with some of the organization of the course series.

When asked to describe what he valued about the discussion section, Santu said,

> "To be honest, it has nothing to do with the course or the material, in my opinion. Just because, I think what I learned the most was [how to] work in a group setting. I learned that a lot, especially with that one group I had, it was amazing. I understood what it meant to work in a team and be more effective when you're working with others."

He went on and explained that while the students need to pass quizzes, discussion sections would not help with that, doing the homework and going to lecture will. The purpose of discussion sections was for students to get used to speaking about their ideas and to improve their social and teamwork skills. He explained that he does not have the perfect way to support groups in this kind of learning. In this discussion sections, he tried to bring quiet group members into conversations and compliment their work or ideas, so that they felt included. Finally, he explained that he struggles with this but was trying to learn new strategies to support students better.

Jason was a CA in Class 2 and 3 with Adam and Jenn. He had been a CA for five semesters and was in his last semester before graduating. Jason described he had been informally tutoring other students since he was in high school, and when he came to college, he found himself doing the same. Jason expressed excitement that after he had taken and exceled, he was asked to be a CA and happily accepted the position. After multiple semesters in the role, he described that what he valued the most from the discussion sections was that the students got repeated exposure to the course material. He found that when students had access to course staff who could explain the content and answer questions, they could do better. Finally, he reflected on problems that he has encountered in the class, including students being on their phones and students who did not engage in discussions with their group members. While he did not feel comfortable calling out these students who would not work together, he said he had not found a good way to bring these students into discussions.

Jenn was also in Class 2 and 3 with Adam and Jason and was a CA for the second time in this course. When asked why she decided to be a CA, she had several reasons for her decision. First, she explained that her mother was a teacher and that she had always enjoyed explaining things to others. In addition to also thinking this would be a fun way to make money, she described that Adam was her TA when she took the course. Adam was a supportive and helpful TA for her, and she hoped to do the same for other students in her position. Jenn described that she valued the relationships that come out of discussion section. In her experience, the people that were in her group in the course became friends and worked closely together. She thinks that interacting with others was beneficial for students throughout their college careers, but especially in this series of courses.

Casey was a CA in Class 4 with Lisa and Santu. He was in his third semester as a CA for this course and chose to accept a CA position to fulfill a scholarship requirement. Similar to Lisa, he would have preferred a research job but could not find one. When asked about what he valued about the discussion sections, he described that he thought the format of the worksheets was essential to help the students learn the content. He also described that most of the groups worked well together because the course grades them on their participation; however, he explained that if a group did not work together, they never would. He elaborated that if a group of students was supportive and communicated well, they could have a better learning experience in the course. In our final discussion about supporting students during discussion sections, I asked if that was a goal for his teaching to help groups be supportive and communicate? In his response, he said, "Oh that's a good question… maybe I should have goals for the students. I've never thought about that." He elaborated and explained that he was not sure a goal was feasible for the course because if he made one, it would be for the students to finish the worksheet. However, he felt that, that was unrealistic because of the limited time in class.

Finally, Raj was a CA for Class 5 with Lisa and Santu. In his interview, which was the shortest of all the CAs, he told us this was his first semester in his role. When we asked Raj why he chose to become a CA, he explained it was for a source of income while in school. Raj expressed that he thought the value of discussion sections was to improve students thinking skills about the homework problems. He elaborated that he knew it was a discussion section, but some groups were naturally better at group work than others. When asked to elaborate on how he supported students doing group work he explained,

> "I cannot push students to talk. And, um, I will try to look at their worksheet and try to find their mistakes and help them to better understand the course content. So that's all I can do as a CA."

He went on to conclude that different people have different abilities to solve problems and that group work conflicts often appeared between traditionally good and bad academic students. However, it was not his role to address them.

Overall, there were significant differences in how all instructors approached collaboration and their motivation for the course, which can influence interactions in the classroom (Lawrence

& Mercier, 2019). Adam and Santu were the two instructors who, before using the CSTEPS tool, had very positive perspectives on collaboration and explicitly expressed a desire to improve their skills at facilitating collaboration. Jenn and Lisa both expressed value in group work, but less so compared to Adam and Santu. While Lisa expressed value in collaboration, she prefaced it with the notion that it was the goal of the research, not necessarily hers. Finally, several of the CAs, including Zain, Casey, and Raj, placed little to no value on group work in discussion sections, and more focus on supporting students' content knowledge. Next, I will use these results to help explain how the instructors used the technology by analyzing log file data from their interactions with the CSTEPS tool.

7.3 Analysis of Instructors' CSTEPS Tool Use

The instructors used the CSTEPS tool in all five classes. During this time, the instructors were asked to use the tool through the entirety of the class. The predictive models that populated the prompts in the CSTEPS tool produced 171 prompts across all five classes. The prompts were either silent on task, indicating that the group was not talking together, or group off task. Of the 171 prompts, 84 (49%) were silent on task, and 87 (51%) were group off task. Of the total prompts that the CSTEPS tool displayed, a TA or CA opened 78 (46%) prompts. Because there were several groups in the classroom, and the tool can produce multiple prompts at once, there were several reasons why instructors did not open some prompts. The instructors may have chosen not to open a prompt, may have chosen to click one, leaving others unopened, or may have already engaged in an intervention when a prompt was shown.

Of the 78 opened prompts, 40 (51%) were silent on task and 38 (49%) were group off task prompts. The tool provided the instructors with the option to confirm or deny a behavior in the software because the predictive models were not guaranteed to be accurate 100% of the time. Twenty-three (29%) of the opened prompts were confirmed by the instructor verifying the prompt was accurate. Instructors denied 55 (71%) of the opened prompts. Specifically, 12 (30%) of the silent on task prompts that instructors opened were confirmed and 11 (29%) of the group off task prompts that were opened were confirmed. Table 7.2 breaks down the prompts presented, opened, and response by class. These results show that the number of prompts presented and opened during each class vary, but there is a relationship between the number of students and the number of prompts. Class 1, 2, and 4 had the most groups and the most prompts presented by the tool. Similarly, Class 3 had the fewest groups and the fewest prompts.

Table 7.2
Number of prompts opened, confirmed, and denied by class.

Section	Total Prompts	Prompts Opened (% total)	Prompts opened and confirmed (% opened)	Prompts opened and denied (% opened)
Class 1	44	22 (50%)	5 (23%)	16 (73%)
Class 2	42	15 (36%)	6 (40%)	9 (60%)
Class 3	17	9 (53%)	6 (67%)	3 (33%)
Class 4	38	20 (53%)	4 (20%)	16 (80%)
Class 5	30	12 (40%)	2 (17%)	10 (83%)
Totals	*171*	*78 (46%)*	*23 (29%)*	*54 (69%)*

While the class level prompts illustrate what was presented to all instructors in the classroom, next, I will explain the differences in instructors' use of the tool (see Table 7.3). Between the two TAs, Adam and Lisa, Adam used the tool more, opening 28 prompts across his three classes, while Lisa only opened three prompts during her two classes. The interview findings above indicated that Adam had more experience with the CSTEPS project and was motivated to use the prompts because he expressed an interest in improving how he facilitated group work in his classroom. Lisa was excited for the students to use the software to get them to work together but focused more on helping the students get the right answer compared to supporting their collaborative interactions.

Table 7.3
Number of prompts opened, confirmed and denied by instructor.

TA/CA	Number of Classes	Prompts Opened	Group off Task		Silent on Task	
			Confirmed	Denied	Confirmed	Denied
Adam	3	28	7	9	2	10
Lisa	2	3	0	0	1	2
Zain	1	2	0	0	2	0
Santu	3	29	3	16	3	7
Jason	2	1	0	0	0	1
Jenn	2	9	1	0	4	4
Casey	1	3	0	0	0	3
Raj	1	3	0	2	0	1

The CAs also had differences among those who opened prompts throughout the courses. Across all CAs, Santu opened the most prompts. Santu was a part of three classes, the most of any other CA. However, like Adam, he was explicit in his interview about wanting to have more strategies to support collaboration within groups. Since the training presented the tool as doing just that, it is not surprising that he used the tool to support his goal. Jenn was also a CA who found value in the group work in her interview, which may have led her to use the prompts more frequently. Zain, Jason, Casey, and Raj each had very few interactions with the prompts presented in the CSTEPS tool.

Technology is rarely implemented exactly as expected. The design of the tool, as described in previous chapters, was intended to be used by selecting a prompt and confirming or denying a behavior. If a behavior was confirmed, the tool would populate with strategies based on the prompt, then instructors can close the prompt and engage the group in an intervention using the strategies provided. While there were several instances where instructors used the tool as designed, there was a variety of other factors that came into play. Here, I will outline emergent themes that illustrate other ways the CSTEPS tool was used by instructors that include external factors or mishaps by instructors (see Table 7.4).

Table 7.4
Emergent themes of instructors' interactions with the prompts.

Emergent Theme of Tool Use	Example
An instructor monitored with the tool and a student initiated an intervention while they were monitoring or reading the prompt	*Adam opened a group off task prompt, walked to the group and while monitoring a student asked him a question about the worksheet*
An instructor denied the prompt because the prediction models were incorrect	*Lisa opened a silent on task prompt, however, the group was working and talking together; therefore, she denied the prompt*
An instructor confirmed a prompt, but the group state changed before the instructor initiated an intervention	*Zain opened a silent on task prompt, he confirmed the behavior and was monitoring and reading the strategies when the group started talking on their own; while the prompt was correct before there was no need to intervene, so he left*
An instructor incorrectly confirmed or denied what was happening in the group	*Jenn opened a group off task prompt and denied the behavior quickly; however, while the group was talking, she did not monitor the group long enough to identify that their discussions were off topic*

Table 7.4 (Continued).

Emergent Theme of Tool Use	Example
An instructor opened a prompt, engaged in an intervention, and then confirmed or denied the behavior after the intervention was over	*Santu opened a group off task prompt, he monitored the group for a few second, identified they were silently working, and engaged in an intervention; when the intervention ended he confirmed the behavior even though they were not off task when he began the intervention*
An instructor confirmed a prompt but chose not to act on it	*Zain opened a silent on task prompt, confirmed it, spent several seconds monitoring the group and reading the strategy but eventually walked away from the group [possible not comfortable with the strategies]*
	Santu opened a group off task prompt, confirmed that it was correct, but chose not to intervene because he had just left the group 15 seconds before
A prompt appeared while an instructor was intervening – the instructor intervening, or another instructor in the classroom, denied the prompt	*Jason was in the middle of an intervention; the students were talking but he was listening to them deliberate on a question when a group off task prompt appeared for the group; he opened the prompt and denied it because he was already in an intervention*
	Lisa opened a group off task prompt for a group where Raj was already engaged in an intervention with a group so she denied the prompt
An instructor selected a prompt and something else became a priority	*Adam opened a silent on task prompt when another group flags him down with a question; after their intervention he denies the opened prompt*
	Adam opened a group off task prompt for a group when a Jenn approaches him with a technical problem with a group; he addresses the problem and then denies the prompt
An instructor accidentally opened a prompt when trying to view the group's work	*Jenn was in an intervention with a group and asked what page they were on so she could join them; she accidentally opens a silent on task prompt, confirms it [it was why she intervened with the group], and then views their work*

Another way the instructors used the CSTEPS tool was by viewing the students' work. This function of the software allowed the instructor to join a group and view and draw on their worksheet. Across all five classes, this function was used seven times (see Table 7.5). Of the TAs, Adam used this function twice; Lisa did not use it at all. However, Adam had an additional class compared to Lisa and again seemed to have more motivation for using the tool. Jenn used the *view work* function the most, and each time used it with the group to talk about something on their worksheet. Even though there were few uses of the function to view the group's work, there were few ways in which instructors used it during the class period (see Table 7.6).

Table 7.5
Number of times each instructor viewed a group's worksheet.

TA/CA	Number of Times Viewed Groups' Work
Adam	2
Lisa	0
Zain	1
Santu	0
Jason	0
Jenn	3
Casey	1
Raj	0

Table 7.6
Emergent themes of instructors' interactions with the view work function.

Emergent Theme of Tool Use	Example
An instructor used *view work* to monitor a group and engage in an intervention	*Zain opened the work of a group and stood near the table; he decided to intervene when he found an error on the worksheet*
An instructor used *view work* to join a group and work directly with them on the worksheet	*Jenn was engaged in an intervention with a group and they asked about content provided on a page of the worksheet, she asked what page it was on, viewed their work, and talked through the problem with them*

7.4 Instructors Monitoring and Interventions

To understand how the use of the CSTEPS tool affected instructors' interactions in the classroom, I analyzed and coded the amount of time they monitored and their intervention strategies. During all five classes, the instructors engaged in 150 interventions with groups (see Table 7.7). The average intervention lasted 1 minute and 54 seconds (*SD* = 2 minutes and 9 seconds) with a range from 2 seconds to 11 minutes and 27 seconds. Of the 150 interventions, 78 (52%) were initiated by an instructor and 72 (48%) were initiated by a student, where a group gestured or called for an instructor to help.

Table 7.7
Interventions by class.

Class	Total Interventions
Class 1	22
Class 2	30
Class 3	22
Class 4	42
Class 5	34

Across the instructors, there was variability in the interventions they engaged in and how they initiated them (see Table 7.8). Lisa had the most interventions compared to all the instructors, and she initiated the majority of these interventions. Santu, Jason, and Adam had a similar amount of interventions; however, Santu and Adam were more often approached by students with questions, while Jason initiated them himself. Zain had the fewest interventions, and the students initiated the majority.

Table 7.8
Interventions by instructor.

TA/CA	Total Interventions	Initiated by students (% total)	Initiated by instructor (% total)
Adam	26	17 (65%)	9 (35%)
Lisa	40	9 (23%)	31 (78%)
Zain	4	3 (75%)	1 (25%)
Santu	27	15 (56%)	12 (44%)
Jason	27	12 (44%)	15 (56%)
Jenn	12	6 (50%)	5 (42%)
Casey	8	5 (63%)	3 (38%)
Raj	7	5 (71%)	2 (29%)
Totals	*150*	*72 (48%)*	*78 (52%)*

As described in previous chapters, one goal of this project was to engage instructors in more monitoring of groups before interventions. Across all five classes, 42 interventions (28%) included at least 10 seconds of monitoring the group before intervening. Since the student interactions were instances where an instructor was called to the table, there was not always the opportunity for monitoring beforehand. Of the 78 interventions where an instructor initiated an intervention, they preceded 34 (44%) of them with monitoring. Whereas, eight (11%) of the 72 interventions initiated by a student included monitoring.

The average amount of time spent monitoring (when at least more than 10 seconds), was 21 seconds (*SD* = 11 seconds) with a range from 10 to 55 seconds. While the average intervention lasted 1 minute and 54 seconds, there was a difference in intervention times between those that had monitoring and those that did not. Interventions that had at least 10 seconds of monitoring averaged 1 minute and 19 seconds (*SD* = 1 minute and 22 seconds) with a range from 2 seconds to 6 minutes and 28 seconds. Interventions that did not include monitoring were longer, with an average of 2 minutes and 8 seconds (*SD* = 2 minutes and 22 seconds) with a range of 5 seconds to 11 minutes and 27 seconds. These results echo Shehab's (2019) findings, where he described that monitoring groups before intervening could lead to shorter, more informed interventions that can be more productive for groups.

As described above, there was more monitoring when an instructor initiated an intervention compared to when a student did because of the nature of student initiated interactions. Therefore, below I analyze monitoring that preceded the intervention initiated by the instructors (see Table 7.9). Lisa engaged in the most monitoring with 15 instances (48%) of the interventions she initiated with groups. Adam and Santu each had a high number of interventions that they initiated, however few of them included monitoring for at least 10 seconds. The remaining CAs had monitoring in about half of the interventions that they initiated. This shows that while Lisa had the most, other instructors were still monitoring groups before intervening.

Table 7.9
Interventions that were initiated by an instructor; number of interventions and monitoring by instructor.

TA/CA	Number of Interventions	Interventions with Monitoring
Adam	9	2 (22%)
Lisa	31	15 (48%)
Zain	1	1 (100%)
Santu	12	3 (25%)
Jason	15	8 (53%)
Jenn	5	2 (40%)
Casey	3	2 (67%)
Raj	2	1 (50%)
Total	*78*	*34 (44%)*

To further understand how the instructors engaged in different kinds of interventions, each intervention was categorized by how instructors' initiation and follow up moves with groups. In this analysis, I include only interventions where the instructor initiated the intervention. As shown above, there was a difference between monitoring with student and instructor initiated interventions, where there was often no opportunity to monitor when the student initiates an intervention. Additionally, when students initiate an intervention the overall focus of the interactions as different. The focus of the tool was on the instructors' monitoring and interventions. Therefore, I excluded student initiated interventions.

Using a coding scheme to identify the instructors' turns of talk as non-collaborative, implicit collaborative, or explicit collaborative during interventions (see Table 3.6), I analyze both the initiation move and follow up moves of interventions. First, I will compare initiation moves across instructors because they have been identified by past research as setting the tone for the quality of the intervention (Shehab, 2019). Then I identify the follow up turns after each initiation moves as including or not including implicit or explicit collaborative turns. According to the design of the CSTEPS tool and results of past analysis (Shehab, 2019), we want instructors to initiate interventions and follow up on them using implicit or explicit collaborative prompts (supplied from the tool and emphasized in trainings). Shehab (2019) showed that interventions that involved no collaborative turns, including explaining content, providing answers, or describing procedural steps of the problem, led to less productive conversations within groups after the intervention ended.

Additionally, past analysis of these discussion sections without the CSTEPS tool showed that instructors use a few implicit collaborative moves and no explicit collaborative moves (Shehab, 2019). Hence, the need for support. Our aim for instructors who use the tool was for them to engage in fewer non-collaborative (NC) moves and more implicit collaborative (IC) and explicit collaborative (EC). Since NC includes all turns that are not related to collaboration, some amount of NC moves were inevitable in each intervention (e.g., simple responses or revoicing what a student says. However, as shown in Shehab's analysis (2019), there were NC turns that were potentially harmful to the group's collaboration when used repeatedly, such as providing elaborated answers or instructing the student on what they should do next. The use of NC turns also limits the opportunities for TAs to support the development of collaboration skills, but using IC or EC turns can provide students with guidance about how to work together.

To understand what kind of interventions instructors engaged in, frequencies of each type of intervention are shown in Table 7.10. Of the 78 interventions, instructors initiated 51 (65%) with an NC move. 45% of those 51 were from initiated by Lisa; she also had the most interventions of any instructor. IC initiation strategies had the next most, with 25 instances making up 32% of interventions, followed by EC with two interventions (3%). Of all the types of interventions, IC and EC initiated interventions aligned with the goals of the design. There were two instances of EC initiated interventions. Lisa and Jenn had an intervention that began with an EC move. These interventions were significant because, in the past analysis of discussion sections, there were no interventions that include explicit collaborative moves (Shehab, 2019). While there were only two interventions across the five classes that begin with an EC move, this shows that some component of the tool or training that took place during this study was able to prompt instructors to use explicit collaborative strategies.

Table 7.10
Initiation strategy by instructor.

TA/CA	**Non-Collaborative**	**Implicit Collaborative**	**Explicit Collaborative**	***Total***
Adam	5	4	0	*9*
Lisa	23	7	1	*31*
Zain	1	0	0	*1*
Santu	6	6	0	*12*
Jason	10	5	0	*15*
Jenn	1	3	1	*5*
Casey	3	0	0	*3*
Raj	2	0	0	*2*
Total	*51 (65%)*	*25 (32%)*	*2 (3%)*	*78*

Comparing across instructors (see Figure 7.1), Jenn had the best proportion of IC and EC to NC interventions. She used IC to initiate the majority of her interventions, but she had both NC and EC interventions. When Zain, Casey, and Raj intervened, they always used NC moves to start the conversations with groups. These three instructors also rarely used the CSTEPS tool, having the lowest tool use besides Jason. Jason, who only opened a prompt once and did not use *view work* function, had the majority NC initiated interventions. However, one-third of his interventions were IC. Since he did express value of collaboration in his interview, this may have been part of his teaching philosophy before this study. Looking specifically at the TAs, Adam and Liz's interventions differed. Adam, similar to Santu, had similar occurrences of NC and IC with no EC initiated interventions. Lisa, however, used the NC initiation moves the majority of the time, with a few IC and one EC move. Since she also had a high number of interventions, her total interventions, the total NC initiated interventions were more than double Adam's total interventions. Corroborated with interview data and tool use analysis, this is not surprising as she placed little emphasis on collaboration and rarely used the CSTEPS tool.

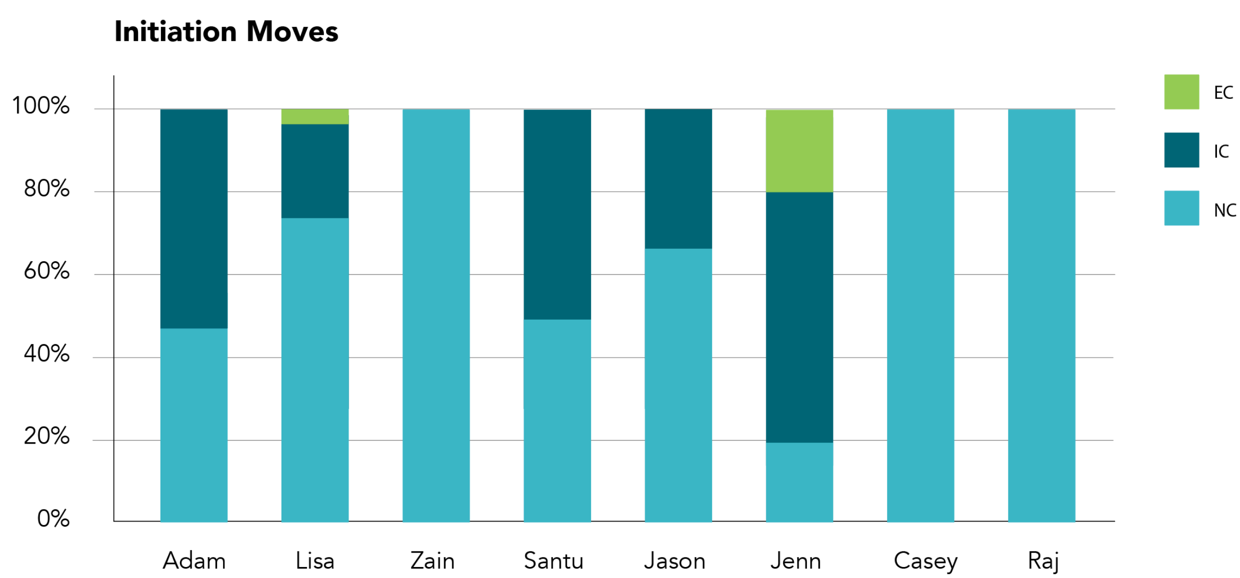

Figure 7.1: Initiation moves, with and without the CSTEPS tool.

Follow up moves were any turns of talk the instructors used after initiating an intervention. Since NC moves included all moves that were not prompting collaboration, this includes neutral moves. For example, simple responses or revoicing what someone in the group had said. This also includes potentially harmful moves for collaboration, such as telling the answer or providing the group an explicit plan of what to do next. While the purpose of this dissertation is to understand how the tool supported IC and EC initiation and follow up moves, I want to illustrate what the overall follow up moves looked like. Across all instructors and all classes, the majority of follow up moves were NC. Table 7.11 shows that all instructors engaged in more NC follow up moves than IC or EC. Only two instructors, Jason and Lisa had any EC moves.

Table 7.11
Number of turns per interaction and percent codes.

TA/CA	Non-Collaborative	Implicit Collaborative	Explicit Collaborative	*Total follow up moves*
Adam	99 (87%)	15 (13%)	0 (0%)	114
Lisa	212 (87%)	31 (12.5%)	1 (.5%)	244
Zain	21 (95%)	1 (5%)	0 (0%)	22
Santu	124 (91%)	12 (9%)	0 (0%)	136
Jason	145 (85%)	25 (15%)	1 (1%)	171
Jenn	37 (90%)	4 (10%)	0 (0%)	41
Casey	10 (100%)	0 (0%)	0 (0%)	10
Raj	5(100%)	0 (0%)	0 (0%)	5

Matching their initiation moves, Casey and Raj used only NC follow up moves. Jason overall had the highest percentage of IC follow up moves. While the TAs do have the same percentage of NC moves, it is important to note that Lisa had 244 total follow up moves, whereas Adam had 114. Proportionately they had similar amounts, although Lisa had significantly more follow up moves compared to all other instructors (see Figure 7.2).

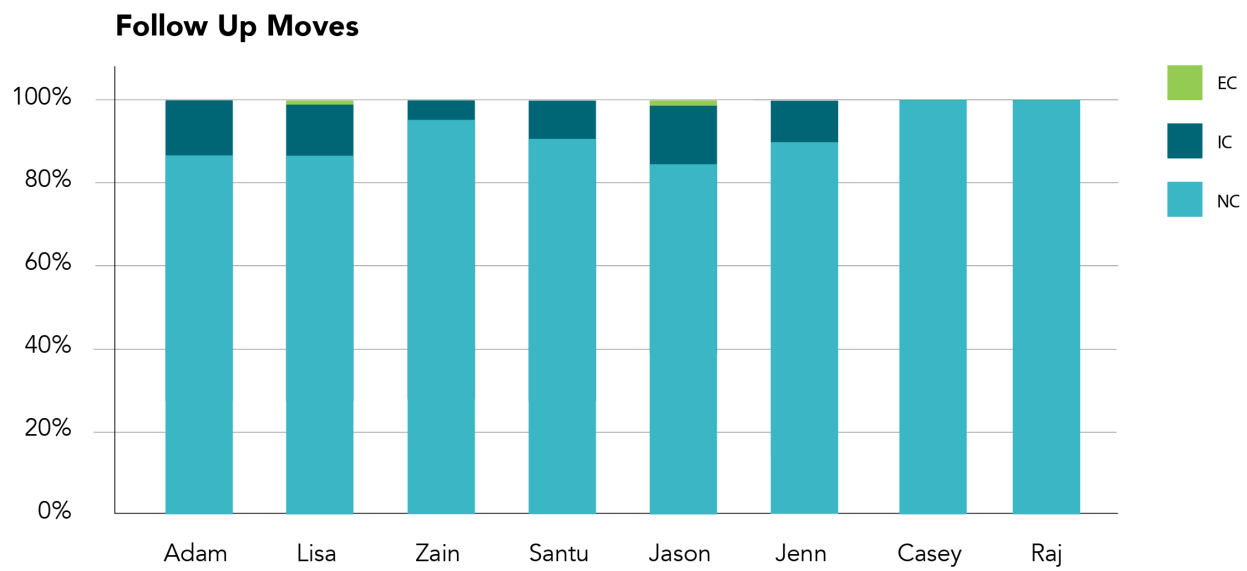

Figure 7.2: Follow up moves, with and without the CSTEPS tool.

These findings show that there were differences in how instructors initiated and followed up with students during interventions and what monitoring and intervention times looked like. To understand how the tool affected those differences, I compare this data by instances where the instructors used and did not use the tool.

7.5 CSTEPS Tool's Impact on Instructors Monitoring and Interventions

To understand how the technology influenced the instructor's interactions with groups of students, I will discuss the comparison of their monitoring and intervention strategies with and without the CSTEPS tool. In this analysis, as well as the analysis above, I include interventions where the instructor initiated the intervention. In addition to the difference in monitoring, I only use instructor initiated interventions because when they used the CSTEPS tool the prompts should be used in the initiation move as well as throughout the intervention. Meaning when an instructor clicks a prompt and intervenes, the strategies supplied in the tool should be fresh and have a direct impact on their intervention. To understand if the tool was useful in monitoring, initiating, and sustaining interventions, those that were initiated by students were excluded from this analysis.

The instructors used the CSTEPS tool 85 times across all five classes; instructors opened a prompt 78 times and seven were viewing the work of a group. Of the 78 prompts opened by instructors, 11 resulted in an instructor engaging in an intervention with a group. Two of the seven times, an instructor viewed the group's work resulting in an intervention. One of the interventions included two instances of tool use; during one intervention with a group Jenn viewed a prompt and used the *view work* function while interacting with them.

Comparing monitoring and intervention times between interventions where instructors used the tool and those that did not, did not reveal significant differences. Seven out of 12 interventions (58%) that included the CSTEPS tool had monitoring for at least 10 seconds. Twenty-seven of the 66 interventions (41%) without the tool included at least 10 seconds of monitoring by instructors. However, while the percentage of monitoring was higher for interventions that included the tool, instructors monitored for longer when not using the tool. Instructors monitored an average of 17 seconds (*SD* = 8) with a range from 10 to 33 seconds when using the CSTEPS tool; instructors that did not use the CSTEPS tool during interventions monitored 22 seconds (*SD* = 12) with a range from 12 to 55 seconds. When using the tool, interventions lasted an average of 1 minute and 38 seconds (*SD* = 1 minute and 21 seconds) with a range from 2 seconds to 4 minutes and 26 seconds. Interventions, when instructors did not use the CSTEPS tool, lasted 1 minute and 34 seconds (*SD* = 1 minute and 58 seconds) with a range from 5 seconds to 10 minutes and 40 seconds. These results show that there does not seem to be a relationship between the CSTEPS tool and the length of monitoring and interventions.

Across all instructors, Jenn and Santu had the most interventions that involved the CSTEPS tool (see Table 7.12). Both Santu and Jenn were in their second semester as CAs and expressed interest and value to collaboration in discussion sections, which may have improved their desire to use the tool. In half of Jenn's interventions, she used the *view work* function, whereas all of Santu's were from prompts. Of the remaining CAs, Zain engaged in one intervention while using the *view work* function, and the remaining CAs, Jason, Casey, and Raj, did not have any interventions with the tool. Casey and Raj had few interventions, few instances of tool use, and also expressed little to no value on collaboration during interview responses. Jason, however, did illustrate some value on collaboration in interviews and initiated 15 interventions, but only used the tool once, leaving little opportunity to have an intervention with the tool.

Table 7.12
Interventions initiated by instructor and number and percentage of those that involved the tool.

TA/CA	Intervention initiated by instructor	Interventions preceded by tool use	View work	Prompt
Adam	9	3 (33%)	0	3
Lisa	31	1 (3%)	0	1
Zain	1	1 (100%)	1	0
Santu	12	4 (33%)	0	4
Jason	15	0 (0%)	0	0
Jenn	5	4 (80%)	2	2
Casey	3	0 (0%)	0	0
Raj	2	0 (0%)	0	0
Total	*78*	*13 (17%)*	*2*	*11*

I also compare intervention categories for the presence of implicit and explicit collaboration moves to identify if the prompts presented in the tool were influential in the instructor's interventions. I argue that interventions that started with implicit or explicit collaboration when the instructor had been using the tool had a more direct impact from the tool. Since the prompts were asking instructors to monitor then intervene with a strategy, the most likely turn to be IC or EC was the initiation move. After the intervention started the instructor could still use IC or EC moves; however, instructors were engrossed in conversation with the group, and were not continuously looking at the strategies.

Results show that most of the instructors' interventions that included the tool were initiated with an IC move (see Table 7.13). This indicates that the tool prompted instructors to begin interventions by probing the group to share what they were doing or explain their reasoning about what they are working on. While there were not enough interventions that included the tool to run statistics on this data, however, Figure 7.3 illustrates the difference across interventions with and without the CSTEPS tool.

Table 7.13
Initiation moves by instructor for each intervention.

	NC	IC	EC	*Total*
Interventions with Tool	4 (33%)	7 (59%)	1 (8%)	*12*
Interventions without Tool	47 (71%)	18 (27%)	1 (2%)	*66*

Comparing percent of the total moves that did and did not use the CSTEPS tool, interventions where the instructor used the tool was prompted more with IC compared to without the tool. Interventions initiated with the tool also had fewer initiation moves with NC. This comparison shows that when the tool was used, it was more likely to prompt IC or EC initiation moves than NC moves.

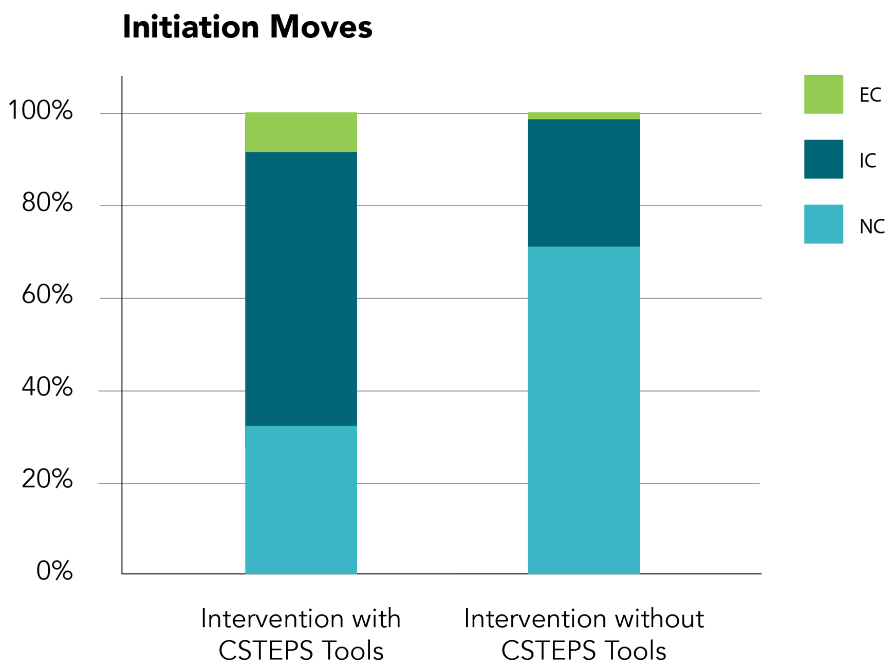

Figure 7.3: Initiation moves, with and without the CSTEPS tool.

When comparing follow up moves, again, there were too few follow up moves with the tool to compare to follow up moves without the tool (see Table 7.14). Interventions without the CSTEPS tool had a total of 621 follow up moves; interventions with the tool had 122 follow up moves. Figure 7.4 shows the comparison of percentages between the two. While there was little difference between the two, interventions with the tool did have more follow up moves that were IC compared to interventions without the tool. Overall, considering that few of the turns were NC, the difference between IC moves in Figure 7.4 does show that the difference may have been caused by the tool. Generally, however, instructors were better at prompting for IC and EC moves during initiation moves compared to follow up moves.

Table 7.14
Follow up moves by tool use and no tool use.

TA/CA	NC	IC	EC	*Total*
Intervention with Tool	103	19	0	*122*
Interventions without Tool	550	69	2	*621*

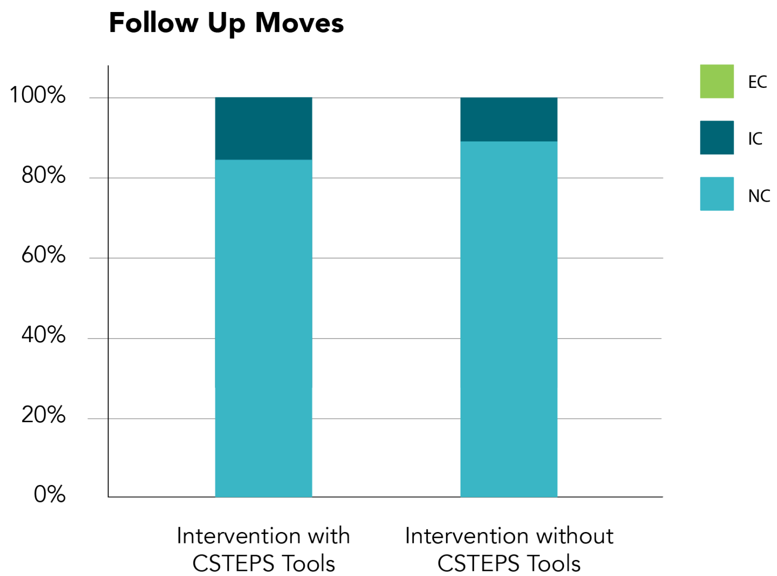

Figure 7.4: Follow up moves, with and without the CSTEPS tool.

To further explain how the tool was used during these interventions, below, I will break down each of the 13 cases from 12 interventions and discuss the application of these strategies across the interventions. Table 7.15 shows the 13 uses of the tool, including the intervention number, instructor, type of tool use, intervention category, and monitoring time. Of the 13 times the tool was used, five times (38%) were group off task prompts, six (46%) were silent on task prompts, and two were cases where the instructor viewed the group's work. Seven of the 12 interventions (58%) that included the use of the CSTEPS tool had monitoring that was at least 10 seconds long. The tool may have prompted some instructors to monitor, but it was not consistently effective.

Table 7.15
Interventions initiated by instructor and number and percentage of those that involved the tool.

Intervention	TA/CA	Type of Tool Use	Initiation Move	Monitoring Time (seconds)
1	Adam	Group off task	IC	10
2	Adam	Group off task	IC	6
3	Zain	View Work	NC	33
4	Santu	Group off task	IC	3
5	Jenn*	Silent on task	IC	9
5	Jenn*	View Work	IC	9
6	Jenn	Silent on task	EC	17
7	Adam	Group off task	IC	6
8	Jenn	Silent on task	IC	19
9	Santu	Silent on task	IC	15
10	Lisa	Silent on task	NC	16
11	Santu	Group off task	IC	10
12	Santu	Silent on task	IC	0

*These two tool uses by Jenn were used during one intervention

Themes emerged from these interventions based on how instructors used the CSTEPS tool. I describe each of these 12 interventions across four themes, explicit tool use, exemplar implicit tool use, neutral implicit tool use, and no tool use. In each section below, I will outline the themes, illustrate examples within each, and describe overall trends of how the instructors used the tool.

7.5.1 Explicit Tool Use.

Explicit tool use interventions were ones where the instructor explicitly used a strategy the tool presented during their intervention. Two of the 12 interventions had explicit tool use.

Intervention 6. Twenty minutes into class, Jenn received and clicked a prompt within the CSTEPS tool. Jenn walked to the group, confirmed the prompt, and monitored the group for 17 seconds. During these 17 seconds, she read the strategies and looked back and forth to the group, indicating she was trying to decide what to say before initiating the intervention.

Jenn	You good? Is everyone on the same page?
Student 1	Uh, yeah just about.
Jenn	Well, is everything making sense?
Student 1	Just adding up all the… [glances at other student's tablet] Wait, what are you looking at?
Student 2	The reference sheet.
Student 1	The what sheet?
Student 2	Reference [Jenn leaves the group]
Student 1	What's the difference?

In this intervention, Jenn used an EC initiation move that was presented to her in the CSTEPS tool. The tool prompted her to make sure that everyone was on the same page and working together. By asking the group if they were on the same page make it explicit that the students should be on the same page. While her intervention did not lead her to provide the group with more support, it does get one student to notice they were not working on the same page. This kickstarted a discussion among the previously silent on task group about where they were each person was on the task and what they were doing. Jenn also decided that since the group was talking, it was time to leave rather than stay and continue the intervention. This intervention was a prime example of the way the tool the team expected instructors to use the CSTEPS tool: provide an instructor with strategies and have them implemented in a way that sparks discussion among a group.

Intervention 11. During the 11th intervention with the tool, Santu received a group off task prompt with two minutes remaining in the 5th class. Instead of trying to finish their problems the group had become off task. Santu arrived at the table after clicking prompt; he confirmed the off topic behavior and monitored the group for 10 seconds. As he monitors, still a little ways away from the table, one student asked, "What can we accomplish in two minutes?" Another student responded, "literally nothing." Santu, observing this interaction, responds,

> "So, just really quickly, if I tell you guys sigma X ends up being a positive value, sigma Y would be a negative value, how are you gonna draw that stress on it?"

This initiation move was an IC move, because while it was content related he explored the students' understanding of a topic rather than asking about a specific answer. Santu probed them with questions and engaged the group in task related conversations for 2 minutes and 9 seconds. A minute into the discussion, Santu identified a misconception within the group.

Student 1	That slope...?
Santu	This is the exact opposite, so this would be going this way, um this is this way, and then they both go [draws the direction on the table].
Student 2	I didn't know that.
Student 3	That actually helps.
Santu	And if this is Y, this is when this is the axis. So if we rotate it, we have to rotate everything with it.
Student 1	Ah yeah, yeah.

Here Santu explained the concept, after several IC moves that he used to identify the misconception. In this intervention, Santu used a strategy supplied in the tool–to ask questions about their discussion to bring them back on task but prompt the group to discuss the topic do not to provide elaborated answers. Rather than asking a general question, he used a content related question to bring them on task and promoted discussion within the group. He probed them and did not provide elaborated responses, until the misconception was identified. This was an example of an intervention that was supported by the tool but was also adapted by the instructor. Santu developed his own question to get them back on task and spark discussion among a group.

These two examples illustrate how an instructor used the tool to identify a group that required an intervention and implemented the strategies provided by the tool to support their initiation and follow up moves. Although infrequently, these interventions show that the tool was used how it was intended, and it was capable to support students' discussions.

7.5.2 Exemplar implicit tool use.

Implicit tool use shows times where the tool prompted the instructors to implement implicit collaborative moves, however, not explicitly from what the tool was asking. In these cases, the tool may have affected what the instructors asked or prompted. These exemplar cases of implicit tool use represent cases where the instructor engaged in an intervention using IC moves to either get the group back on task or end a period of silent on task work.

Intervention 1. In the first intervention, Adam used a group off task prompt to intervene with a group. This intervention took place 41 minutes into the first class and three of the four students in the group had been off task for a few minutes preceding Adam's arrival to the table with the fourth student working silently. Adam opened the group's prompt, walked over to the table and monitored the group for 10 seconds before confirming the prompt. The group got quiet as Adam stands by the table, and he asked, "having trouble with the worksheet?" This initiation move was coded as IC, where Adam was asking an open ended question to try and prompt the group to talk. One member of the group who was off task responds to him, “I’m making… we’re almost ready…”, followed by a few seconds of silence across the group. Another member of the group, who had not been engaged in the off topic conversations with the other three group members, responded to Anthony, “So I have got a question…” The total intervention lasts 3 minutes and 6 seconds, during that time the remainder of Adam’s moves were coded as NC. First, he explained content that one student was struggling with. The majority of the intervention was not related to the worksheet, but he answered questions about other components of the course with the whole group. In this first intervention, Adam used the tool to monitor and identify a group that was off task and intervene to get them back on task. While his intervention had mostly NC moves, he got the students back on task when he left the group.

Intervention 5. In the fifth intervention, Jenn used the technology in two ways, one of which was accidental. Fourteen minutes into the second class, Jenn walked by a group of three students that was silently working. She monitored them without a prompt from the tool for 6 seconds and then asked them how they were doing. One group member responded and said, “we’re good”, to which another member of the team admits, “I’m not.” The first student then asked a question about a table on the worksheet. She started to talk about it and explained that she would open it on her tablet. Rather than clicking the *view work* button, Jenn missed and clicked the prompt. She confirmed that they were silent on task, which was why she intervened, closed the prompt, and opened the *view work* function for the group. She pulled up the table, paused for a moment as she glanced over it, and asked the group a question,

Jenn	The table system's like the um… symbolic reference for the stress element so… Is it zero or is it nonzero?
Student 1	So they want it in terms of PX and PY?
Jenn	They didn't say exactly what it needs to be in terms of, but yes.

Student 1	They do want it?
Jenn	It's like the- pretty much you're gonna say if its zero or not zero, what are like what, um… how would you solve for it? Which is some.. like if it's torque like an r cross x you know what I mean? Something like that…
Student 2	Oh! Okay
Student 3	That is better
Jenn	Yeah

In this intervention, Jenn tried to prompt the students to identify if it was zero or not. The students did not answer her but asked a follow up question. She answered their question, however, did not provide an exact answer to the problem. She gave them an example and described that they still needed to identify if it was zero and then explained how they would solve for it. In doing so, she engaged all three group members. This was an example of how mistakes can happen in using the technology in the classroom, and also how the *view work* function helped an instructor get a closer look at what the students were doing so that they could make informed interventions. In this case, Jenn got them talking to each other without providing them with an answer and gave them something to talk about when she left.

Intervention 7. Thirty minutes into class two, Adam received a group off task prompt about a group of three students. He clicked the prompt, walked to the table, and monitored for six seconds. While intervening, Adam caught part of a conversation between the three students. Adam arrived at the table as student one asked his question to his group, to which he responds to.

Student 1	Wait, for this… what could be the relation between [Adam arrives] like the X and the Y moments and shear stress are related… I don't know how they are related
Adam	What do we call a moment acting perpendicular to the direction?
Student 2	Torsion
Student 3	It's like a twist

Adam	Torsion. Do we have a way to relate torque to a shear stress? You may not remember it was earlier in the semester…
Student 1	I don't, I don't…
Adam	Look on the equation sheet, see if that will spark your memory.

Adam intervened by asking the group a question about the content that was related to the question. His question was coded as an IC move because he was prompting to further explore what the students know. They responded to his question, and he asked another question, which they did not know the answer to. He then prompted them to look at the equation sheet. Adam left the group and confirmed the group off task prompt, even though the group was on task before and after the intervention. Adam did not confirm or deny the behavior before intervening, which meant he missed the strategies before intervening. However, he engaged the group to start talking and used all IC moves except for his last turn when he suggested where the students should look for the answer. Here, he prompted the students where to look but did not take away the collaborative opportunity by giving them the answer. Instead, he likely used his experience teaching and knowledge about collaboration to leverage the students' discussions so that they continued after he left the group. This case illustrates ways in which the context of the project may have influenced his intervention. However, because Adam did not confirm or deny the prompt, he was not provided with collaborative support to intervene but engaged in an interaction that got the group talking and back on task.

Intervention 12. Santu engaged in an intervention with a group of three students 32 minutes into class. After clicking on a silent on task prompt, he confirmed, quickly glanced at the strategies, and walked up to the group. He then asked the group what they were working on so far. After his IC initiation move, he has several follow up moves that were NC as he responds "yeah" and "alright" while one student explains what the group was doing. Then student one asks Santu a question and which he responds to with a question.

Santu	Okay, so what are the three possible normal stresses that could ever exist?
Student 1	Um, so it would be caused by the load in the axial direction.
Santu	Okay so the axial force?
Student 1	And then um two moments in bending.
Santu	So- that's actually- so a bending stress, that's one type of stress right? So basically there's one due to force, axial force, one due to bending, and one more that… [pause for a student to finish the sentence].
Student 2	Pressure.
Santu	Pressure, exactly, right! So look into pressure, both y and x will end up having stresses due to pressure and that should be the only stress for X. Does that make sense?
Student 1	Yeah

In this intervention Santu prompted discussion among the group members by asking questions about content and leaving gaps in what he was saying so that students in the group could engage in the conversation. This shows that his use of the tool prompted him to intervene and may have influenced his follow up moves as they align with the strategies in the tool. Santu's intervention prompted the group to talk, and they continued to talk after he left the group.

7.5.3 Neutral, Implicit Tool Use.

Cases of implicit tool use show that the instructors implemented some kind of IC moves in their intervention with students. However, not all cases had IC moves or prompted the groups to get back on task or work together. Below I describe neutral implicit tool use cases where an instructor used IC moves to initiate a discussion, but the outcome of the intervention did not get the students back on task or talking.

Intervention 2. Forty-five minutes into the class, a group of four students was off task. Two of the students were talking about something unrelated to the task, one was scribbling on the tablet, and the fourth was staring off into space. Adam received a notification through the tablet, selected the group off task prompt, and walked over to the group. He stood next to the group for 6 seconds, approved the prompt, and intervened by asking the group what they were working on. By prompting them to explain what was going on in their group, he used an IC move to get the group talking. He followed up on his initiation move with more IC moves by asking the group if they remembered discussing stress formations in the lecture and asked one of them to explain what it is. By prompting this, two of the group members engaged in discussions with him. He identified a point of confusion about stress formations and provided the group with a long, elaborated explanation. In total, the intervention lasted 3 minutes and 20 seconds. The majority of the time was Adam explaining and “mhmm” and “okay” responses from the group. While the CSTEPS tool brought him to the group and prompted him to engage the group in discussion, he spent the majority of the discussion with all NC moves, specifically elaborated explanations that did not prompt any additional discussion from the group. Upon leaving, the group immediately went back to their off task behaviors. This intervention illustrates that the tool facilitated IC initiation move, and some follow up moves, but Adam still used mostly NC moves to follow through the intervention. In this case, the wrap up of the intervention closed off the conversation and left the group off task.

Intervention 4. Forty-eight minutes into the class Santu received a group off task prompt. This group received an intervention from Zain (intervention three described below) a few minutes before Santu came to the table. The group off task prompt was correct, one group member was on his phone and the other was staring off. After receiving the prompt, Santu intervened before confirming or denying the prompt, therefore, missing the strategies. He asked the group how they were doing, and one group member asked him a question. Over a minute and 14 seconds, Santu spent the entire time explaining a concept and how to solve a part of the problem to the student who asked the question. During this time the other group member sat silently scrolling on his tablet. In this intervention, Santu's initiation move was IC, but he followed it with all NC moves where he explicitly described what the student should do. Santu's interaction with this group mirrors Zain's experience, described below. Santu spoke to the group member who asked the question but did not include the other group member who sat quietly working on his tablet. This shows a missed opportunity to engage the two group members in discussion to see if the silent group member had an answer to his question, which would have been the strategies he received had he confirmed the prompt before intervening. This case conveys that the instructors did not always use the tool as expected, making it unclear if the strategies presented in the tool would have been helpful to remind Santu to include the second silent student into the discussion.

Intervention 8. Seventeen minutes into class Jenn was monitoring a group when she received a prompt from the CSTEPS tool. While still standing by the table, she opened the prompt and read that it was silent on task. The students in this group split themselves up. Two group members who were closest to Jenn were talking to each other and working on the task, while the two members furthest from Jenn on the other side of the table were silent and not engaging. Jenn monitored for a total of 19 seconds. After she confirmed the prompts and glanced at the strategies, she moved to the other side of the table where the two quiet group members were seated. She addressed the two group members with an IC move asking, “how are you guys doing?” One of the group members acknowledges her and responds “good” as the other member stays silent. They do not turn or attempt to engage with her beyond this. She responds to the group member and says, “good” but stand by the table for 13 seconds before leaving. In this example, Jenn tries to prompt the two members of the group who were not working with the group, but they were not willing to talk to her. She used the prompt to identify who needed help; however, did not prompt the group members after they did not seem to be interested in talking with her. The tool prompted to her monitor and intervene, but the unwillingness of the students did not help her in trying to support their conversations. Additionally, while Jenn confirmed that the group was silent on task, only half of the group was. Her confirm selection was not wrong, but this illustrates times where the confirm and deny may be challenging to choose between when a group was split like this case.

Intervention 9. Twenty-six minutes into class, Santu arrived at a table after selecting the silent on task prompt from the tool. After monitoring for 15 seconds, he confirmed that the prompt was correct, and after closing the prompt monitored for a few more seconds before intervening. His intervention starts with an IC move, where he comments on the student’s work but asked them how they got there.

Santu	So you guys are really close um your values are correct it's just your signs are off so like FX shouldn't just equal to PX and then AX. So, I feel like the reason that's probably occurring is because there's probably a problem in the sign convention. So how are you guys going about figuring out what's positive and negative in your equation?
Student 1	So, yeah, so FX is pointing this way, FY is pointing this way, and PY is also pointing in the same direction.

Santu	Okay so that's very common to want to do that but if you look at it, that's the sign convention for positive cut and your forces PX and PY actually in the negative cut. So it's like two opposite sides. So if you wanted to use this side of it, you would have to use the reaction forces at the corner where it's pinned in. But I would say there's an easier way is actually to work on this side of the cut and the positive reactions are just the opposite of this.
Student 1	Gotcha
Santu	So that's like the gist of everything there is because then you'd see that FX is positive going downwards on this one, FX is positive going upwards on the other one and so then you have FX minus PX equals zero, so you have FX equals PX. Does that make a bit more sense?
Student 2	Yup
Student 3	Yeah
Santu	Cool sounds good.

In this intervention, Santu gave elaborated NC moves after his IC intervention. The tool prompted him to use IC strategies to encourage the group to talk, although, he asked one IC question but does not bring these through the follow up moves. In fact, when Santu left, one group member said, “I wish he didn’t explain it like that” and the group discussed how they did not understand what was positive or negative. Had Santu done more prompting for the group to explain rather than explaining himself, he may have identified that the group was still not understanding. The tool did engage Santu to bring the group out of the silent on task state, because upon leaving the group discussed the different sign conventions for several minutes as a group.

In these four cases of neutral, implicit tool use the instructors used IC moves to initiate the interventions but did not wrap up the intervention in a productive way. The tool supported these interventions from the beginning but indicated some gaps in how the CSTEPS tool supports instructors throughout the intervention.

7.5.4 Content Focused Tool Use.

The last two cases where the CSTEPS tool was used to intervene did not have any explicit or implicit implementation of the tool. In both cases described below, the instructors used the tool but only used NC moves that focused on content.

Intervention 3. The third use of the tool was Zain's only interaction with the tool during his class; in this intervention, he used the *view work* to intervene. A group of two students was working silently 42 minutes into the first class. This group was the same group that Santu interacted with in fourth intervention; Zain's intervention took place a few minutes before Santu's. Zain approached the group, monitored them for 10 seconds and then opened their work on his tablet. For 23 seconds Zain paced slightly away from the table with his back turned before turning back around and addressing the group. He says, "Did you guys get the answer for 5 and 6?" This was coded as an NC initiation move because he was asking an explicit content related question. One of the group members responds, "For 5? Is that correct?" as he gestures toward his tablet. Zain pulls out his phone to reference the solutions, during which he identifies an incorrect answer. In this intervention, Zain has one IC move. While comparing his solution to their answers, he gets frustrated,

> "I got negative 185… I got 3000… hmm. Wait, this is just incorrect… Say… ok you got negative… I'm just not gonna… how did you get negative 185?"

This was an IC move because he was prompting the group to explain how they got their answer. However, he asked only one group member, and the second student in the group remained quiet. Through the rest of the intervention, the student explained what he did and how he got the answer. Zain responded with “yeah” and “mhmm” to invite him to continue talking, which were all coded as NC. Finally, Zain identified the mistake and explained how they should do the problem before leaving the group. During this intervention, Zain only talked to one students; the second student remained silently working on his tablet. This intervention mirrors Santu’s interactions with the group in intervention three. Zain used the technology to initiate the group with an NC move focused on the content of the worksheet. While he has one IC move that engaged one student in discussion, the second student did not engage. This intervention illustrates problems that arise with interventions that were focused on content and identifies missed areas to promote collaboration within group members.

Intervention 10. Lisa’s only intervention using the tool was similar to Zain’s. Fourteen minutes into class, Lisa received a silent on task prompt, she opened the prompt, went to the group and monitored for 16 seconds. Before confirming or denying the prompt, she decided to intervene using an NC initiation move to start the intervention, “Are you guys solving for the moments right now?” The intervention lasts for 23 seconds, where Lisa instructs them to go back and solve the problem on page two rather than jumping to the table on page three. Lisa’s four follow up moves were all coded as NC. After leaving, one student asks another, “Ok, what are we supposed to be doing then?” The group became off topic when they realize they were unsure of what to do next. After Lisa leaves the group, she denies that the group was silent on task. The CSTEPS tool prompted her to go and monitor the group, but she did not deny the prompt, meaning they were working together on task. Instead she engaged in a content related intervention that caused the group to go off task. This was one of the few times Lisa used the tool in the class. She did not use it to prompt collaboration but used it in a way that aligned with her goals for the students.

7.6 Post-Interview Analysis

As described above, each TA and CA had different approaches regarding how they used the tool, monitored and intervened with groups, and viewed their jobs. While these approaches illustrate how they used the CSTEPS tool in the classroom, I also collected interview data after the instructors had used the tool for several weeks to better understand how the instructors made decisions with the CSTEPS tool in the classrooms. In these interviews, the instructors reflected on how they used the tool and any challenges they faced. Using narrative analysis, below, I describe instructors' responses to interview questions.

7.6.1 Post-Interview Analysis: Teaching Assistants

Overall, Adam used the tool quite often in his classroom, had a few supportive interventions using the tool, did not engage in monitoring and indicated a positive perspective of collaboration over the course of this study. In his interview, I asked him to reflect on how he used the tool during the classes. He described, "[I] used it to supplement my assessment of if a group needs help." He elaborated that he preferred his second two sections because he could set the tablet down in the middle of the classroom at an empty table and glance at it as he moved throughout the room. When provided a prompt and asked to monitor, he explained that he would go to the table to monitor and had one of three interactions every time. He either monitored and prompted the group with an open ended question, the group started talking or got back on task because he was standing near the table, or a student would ask him a question. In his experience in this classroom and on the larger project, he explained that if a group started talking naturally, he would not intervene. He described that he tried especially hard to be conservative with interventions because he has learned that they can be disruptive to students. However, sometimes they were necessary if students cannot get themselves back on track. When asked how he used the strategies within the tool, he explained that the explicit collaborative prompts felt confrontational, and he was not comfortable using them verbatim. However, he clarified that the reminder from the prompts was helpful to know that he should not be doing all the talking during interventions and that he needed to prompt the groups to talk among themselves. Finally, Adam said that during class, he used the prompts but did not use the *view work* as he had done in the past implementation.

Comparing Adam and Lisa's post interviews, Lisa had a lot more to say about the nature of the project and collaboration in discussion sections. Initially, during the interview, Lisa described that collaboration was a valuable piece of discussion sections, but that does not mean that collaboration was implemented equally in all discussion sections. She explained that in her classes, there were instances the tool prompted her that would not be a priority in a normal discussion section,

> "[the tool] specifically drew me to one table, where I know they are good workers, but I think their collaboration could be better. In a normal classroom setting I would probably ignore that. It's only because we're doing this study that I pay attention, or even address the group."

She elaborated that there were times the tool was wrong because another instructor was with the group. Although she described one group, who seemed to be doing fine that the tool continuously prompted about, was never on the same page to the point that a few students in the group were lost and not doing well with the content. She was surprised the tool was capturing this and did not identify it for a few weeks. The remainder of her interview, I asked questions about how she monitored and intervened with groups; she described several issues with the technology. First, she explained that the prompts do not work for groups who are not struggling with the content, “you can’t say to a group, ‘ask your group member how to do that’ if they all know how to do it.” Groups who understand the content were never the focus of her interventions. To her, groups that were struggling with the content need more direct content interventions compared to groups that do not have good collaboration skills. In the group she described above, she explained that she was continuously pulled to that table because of the tool. However, she felt her interventions were more necessary for other groups who were struggling with the content. My final questions for her were centered around using the prompts and *view work* functions. She did not use the *view work* function; she described that this was because she felt more comfortable looking and pointing to the students’ tablets. She did use the prompts, but never the strategies. During her interventions, she explained that she would receive the prompt and go monitor, as she does in all in classes, and engage in an intervention if necessary. She never confirmed or denied a prompt because during monitoring, she turned her attention toward the group, not the tool. If she confirmed a prompt, she dismissed the strategies because the intervention was over anyway. These findings show there may be issues with the user experience for some instructors.

7.6.2 Post-Interview Analysis: Course Assistants

Overall the CA’s interviews were shorter than the TA’s; Zain’s was one of the shortest. The data analysis above shows that Zain, who was a CA in one class, had the fewest interventions of any instructor, he rarely used the tool, and the intervention where he used the tool was content focused. In Zain’s interview, he explained that he primarily used the *view work* the most, but in general, he had trouble remembering to use the tool. He could think of one case, he used a prompt and described that as he was standing by the group, they started talking after he confirmed the silent on task prompt, so he did not intervene. Throughout the interview, he seemed hesitant in talking about the tool. He expanded on this toward the end when he explained he did not feel comfortable using the prompts. He found the prompts to be a good reminder but did not use any during the courses he had the tool.

This group of instructors shows the range of comfort level with the CSTEPS tool. In Santu's interview he described his challenges but excitement about the tool. Santu found the tool challenging to integrate at first, because it was clear to him that he was looking for content errors in the past but felt his comfort with the tool increase over time. He said, "[the tool] helped me figure out where I've got to be going, because usually I'm just walking around hoping someone raises their hand or a I see some sort of big mistake." He elaborated that even when the tool was wrong, it often brought him to groups that would ask him questions or bring up a concern. He thought that the tool guided him rather than arbitrarily roaming around the room, hoping something happened. Finally, he thought the prompts were a good reminder that the goal was to get students to talk. However, he preferred using his methods of interventions rather than explicitly using the language provided in the strategies, showing the tool did not match the TA's perceptions.

During Jason's interview, he described that he mostly used the *view work* function more than prompts embedded in the tool. He found the *view work* helpful because he could see exactly what students were doing. However, he explained that it was not that he did not want to use the prompts, but that Jenn was often too good at selecting the prompts before he was able to. Jenn, who was in both of his classes, opened nine prompts to Jason's one. While this was Jason's hypothesis, results from above indicate that Adam, who was the TA for both of his discussion sections, also had a high number of prompts open, possibly leaving less for the others. Jason also echoed some themes identified in both Zain and Santu's interviews about the prompts themselves. He explained that even when he got a prompt, he chose to initiate interventions with more open ended questions rather than the strategies provided in the tool. In his opinion, opened ended questions provided more dialogue with students than the prompts to identify what they needed help with.

Jenn, who was in both of her classes with Jason and Adam, used the tool often, engaged in fewer interventions than Adam and Jason, and also had one of the explicit tool use interventions. Her interview was one of the longest among the CAs. Similar to Santu, she expressed value in the tool because it helped her identify where to go rather than walking aimlessly around the classroom, hoping someone needs help. She explained that there were several times the tool was wrong, where another instructor was already with the group or the students were talking on task, but she did not find it discouraging to use. The aspect of the tool she found most useful was the *view work* function. She described that during her discussion sections in the past, she would carry around a piece of paper and pencil to sketch things out with groups, so she had a smooth transition between that and the new format in the tool. Similar to several other instructors, she too found the prompts too formal and not in a language that she would use with students. She prefers more informal interventions and that she only intervenes about group interactions when a group has consistent bad group behaviors. However, even then, it was awkward for her to do so.

Casey, who had one class, had few interventions and instances of tool use. Casey described that he used the tool by carrying it around the classroom but found it hard to strike a balance between looking at the tablet and the classroom. He illustrated this by describing times where he was focused on the tablet while a student was raising their hand. With some confusion, he had a hard time remembering how he used the prompts and if he confirmed any or not. Which was clarified later when he realized he was not sure where the strategies were in the tool and began asking questions about how to find them. The analysis above confirms this, showing that of the three prompts he clicked, he declined them all; therefore, he never saw a strategy. Finally, he explained that he used the view student work function, but often found it simpler to point or write on a student's screen.

Finally, Raj, who was very similar to Casey, was a CA in one section and had infrequent interventions and tool use. At the beginning of the interview, I asked Raj to describe how he used the tool in the classroom. He responded, "actually, I don't quite use the tool. Because, from my looking, all of the groups are participating very well." He elaborated that the tool was heavy to carry and that when he selected prompts, they were always wrong. He reflected that of the two prompts, he could remember one was incorrect because there was another instructor at the table, and the other time, the group was talking when the tool said they were not. Raj wrapped up by explaining that he did not engage in interventions with the tool and that he decided not to use the *view work* function because it was easier for him to point at a student's tablet.

7.7 Takeaways

7.7.1 Takeaway #1

When the CSTEPS tool was used, it was effective at prompting implicit and explicit interventions from instructors. Meaning when the instructors used the real-time provided strategies their interventions were more collaborative compared to interventions without. However, there was minimal use of the CSTEPS tool in the week analyzed. Additionally, only two of the interventions that included the CSTEPS tool were explicit collaborative interventions.

7.7.2 Takeaway #2

The instructors' philosophies of teaching matter for how/if they used the tool. If the instructors had little experience with collaboration or held conflicting understanding or expectations about collaboration, then they exhibited little interaction with the tool. This misalignment between the goals and pedagogical approaches of some of the instructors and the research team shows that there is more reform within this engineering course system, as was one of the initial goals for this sequence of goals. Instructors who used the tool and found it useful were ones who either had positive experiences with collaboration or were familiar with collaborative teaching before this implementation. However, interview responses show that overall, all instructors were uncomfortable prompting for collaboration; even the instructors who were highly motivated and used the CSTEPS tool.

7.7.3 Takeaway #3

While monitoring was identified as an important component of the design process and past iterations of analysis (Shehab, 2019), interventions that had monitoring did not lead to better collaborative interventions. Interventions that had monitoring were shorter in time compared to interventions without; as past research showed that shorter interventions were better for the quality of collaboration. However, interventions with monitoring had lower collaborative interactions. While this is true, the majority of interventions with monitoring were from Lisa. Lisa had shorter, less collaborative interventions compared to other instructors. While monitoring maybe an important characteristic for collaborative interventions, numerical values is not enough to depict *what* is being monitored for. Additionally, the monitoring prompts in the tool may not have been enough to indicate *what kind of behaviors* instructors should be monitoring for.

7.7.4 Takeaways #4

Part of this work is to understand how the CSTEPS tool was used and suggest design recommendations for future iterations of this tool. The CSTEPS tool was a good first step of this exploratory project and was successful at prompting real-time strategies for instructors. Several design recommendations emerged from this analysis:

- Redesigning the confirm/deny interactions so that instructors have more immediate access to strategies. Often times instructors missed the strategies because an intervention began before they had time to select an option.
- The language used in the strategies needs to be redesigned to have more of a range of formalities. The majority of instructors expressed a dissatisfaction with the formal language of the prompts, making them feel confrontational. Working with instructors, future iterations should iterate on the language used and present a range of strategies that are usable and feel comfortable for instructors.
- Another method to support instructors and provide them with approachable strategies is to find different ways to embed collaborative scaffolds so they have more than one avenue to interact with them. For example, Lisa and Adam went on to embed adapted strategies into solutions for the entire course series (Lawrence, Shehab, Margotta, Livingston, & Mercier, 2020). Working with instructors, future iterations can find more sustainable solutions within and separate from the technology.
- Finally, based on the findings from this analysis we as a team need to reflect on the questions: *How do we design for those who have opposing philosophies of collaboration? How do we approach the tradeoffs between content and collaboration to better support all instructors?* If the goal is to simultaneous train instructors how to facilitate

collaboration as they work with groups of students, then the training and design needs to meet the expectations of the both groups.

CHAPTER 8: DISCUSSION

8.1 Review of the Study

This study provides insight into the design process and implementation of the CSTEPS orchestration tool. The first goal of this dissertation is to study how an interdisciplinary team designed an orchestration tool for engineering, graduate teaching assistants (TAs) and undergraduate course assistants (CAs). The second goal addresses how a real-time supportive orchestration tool was implemented and used by the TAs and CAs in the classroom. This work responds to calls over the past few decades for researchers to have a more open discourse around the design process in DBR (Easterday, Rees Lewis, & Gerber, 2017; Edelson, 2002; Kolodner, 2016; Phillips, 2006; Sandoval, 2014). Innovative learning takes place during the process of designing educational technology, and researchers are not documenting or assessing this to the same extent as other forms of learning (Kali, 2016). This study analyzes and reports on this design discourse, and discusses the interplay between collaboration, the connectedness of conversations, and critical moves to understand how an interdisciplinary team generated ideas. I then present findings from the classroom implementation to identify the success of the design process and outcomes. It is not enough to solely present on the findings of the design process, but also articulate how they were implemented and used in the classroom. Here, I discuss findings and implications for the following research questions,

- RQ1. How did ideas about the CSTEPS tool emerge during an initial brainstorming meeting among an interdisciplinary team?
- RQ2. How did the ideas that emerged during the design process get implemented in the classroom?

- RQ3. How did the design decisions embedded in the classroom influence the instructors' interactions in the classroom?

8.2 Summary of Design Phase

The design process was analyzed to understand how an interdisciplinary team collaboratively designed the CSTEPS orchestration tool. Several findings emerged from this design process. First, regarding contribution, Erica and I contributed the most turns of talk during his brainstorming meeting. As discussed in the results chapter, my role as a facilitator influenced my turns of talk since I was the member of the group leading the discussions, introducing new topics of discussion, and summarizing and making conclusions. Since the focus was on learning, it is not surprising that Erica, the PI who identified as a learning scientist, had the second most turns. Since the core purpose of the grant was to support students' and instructors' collaborative behaviors, Erica had the most to contribute because she not only had the most experience but was also the Principal Investigator of the grant. Had the focus of the project been on learning analytics, human-computer interaction, or something else, it may have influenced who contributed more. For example, if the focus of the project was on the prediction models, Levi may have contributed the most compared to Erica. This shows that while interdisciplinary teams can collaborate and work together to build affected design-based research artifacts, there are still dynamics and power structures embedded within these teams that need to be accounted for when reporting these processes.

Overall findings from the design process indicate that the initial brainstorm meeting was effective at producing the major themes that were implemented in the classroom, including monitoring, interventions, and data visualization changes. These outcomes mirror research that shows that interdisciplinary teams can develop innovative solutions through brainstorming (Cummings & Kiesler, 2008; Rhoten, Boix-Mansilla, Chun, & Klein, 2000). Although it was a long meeting, the group sustained quality discussions over time, with dips in discussions during the first and second scenarios. Using scenarios did break up the meeting and provide variety that supported the development of different ideas, echoing findings from the literature on design processes in design-based research (Svihla & Reeve, 2016) and interdisciplinary work (Rosson, Carroll, & Hill, 2002).

Analyzing the findings from the linkographic analysis shows that the team engaged in collaborative, high linked discussions across all three scenarios. Although, vertical areas lead to higher collaboration, higher link index, and more critical moves compared to lateral areas. Additionally, vertical areas that were overlapping had more critical moves and led to more convergent idea generation. These findings echo the literature that suggests that areas of dense linking lead to more quality ideas (Goldschmidt & Tatsa, 2005). Segmented, lateral areas had less critical moves and lower collaboration and link index, also echoing findings from the literature (El-Khouly & Penn, 2013). These findings are essential to understand what components of the discussions were most beneficial. Future research needs to elaborate on how to scaffold these kinds of discussions and also reflect on in-progress conversations to understand how to improve idea generation.

Finally, one significant finding from his design process was that not all goals developed in the brainstorming meeting were achieved (Anderson & Shattuck, 2012). While several researchers outline the challenges and limitations of DBR (Engeström, 2011; Kolodner, 2016; Ormel et al., 2012; Phillips, 2006), few studies articulate how this affects outcomes (Kali, 2016). The team generated several ideas during the design process that may have supported instructors and improved collaborative behaviors. However, due to the nature of this process there was not enough time to design and implement them all. The primary goal of the NSF grant was to develop real-time prompts to support instructors as they facilitate collaboration. The design of the prompts was time-consuming and complex, leaving no time to make other changes that may have been useful for instructors and students. By documenting this process, outlining those ideas, and reflecting on what was not implemented, our team can use these findings to iterate and develop more effective technology in the future.

As discussed in the literature, design-based research outcomes are often novel and pragmatic in ways to support students and instructors (Ormel, Roblin, McKenny, Voogt, & Pieters, 2012). By analyzing this design process, I was able to identify gaps in our design process, solutions that were not enacted, and collaborative structures that may improve our process in the future. From these findings, I have four recommendations for others doing this kind of design.

- *Make goals explicit*. Research has shown that constructing ideas requires a common ground to build collaboratively (Klein, 2008; Leahey, 2018). Establishing goals during brainstorming allows everyone to be on the same page and reflect on if the group is achieving them.
- *Add methods for reflection*. Our team had a moment when two members reflected on their own on the lack of progress made toward our goal. This was a productive turning point for our discussions but was not planned. Groups should reflect on how they are doing at achieving their goals as they are designing. While our group naturally did this, more reflection throughout may have been beneficial to identify if we were meeting our design goals.

- *Use a variety of methods to generate ideas*. Using two scenarios and one more structured design brainstorming led to diverse ideas and discussions. Embedding variety into brainstorming allows team members to brainstorm in different ways and develop ideas without getting sucked into conversations that are too open ended and not productive (Rosson, Carroll, & Hill, 2002).
- *Document ideas and changes.* This analysis was a fine-grain analysis of the conversations that led to the final CSTEPS tool. While this analysis is necessary to understand how these collaborations take place, documenting ideas and designs in DBR are equally important. There are many ways to share design processes with DBR, and researchers must continue documenting and disseminating these processes in a variety of ways – both at the fine grain and large scale levels (Barab and Squire, 2004; Kali, 2016).

8.3 Summary of Implementation Phase

The primary finding from the implementation phase was that when used, collaborative real-time prompts were effective. Instructors who used the tool and implemented prompts into their interventions led to productive interactions where the instructor sparked discussion among group members or brought them back on task. However, there were few instances were prompts were used, showing that the degree of integration profoundly impacts the use. The findings from Chapter 6 show that there are several reasons why instructors did not use the prompts. First, several instructors indicated during interviews that they had different opinions of what they thought was needed in discussion sessions compared to the goals of the CSTEPS tool. If the instructors had little experience with collaboration or held conflicting understanding or expectations about collaboration, then they exhibited little interaction with the tool. Similar to the literature, varying levels of teaching experience and perceptions about teaching, influences who used the tool and how (Hammerness, 2005; Tchounikine, 2013).

Some instructors had conflicting views of collaboration and misunderstandings of what kind of collaborative behaviors we were trying to support in the classroom. For example, some instructors described that discussion sections were already highly collaborative; therefore, there was no need for an orchestration tool. On the contrary, some instructors found it highly valuable and described several instances where the tool was supportive. Varying views and perceptions of collaboration are influential in how instructors interact in the classroom (Hofmann & Mercer, 2016). This range in views is expected from this DBR, due to the nature of the context in engineering. The faculty that worked on this project remained consistent over the course of this series of grants; however, the instructors continued to change semester to semester.

As discussed in chapter 3, only one instructor worked with the grant more than one semester, the remaining instructors were new to the project. This turn-over both illustrates the realities of scaling technology to new users within a context while also posing challenges with uptake. Co-design of this technology included faculty and instructors from the past iteration of the CSTEPS tool. While these instructors' feedback was instrumental in building the technology, they were not the instructors who used it in its final form. The introduction of new instructors who did not take part in the design process allowed the project to adhere to a more authentic use where scalability could be tested with new users. While the findings presented in this dissertation show that instructors ranged in their use and perceptions about collaboration and the tool, this allows us to reflect on how the tool is used by instructors who have experience with it and those that do not. This reflections provides real insight into what was and was not successful about the current design and allows for conclusions about how this tool may be used in other similar classrooms.

From an orchestration perspective, there were several limitations of the tool that align with findings in the literature. Some instructors did not use the full capabilities of the technology mirroring findings from other studies (Derboven, Geerts, & De Grooff, 2017; Lawrence & Mercier, 2019). While this is an issue to be addressed in future iterations, of the instructors who found the tool useful, they explained that it helped them navigate which groups may need attention. Tissenbaum and Slotta (2019) described this navigation through the classroom as the "wandering facilitator." Future iterations of the tool can better support instructors as wandering facilitators as they identify which groups may need assistance and more importantly, which ones that may be disrupted if they are interrupted. Additionally, the inaccuracies of the predictive models were more discouraging to some instructors over others. While 100% accuracy in the prediction models is not likely, which is why the human confirmation was designed into the tool, future iterations of the tool will improve these models and develop more reliable categorizations of group behaviors for instructors. Distrust in the tool adds conflicting constraints to the classroom that overwhelms and causes unnecessary tension within the classroom (Darling-Hammond & Bransford, 2005; Dillenbourg & Jermann, 2010).

8.4 Design Recommendations

Triangulating all data from the design and implementation phases, I suggest recommendations for improving the design process and the CSTEPS tool for future iterations. Beginning with the design process, several components of this design process were successful, while others less so. First, including faculty from the course and one teaching assistants who had previously taught were crucial in reflecting on what was helpful for instructors. Past iterations of this project included workshops with instructors (Lawrence & Mercier, 2019), while this iteration did not use workshops, it did benefit from the inclusion of these two team members. They provided invaluable insight into what instructors need, mirroring findings from similar co-design processes (Matuk, Gerard, Lim-Breitbart, & Linn, 2015; Severance et al., 2016). However, future iterations of this software need to include both instructors and faculty perspectives into the design process and also leverage instructors' voices to test designs before implementation. While past iterations of this project had done so, due to time limitations, there was no time to receive feedback from a larger group of instructors. This feedback would have been helpful to reflect on the formality of the prompts.

Chapter five outlines ideas that were generated during the design process but were not implemented in the final implementation. Several of these ideas were unanimously agreed on by the team as potentially useful for instructors and students. First, there needs to be a mechanism to identify if an instructor is present at a table. There were several instances during this implementation where instructors would receive a prompt, select it, and then identify that an instructor was already with a group, meaning an intervention was unnecessary. While some instructors found this to be a mild nuisance, others founded it a reason not to trust the tool. This mistrust of the technology majorly influenced its impact for some instructors, making it a priority for future iterations.

Another idea that was discussed during the design process was sequencing prompts over the semester. While the tool did not include a wide range of strategies, this iteration was exploratory. It was successful in developing a real-time orchestration tool and providing a smaller range of prompts. However, instructors expressed during interviews that the prompts were very formal and hard to implement. Due to time limitations that accompany this kind of research, the process lacked the time necessary to build a wide range of prompts and strategies. Future design work for this project needs to develop a wider library of strategies to be used in the tool as well as a range of language options for instructors.

Another necessary recommendation is for the training and support of instructors beyond merely implementing a tool. As discussed in chapter three, there have been several iterations on methods to train and support instructors on collaboration and the CSTEPS tool. These ranged from full semester courses covering collaborative learning to hour long workshops to train instructors on the technology. In this iteration, the instructors took part in an hour and a half long workshop to learn about collaboration and have a chance to interact with the software. However, analysis of interviews and interactions in the classroom indicated that there were a few instructors who had a misunderstanding of collaboration and how the tool was designed to support them.

The two TAs who worked on this iteration had mostly positive experiences with the technology. The two of them went on to collaborate with several members of this team to embed content in collaborative related tips into solutions for all instructors for all discussion sections (Shehab, Lawrence, Margotta, Livingston, & Mercier, 2020). While their initiative and motivation to use and implement collaboration was an exciting outcome of the project, other instructors on the project did not walk away with the same perspective. The instructors' perspective of collaboration and goals for discussions sections heavily influenced their interactions in the classroom and their takeaways from the study.

Overall, I recommend better training of instructors to help articulate the goals of the project, the tool, and discussion sections to hopefully alleviate some tension between engineering philosophies of collaboration and the project's philosophes of collaboration. This tension is what created a divide between instructors who found the tool useful and those who did not. This is, in part, due to training, but also to differences in philosophes about learning, teaching, and collaboration. If participants have conflicting expectations about learning and collaboration, that do not align with those of the project, then the outcomes of the prompts and technology may not be as expected. Therefore from the initial design process and implementation and training we must address the questions:

- *How do we design for those who have conflicting perspectives about collaboration?*
- *How do we approach the tradeoffs between content and collaboration to better support all instructors?*

8.5 Limitations and Future Studies

8.5.1 Design Process

There are several limitations of the design process analysis within this dissertation. First, this analysis only addresses one design team from a very small sample size. Conclusions can be drawn from how this team designed an orchestration tool, but that does not mean that every design team may interact and design in the same way. Additionally, my role in the study also plays a part in these findings. My positionality in the study allowed me to deconstruct the process using my experiences on the team and relationships with the project and team members. Other researchers do not have my subjectivities and could interpret findings differently; however, the description and narrative from my insider perspective is a value because of my role within the project.

Although these limitations play into the analysis and conclusions that I could draw, several future studies can be proposed from these findings. First, further studies are needed to look more broadly at factors that lead to innovative and successful research among diverse teams. Looking at more teams can validate if integrated, intersected, and separated conversations lead to similar patterns in other design processes. This work will also allow us to understand how we scaffold design discussions to support these interactions among interdisciplinary teams. Additionally, this line of research needs to continue investigating other methods to analyze the design process. Linkography was useful for deconstructing the process and understanding how ideas were created and connected over time. Due to the overall lack of analysis of this process in the literature (Edelson, 2002; Kolodner, 2016; Ormel et al., 2012; Phillips, 2006; Sandoval, 2014; Svihla & Reeves, 2016), there are other potential ways to analyze this process. Further studies should adapt and integrate linkography as well as other mechanisms to understand how interdisciplinary collaborations take shape and how these findings can impact implementation results and DBR methodology broadly. This line of research allows for the deconstruction of the complexity and messiness of DBR in the context of a research project, providing a window into ways to improve.

8.5.2 Implementation

The primary limitation of this work is concerned with a relatively small sample size. Only eight instructors were analyzed across four classes. While this allowed for in-depth analysis of each individual and their interactions in the classroom, it also has limitations for the generalizability of this work. Future research should employ a larger sample size to understand further how instructors use the CSTEPS tool.

Future analysis of this data will identify more instances where the tool was used in other weeks of the semester to understand if this interaction sustained or change their behaviors. Additionally, analysis is needed to understand the relationship between instructor interventions and student collaborative processes. This will aid in learning how strategies were embedded within the classroom rapport and also how that affected students directly. Other possible studies with the technology will look at how the implementation is affected by different settings to understand that these tools translate across contexts.

8.6 Conclusions

The CSTEPS tool was a good first step toward supporting instructors' collaborative orchestration. To be effective, the design team, instructors, and students need to come to a common understanding of how and why collaboration has value in discussion sections and beyond. This common goal can aid in building more effective designs *with and for* instructors. Exploratory DBR studies are not clean or clear cut, but complex and everchanging (Svihla & Reeve, 2016). This complexity is what makes DBR cases rich examples of how design happens and is enacted (Wang & Hannafin, 2005). As Erica described in the second scenario of the design brainstorming meeting,

> "You know, this is an iterative project, and we can write the list of things that we would do differently next time. No one knows how to do this yet, but that's the exploratory part of this project."

This is just one instance of this interdisciplinary team being explicit about the challenge of this project: working on problems that have no clear answer. The openness of this rapport is one of the perspectives that enabled this team to successfully design and implement a real-time orchestration tool for engineering instructors. Analysis of DBR design process and implementation, like that presented in this dissertation, allows researchers to explore the creative and exploratory components of DBR and further understand how to improve this methodology (Kali, 2016; Puntambeka, 2018).

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APPENDIX A: PROMPT POOL

Category	**Prompt**
Off task	Ask a general question about their discussions. Try not to explain or give answers but promote discussion among the group. For example: "Can you tell me how far you've got with the problem?" "How are you going to solve this problem?"
	Explain to the group that a good way to start is by developing a plan together to solve the problem. For example: "What you need to do is discuss the steps you need to take to solve the problem." "The purpose of this activity is to solve this problem together, which can help build your understanding." "The purpose of this activity is to practice solving the problem as a group."
	Prompt group to develop common goals and a plan of how to solve the problem. For example: "Have you developed a plan to solve the problem?" "Why don't you develop a plan to solve the problem first?" "What do you think needs to be done first?"
	Prompt the group to explain their joint plan to solve this part of the task. For example: "Can you explain to me what your group's plan is to work on this part of the task?" "How are you going to solve this section of the activity?"
Silent on task	Ask a lot of questions until the group knows what they need to do next. "What's your next step?"; "How do you plan on using that methods?"; "Do you think that will work?"; "Have you thought about other methods to solve the problem?"
	Ask the group how they plan on accomplishing the task as a group. For example: "What is the process you're going to take to solve the problem?" "How are you dividing the task up among your group members?"
	Engage the group in discussion. Ask a student to explain what they are doing to their peers. For example: "Can you explain to me what your other group members are working on?"

	Explain that this is a collaborative task, which means they have to help each other to understand the problem. For example: "This is a collaborative task. Try to discuss your ideas; provide evidence for your reasoning." "Discussing the problem with your group members will help you build on each other's' ideas to arrive to one solution to the problem." "Share your ideas with the group; provide an argument for your reasoning."
	Prompt the group to explain to you what they have been working on. Ask another group member to respond to what was said. For example: "What do you think of what your group member said?" "Do you agree with the method that your group member just described? Why or why not?"
	Remind the group this is a collaborative task; they need to work together to solve the problem. For example: "This is a collaborative task. Talk to your peers to solve the problem together." "Talk to you peers to come up with a plan for solving the problem."

APPENDIX B: INTERVIEW PROTOCOL

Introduction to participant

Thank you for meeting with me to talk about your class! To facilitate my note-taking, I will be recording our conversation today. If at any time you wish to stop the interview, please just say and I'll shut off the recording. Also, feel free to skip a question if it makes you uncomfortable or you don't want to answer.

The purpose of this interview is to help us better understand how you used the CSTEPS tool in class. While we are documenting your experience in the classroom, we also think it's important to understand your perspective of using the tool. To look at this we would like to watch about two videos of interactions you had with groups and hear more about what was happening from your perspective. Watching these videos today is not meant to be an evaluation of your teaching or interactions in the classroom, but just allows us to get more context about how you used the tool.

We are going to watch two different interactions you had with groups from your class. We will start by watching a short clip of the CSTEPS tool and what it showed before your intervention. Then we will watch a video of an interaction you had with a group afterward. After we viewed both videos I will ask you a few questions about the tool and what happened before and during your intervention. Feel free to play the video of your intervention as many times as necessary while answering the questions. Do you have any questions for me before we get started?

View 1st CSTEPS tool screencast

View 1st intervention

Interview questions

Tool Use

- What did you think this prompt was asking you to do?
    - How did you react to this prompt?
    - Was this prompt what you were expecting?
- What did you do after reading the prompt?

Monitoring

- What did you notice about the group before you intervened?
- What were you looking for in the group?
    - How did it align with what the tool was prompting?
    - Did you identify any issues?

Intervention

- Can you explain how you started this intervention?
- How do you think you integrated the prompt into your intervention?
    - What would you like the group to do with the information you gave them?
- What do you think your intervention did for the group?
    - What would you have liked to happen after your intervention?

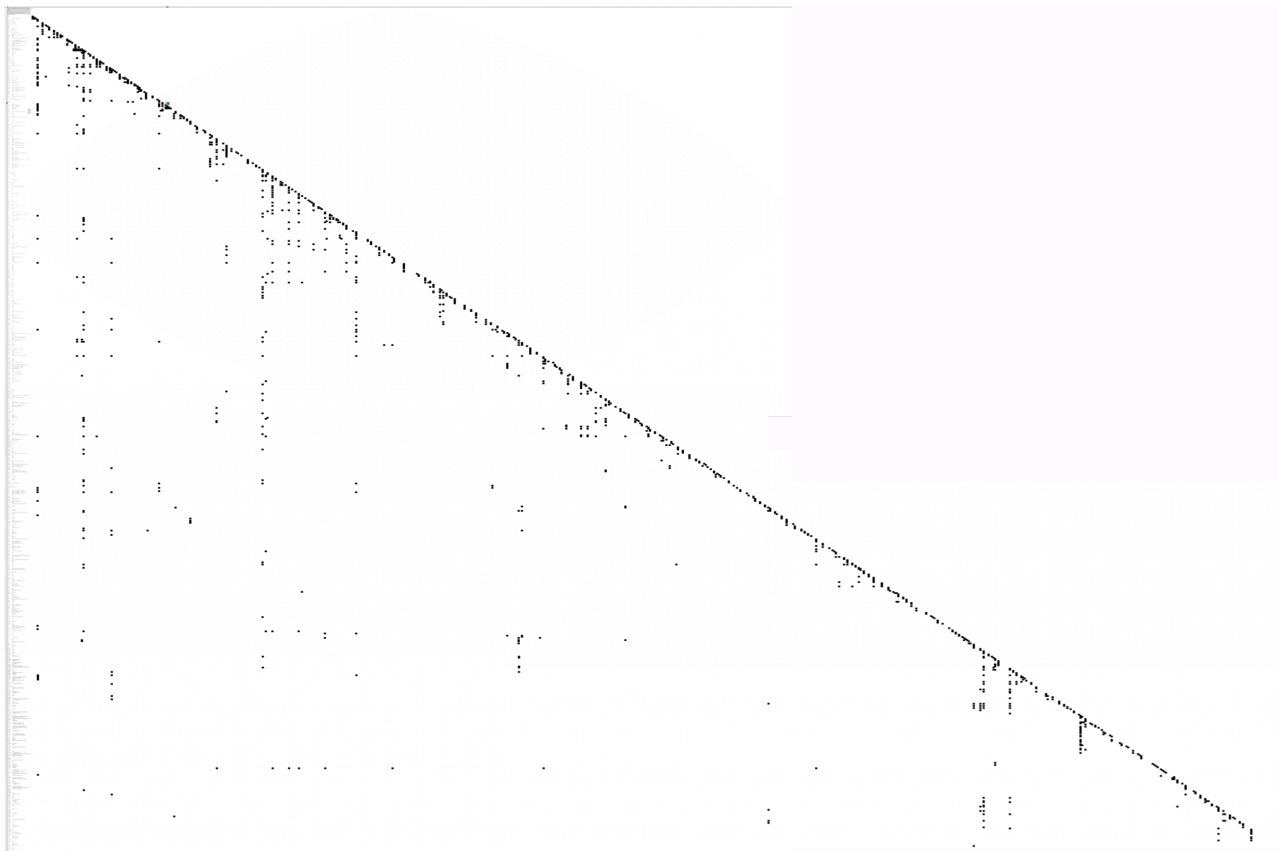
View 2nd CSTEPS tool screencast

View 2nd intervention

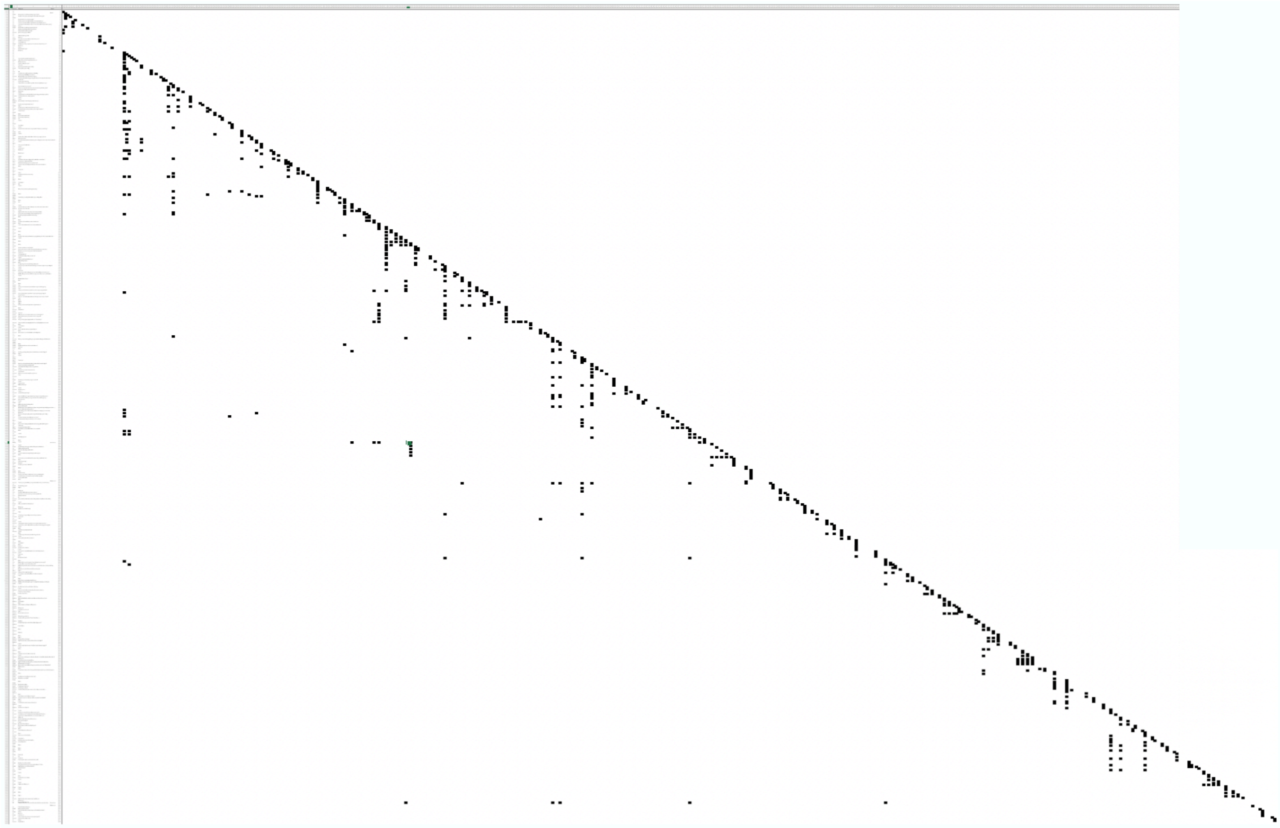
Same interview questions…

APPENDIX C: LINKOGRAPHIC REPRESENTATIONS

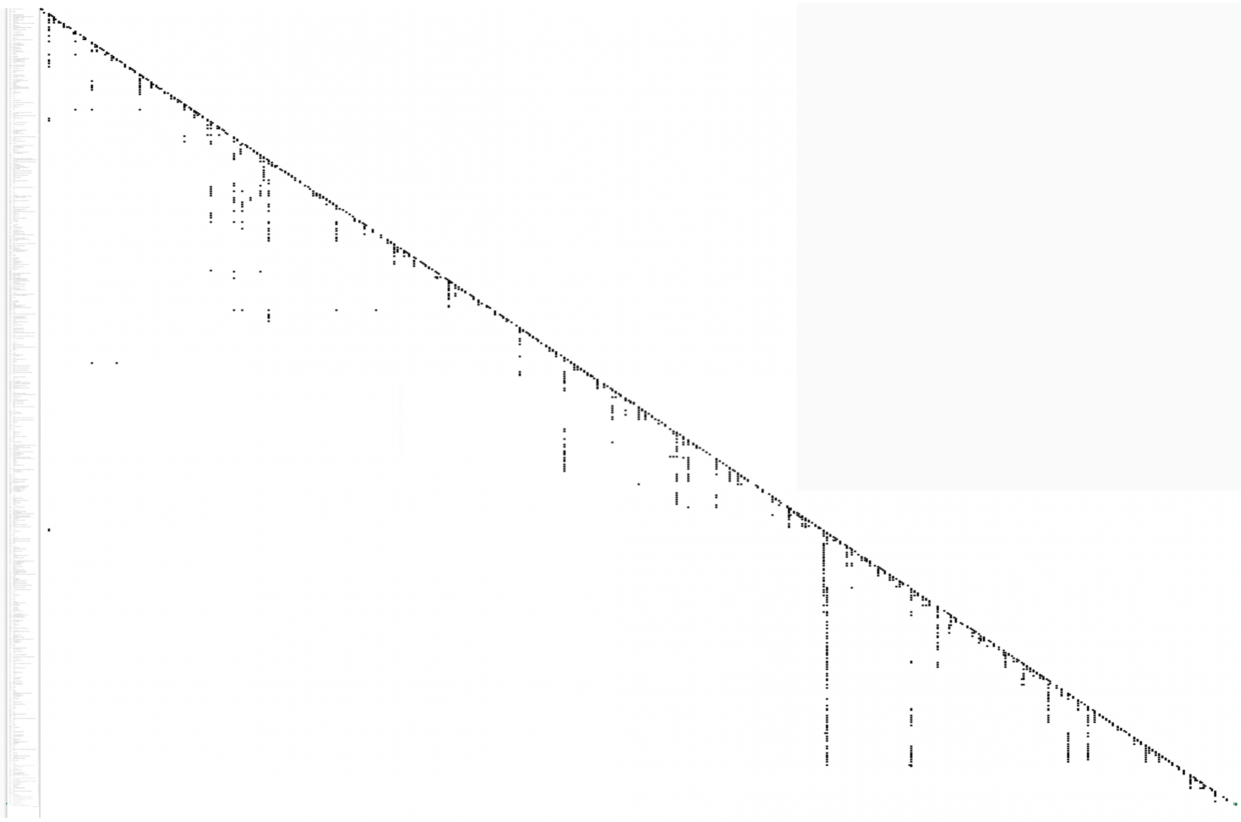
Linkographic Representations for Scenario 1



Linkographic Representations for Scenario



Linkographic Representations for Scenario 3



APPENDIX D: LATERAL AND VERTICAL AREAS