The Impact of a Brief Design Thinking Intervention
on Students’ Design Knowledge, Iterative Dispositions, and Attitudes Towards Failure

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ABSTRACT

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This research explores the benefits of teaching design thinking to middle school students. The design thinking process, with its emphasis on iterative rapid prototyping, portrayal of mistakes as learning opportunities, and mantra of “fail early and often” stands in stark contrast with the typical high-stakes, failure-averse culture of the classroom. Educators laud the process as a way to teach integrative STEM curriculum, foster 21st century skills, and engage students in constructivist learning. However, few studies have examined the potential motivational benefits for K-12 students who learn design thinking. Therefore, the present research explored if design thinking instruction could reframe how students perceived failures and teach them to iterate, or “try again,” as they engaged with complex problems.

In two quasi-experimental studies, with 78 and 89 students respectively, I investigated the effectiveness of a brief intervention, intended to teach a critical component of design thinking – the iterative process of design – and its unique philosophy surrounding failure, whereby mistakes are natural and expected learning opportunities as students work towards increasingly better solutions to ill-defined problems. Students in an iterative design mindset condition (Mindset) learned about iterative rapid prototyping, employed the process on two different design challenges with embedded reflections, and developed brochures about design thinking. In a comparison STEM-focused condition (STEM), students participated in an analogous intervention focused on the importance of using science and math in design. Results from both studies indicated that Mindset students learned the philosophy and process of iterative rapid prototyping
from the brief intervention and were able to transfer the process to a target design task.
Furthermore, results confirmed a performance benefit to iterating early and often. Moreover, Study 2 results suggested that students in the Mindset condition developed more adaptive attitudes to failure, compared to students in the STEM condition. These studies provide compelling evidence that design thinking education has the potential to instill persistence in the face of ill-defined problems, reframe failure, and improve task performance for middle school students. This work also presents a model for evaluating the design thinking process using quasi-experimental studies and quantitative methods.

This dissertation consists of a brief summary of relevant literature and two journal-style articles. First, I define design thinking and explain how iterative rapid prototyping connects to key motivational constructs in the classroom, ultimately resulting in improved engagement and performance. Next, a design case describes the final intervention used in Study 2 and notes the ways in which the learning sciences literature and the iterative development process informed its design. I consider trade-offs in the effort to develop curriculum for a research study and detail lessons learned along the way. Subsequently, an empirical chapter presents two studies of the design thinking intervention. I end by considering the implications of this body of research and suggest future directions for researchers interested in bringing design thinking into the classroom.
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CHAPTER 1: INTRODUCTION

Design thinking, the problem solving style and process traditionally involved in engineering and other design fields, has rapidly gained traction across many contexts beyond those traditionally associated with design. Used to improve everything from hotels (Lub, Rijnders, Caceres, & Bosman, 2016), to chronic disease care (Johnson et al., 2016), to the management of multi-billion dollar corporations (Ignatius, 2015), the rationale is that the way designers solve problems is of value to anyone who is trying to innovate or problem solve in the context of ill-defined problem spaces. Design thinking is characterized as a nonlinear, often collaborative process of development, involving rapid prototyping and iterative refinement through testing and feedback. It is a process that entails taking risks and using failure as a learning opportunity. Consequently, this process and philosophy promote innovation and empower individuals in the face of complex, ill-defined problems (Carroll et al., 2010; Gerber & Carroll, 2012).

In the realm of education, design thinking is in vogue and has recently been incorporated into science standards as an essential skill for middle school students (NGSS Lead States, 2013). Lauded as a valuable component to incorporate into curriculum, it both aligns with and supports 21st century learning goals. Up until recently, education has been structured around the needs of the Industrial Age where knowledge was considered a stable, core set of facts or skills. However, this 20th century educational model is no longer adequate in the 21st century, where technological advances have enabled computer programs to perform routine cognitive work or manual labor (Bereiter & Scardamalia, 2006). In today’s workplace, individuals must be capable of using higher-level cognitive skills, often working within diverse teams, to do the sorts of complex reasoning that computers cannot yet do. It is critical that students learn a set of skills, often
referred to as 21st century skills, that will enable them to thrive in the world today, and design thinking holds major promise for bringing education into the 21st century. Studies of design thinking in classrooms suggest that it benefits students in a variety of ways: bolstering collaboration, creativity, metacognition, and STEM learning by providing a meaningful context within which students can hone various proficiencies (Koh, Chai, Wong, & Hong, 2015).

However, the concept is understudied; the majority of research on design thinking is qualitative, and while teachers are excited about the promise of design thinking, there exists some confusion around what exactly design thinking is and what it might look like in their classrooms (Kimbell, 2011; Lahey, 2017). Furthermore, a key philosophy of design thinking is that designers embrace failure, yet few studies explore how a designer’s motivation, particularly her willingness to persist in the face of mistakes and setbacks, is affected by designing. Keeping students motivated to engage in school, particularly in the face of challenging work, is a constant struggle in the classroom. In particular, the middle school transition is marked by declines in self-esteem, decreased school engagement, and reduced failure tolerance (Clifford, 1988; Simmons, Burgeson, Carlton-Ford, & Blyth, 1987; Watt, 2004; Wigfield, Eccles, Mac Iver, Reuman, & Midgley, 1991). Therefore, this dissertation focuses on one aspect of design thinking, rapid prototyping, or iterative cycles of ideation, prototyping, and testing as one refines a design into a desired product over the course of incremental development (Cross, 2011). While many other components of design thinking are of important educational value, I purport that the process of iterative rapid prototyping holds unique potential to benefit students. Specifically, by creating a culture of diving in, trying again, and using mistakes as stepping-stones to success, rapid prototyping can shift the motivational landscape of the classroom, empowering students to view failure as a learning opportunity and persisting as a worthwhile endeavor.
In this dissertation, Chapter 2 provides a brief overview of the literature and research on design thinking and identifies a gap concerning its motivational potential. I assert that design thinking – specifically the process of iterative rapid prototyping – holds promise to increase persistence and reframe failure in the K-12 classroom, and I draw from theories of motivation to propose how motivation functions in the design process. Chapter 3, a standalone design case, presents a detailed rationale for and description of the design thinking intervention I developed for my two quasi-experimental classroom studies. Chapter 4 is an empirical journal article describing these two studies where I investigated how learning design thinking may benefit students’ motivation and problem solving processes. Particularly, I explored whether or not students could learn the philosophy and process of design thinking through a short classroom intervention, and how learning this process affected students’ attitudes towards failure and iterative dispositions, or proclivities toward early and frequent prototyping cycles and willingness to try again on future complex tasks. Results from both studies indicated that students in an iterative design mindset condition (Mindset) demonstrated significant gains on design thinking knowledge and beliefs, asked for more iterations on a prospective future tasks, and employed the iterative process on a transfer design task, compared with students in a comparison control STEM-focused group (STEM). Moreover, Study 2 results suggest that students in the Mindset intervention developed more adaptive attitudes towards failure. Consequently, these studies suggest that design thinking can affect how students engage with and perform on ill-defined problems and how they react towards failure. Last, Chapter 5 is a general discussion of the contributions this dissertation brings to the field. Due to the succinct nature of this dissertation, additional analyses that did not make it into Chapter 4 are included in an Appendix.
CHAPTER 2: REVIEW OF THE LITERATURE

Design Thinking: A Process, A Skill, A Philosophy

Despite the rising popularity of the term, design thinking is a fledging and “fragmented discipline” (Kimbell, 2011, p. 290). Encompassing a complex set of approaches that designers use when approaching and solving ill-defined problems, a recent review paper broke the paradigm down into a grand total of 26 subcomponents (Razzouk & Shute, 2012). One reason that the construct seems so complex is that the umbrella term is simultaneously used to characterize what designers do, what designers know, and more broadly, how they approach and cognize the task at hand (Kimbell, 2011). Some authors focus on the physical process of design, highlighting the ways in which designers create, seek feedback, and revise (Razzouk & Shute, 2012), while others emphasize the cognitive skills involved as practitioners “frame, explore, and re-frame ill-structured problems to derive design solutions” (Koh et al., 2015, p. v). Still others ascribe a more broad set of mindsets or philosophies to the term. Carroll et al. (2010) identified seven fundamental design mindsets: human-centeredness, empathy, mindfulness of process, culture of prototyping, show don’t tell, bias toward action, and radical collaboration. Ultimately, design thinking is all of these things: it is a problem-solving process to use in the face of complex or difficult problems (what designers do) that necessitates a set of skills (what they know) and embodies a specific philosophy (how they approach and understand their work).

In terms of what designers actually do, the design thinking process entails repeated, iterative transitions across often-nonlinear steps (Plattner, 2010, Figure 1). These steps include:

1. empathizing with the user or the target audience of the design,
2. defining the challenge or problem one aims to solve,
3. ideation, or the act of coming up with a breadth of ideas for possible solutions,
4. prototyping, or building out one or more solutions, and

5. testing ones idea(s) to gather feedback and gain insight on their strengths and weaknesses.

While the entire process can be nonlinear, a common movement through the space is *rapid prototyping* or repeated cycles of ideation, prototyping, and testing as one refines a design into a desired product over the course of incremental development (Cross, 2011). This movement through the process is the focus of my dissertation and will be described in greater detail in the following section.

![Figure 1](https://dschool.stanford.edu/groups/k12/wiki/606dd/Process_.html)

**Figure 1.** The design thinking process entails nonlinear, iterative movement through five steps. (Barry, 2010, [https://dschool.stanford.edu/groups/k12/wiki/606dd/Process_.html](https://dschool.stanford.edu/groups/k12/wiki/606dd/Process_.html))

The skills associated with design thinking largely correspond with the process, enabling designers to thrive as they complete various steps and more generally in ill-defined problem spaces. Broadly, the design thinking process employs skills such as empathy, exploration, integrative thinking, collaboration, reflection, and risk-taking (Carroll et al., 2010; Cross, 2011; Michlewski, 2008). As will be explicated in this chapter, research suggests that various types of design thinking instruction can facilitate skill development, providing a meaningful context within which students can hone these proficiencies.

Moreover, designers are guided by overall philosophies or mindsets. As argued by Goldman and Kabayadondo (2017), the goal of teaching design thinking is to
move beyond... the process and to develop mindset change experiences such as empathy development, participation in ‘team collaborations,’ commitment to action-oriented problem solving, a sense of efficacy, and understanding that failure and persistence to try again after failures are necessary and productive aspects of success. (p. 3)

Of particular interest in the present research is this last mindset, what Carroll et al. (2010) call culture of prototyping and others dub permission to fail (Cross, 2011; Gerber & Carroll, 2012; Maccoby, 1991). The cyclical rapid prototyping process of developing solutions early into the process, testing them to receive feedback, and then creating a new prototype is associated with mantras such as “try early and often” and cultivates a general expectation of experimentation (Brown, 2008). Designers are urged to fail forward, with the attitude that any product will be riddled with mistakes in its initial stages and iteratively improved through testing and refinement across iterations (Babineaux & Krumboltz, 2013).

To summarize, design thinking follows a nonlinear, often collaborative process of development that begins with empathy for those affected and definition of the problem one is addressing. One analyzes and synthesizes information and explores possibilities to generate ideas for potential solutions. One prototypes many ideas, which are iteratively refined through cycles testing and feedback, a process that entails taking risks and using failure as a learning opportunity. Consequently, this process and philosophy promote innovation and empower individuals in the face of complex, ill-defined problems.

The present research focuses on a piece of the overall design process, rapid prototyping, its corresponding culture of experimentation, and its philosophy about failure and mistakes. As explained in the following sections, existing research on K-12 design thinking is focused on the ways in which it facilitates a variety of 21st century skills and STEM learning. However, few
frameworks of 21st century skills or studies of design thinking emphasize the motivational dimension of 21st century problem solving. I purport that persistence and the resolve to try again are important skills for the 21st century learner that are embedded within the iterative rapid prototyping process. Therefore, this process holds promise for K-12 education because of the way in which it teaches students that effort is worthwhile, provides a framework to scaffold persistence in the classroom, and ultimately can benefit student performance.

**Design Thinking in K-12 Education**

While the term “design thinking” is currently coming into fashion in the classroom and being added to middle school standards (NGSS Lead States, 2013), theorists have seen educational promise for design tasks since the 1980s, citing how they introduce students to ill-structured and authentic problem solving and necessitate both reflection and communication skills (Cross, 1982). Importantly, design thinking aligns well with and provides an ideal framework to support constructivist learning (Scheer, Noweski, & Meinel, 2012). Constructivism is a learner-centered theory that views learning as an individual’s active process of making meaning and constructing knowledge. Constructivist learning environments are learner-controlled, employ meaningful contexts, and involve authentic tasks. These affordances, among others, make design thinking particularly well suited for educating students to succeed in the “real world” and the 21st century workplace.

However, there is a lack of scientific research on the process and its role in K-12 education. Design is understudied; two recent electronic database reviews concluded that little formal empirical work has been conducted with design thinking, especially with K-12 populations or through quasi- or experimental study designs (Koh et al., 2015; Razzouk & Shute, 2012). The majority of research is ethnographic and qualitative, relying on observations,
interviews, and analysis of designed documents. While quantitative research on design thinking may be sparse, the existing body of research indicates that design thinking cultivates 21st century skills and is a means to deep learning and application of STEM content.

This section summarizes existing research on educational benefits of design thinking, focusing on the ways in which it facilitates the development of 21st century skills and provides an avenue by which to learn STEM content. Although research describing design thinking and its iterative rapid prototyping process characterizes the process as one that celebrates failure and fosters confidence, there are few empirical studies documenting how learning the process of design thinking may affect students’ persistence or willingness to “try again” in the face of setbacks and mistakes. In the next section, I elaborate on the underexplored connections between design thinking and motivation.

**Twenty-first Century Skills**

A nascent body of research suggests that design thinking curriculum cultivates 21st century skills. Synthesizing numerous frameworks of 21st century learning, Koh et al. (2015) distilled the following five key dimensions of a 21st century education: (1) a socio-cultural dimension, which demands skills such as collaboration and cross-cultural competency; (2) a cognitive dimension, involving critical and creative thinking, risk taking, and problem solving in ill-structured scenarios; (3) a metacognitive dimension, emphasizing self-assessment, reflection, and other self-regulatory skills; (4) a productivity dimension, involving authentic tasks and development of real products; and (5) a technological dimension, entailing information and communication technology (ICT) proficiency and digital literacy.

Koh et al. (2015) affirm that teaching students design thinking can facilitate the development of many of these 21st century skills, and existing research supports this assertion.
From the sociocultural perspective, studies have suggested that design thinking curriculum can facilitate development of collaborative skills (Kangas, Seitamaa-Hakkarainen, & Hakkarainen, 2013; Kolodner et al., 2003) and empathy (Goldman, Zielezinski, Vea, Bachas-Daunert, & Kabayadondo, 2017). Collaboration as a challenging and rewarding experience emerged as a theme in Carroll et al. (2010)’s ethnographic study of students and instructors participating in a series of design challenges. Likewise, in an analysis of video data of three elementary school students designing a lamp, Kangas et al. (2013) concluded that design is implicitly collaborative. Across numerous studies of the Learning by Design (LBD) curriculum – a program teaching earth and physical sciences through a series of hands-on design projects – students who participated in the LBD curriculum outperformed those in non-LBD classrooms on collaboration skills, as coded from video data of assessment tasks (Kolodner et al., 2003). Regarding empathy, Goldman et al. (2017) taught a month-long design curriculum to middle school students and found that students learned the steps of the process and importance of placing the user’s needs at the center of one’s design.

Cognitively, design thinking cultivates high quality conceptual understanding and imaginative thought (Barlex & Trebell, 2008; Gerber & Carroll, 2012; Schooler, 2004). In an ethnographic study of a 35-member design team, Gerber and Carroll, (2012) determined that within the design process, the act of rapid prototyping strengthened creativity beliefs. In K-12 design, Barlex and Trebell (2008) found that design activities facilitated creativity and imaginative thought among 9th grade students. Moreover, in an interdisciplinary two-week lesson integrating math, science, and technology into a design challenge with two 7th grade classes, Schooler (2004), one of the teachers of the course, reported that design challenge facilitated higher-order thinking skills such as analysis, synthesis, and evaluation.
Furthermore, studies suggest that design thinking increases metacognitive skills such as reflection and self-regulation (Conlin, Chin, Blair, Cutumisu, & Schwartz, 2015; Kolodner et al., 2003; Sabag, Trotskovsky, & Waks, 2014). Reflection is fundamental to the design process, and design thinking itself has been called reflection-in-action (Schön, 1983). As designers make incremental improvements, they must reflect meaningfully on feedback and determine how to change their designs. One ethnographic study of high school students in an engineering course concluded that the engineering design process is particularly well suited to fostering reflective thinking: the inherent collaboration and iterative refinement process in engineering catalyze reflection (Sabag et al., 2014). Additionally, studies of the LBD curriculum found that students who participate in it outperform those in non-LBD classrooms on metacognitive skills, as coded from video data of assessment tasks (Kolodner et al., 2003).

The final two dimensions of 21st century skills – productivity and technology – are implicit in many design activities. From creating a lamp (Kangas et al., 2013) to developing a game (Casey, Hastie, & Rovegno, 2011), design challenges often involve a level of authenticity in that they deal with the development of real products under realistic constraints. Furthermore, students employ design thinking in a variety of technological environments, including programming environments like Logo MicroWorlds (Ching & Kafai, 2008), augmented reality platforms (Bower, Howe, McCredie, Robinson, & Grover, 2014), and virtual maker spaces such as FabKids (Beyers, 2010).

**STEM Content**

In addition to promoting and fostering the use of 21st century skills, design thinking pedagogy can affect deep, meaningful learning in a variety of STEM topics and facilitate application of this knowledge in authentic tasks. For example, Casey et al. (2011) studied two
classrooms of 14-16 year olds designing games. Through interviews, observations, and analysis of students’ design process and products, the authors concluded that design thinking facilitated sophisticated understanding of game structure. Moreover, in Schooler's (2004) analysis, he asserted that design thinking facilitated use of content-area skills and deepened students’ understanding of surface area and volume. Similarly, in a study of 100 students taking an engineering course across seven high schools, Berland et al. (2013) interviewed students and found that they improved in their application of science concepts to engineering tasks, albeit inconsistently. Additionally, a small number of quantitative studies corroborate these findings. Perhaps unsurprisingly, design thinking facilitates deeper understanding of engineering concepts; Bennie, Corbett, and Palo (2015) found gains from pretest to posttest on “what it means to be an engineer” for elementary students who participated in a design afterschool program.

Additionally, numerous studies of the LBD curriculum have found that students in LBD classrooms outperform or match comparison classrooms on science content learning (Kolodner et al., 2003). Furthermore, design thinking curriculum appears to level the playing field for students who are often considered at a disadvantage in STEM fields: low-SES, low-performing, and female students (Conlin et al., 2015; Kolodner et al., 2003).

Benefits of Iterative Rapid Prototyping

In addition to the skill and learning gains fostered by design thinking more broadly, research and theory suggest something uniquely promising about iterative rapid prototyping. This term can refer to both the physical process of repeating design activities and/or the cognitive thought processes and reasoning involved in changing the design (Costa & Sobek, 2003). Additionally, as iteration refers to the revision of a design concept, iterations themselves can be big and small, and the physical products or ideas resulting from iterations include both
modifications to a current prototype as well as entirely new prototypes. In this paper, I define iterative rapid prototyping as the physical process of testing, seeking feedback, and revising one’s design in pursuit of a design goal, with the implicit understanding that cognitive processes may be involves and iterations may vary in type.

This process is an integral component of design thinking. First, research suggests that individuals who iterate during design tasks outperform those who do not (Bayles & Orland, 2001; Dow, Heddeleton, & Klemmer, 2009; Looijenga, Klapwijk, & de Vries, 2015). Studies have found that iterative students create more artistically sophisticated ceramic pots (Bayles & Orland, 2001), egg drop containers that can withstand drops from greater heights (Dow et al., 2009), and develop greater insight in a boat design task (Looijenga et al., 2015). Furthermore, iterative prototyping has motivational ramifications. Importantly, the choice to iterate and therefore seek out feedback that could potentially be negative is a difficult one; it is easier to consider an initial solution “good enough” and call it quits (Schunn, 2011), and qualitative evidence from studies of prototyping suggest that individuals feel anxiety when pushed to iterate early and frequently (Dow et al., 2009). More broadly, studies of adolescents have documented that students do not actively seek out feedback (Good, Slavings, Harel, & Emerson, 1987; Newman & Goldin, 1990). Therefore, a student’s decision to iterate demonstrates overcoming a motivational hurdle and displays persistence, or willingness to try again, despite a “good enough” solution.

Moreover, research suggests that the process of rapid prototyping can lead students to reframe failure as an opportunity for learning by minimizing the affective impact of mistakes or setbacks (Carroll et al., 2010; Gerber & Carroll, 2012; Sadler, Coyle, & Schwartz, 2000). This is because interconnected to the culture of prototyping is the philosophy of permission to fail;
designers are urged to fail forward, with the attitude that any product will be riddled with mistakes in its initial stages and iteratively improve through testing and refinement across iterations (Babineaux & Krumboltz, 2013; Cross, 2011; Maccoby, 1991).

Numerous studies have demonstrated that the process of rapid development shifts the focus off of perfection. In Gerber and Carroll's (2012) ethnographic study of professional designers, they found that the creation of many low-fidelity prototypes minimized the importance of any specific one, and the process dissuaded members of the team from ruminating on failures. Additionally, the researchers found that the prototyping process reframed failure as an opportunity for learning. As one participant in the study reflected, “Failure is the key to success if an iterative approach is used for design… the more that a designer fails, the better the design eventually becomes” (Gerber & Carroll, 2012, p. 72). Similarly, in Maccoby's (1991) interview study of eight highly innovative engineers, he found that they were not discouraged by failure but rather expected to learn from it. As Carroll et al. (2010) concluded in their study of middle school designers, bringing design thinking into education requires a fundamental reconceptualization of failure. Moreover, some research suggests that this reconceptualization has broader motivational repercussions; one study of iterative rapid prototyping found that iterative students reported higher self-assessment of their performance and greater confidence than non-iterative students (Dow et al., 2009).

In summary, as designers participate in rapid cycles of iterative prototyping, they learn that failures are simply a part of the process. Consequently, the choice to iterate in the face of a complex problem both illustrates persistence and, more broadly, may alter how students view failures or mistakes. Turning to the motivation literature, this connection is unsurprising.
Implications for Motivation

While experts write about the unique culture around failure embedded in design thinking and studies of prototyping suggest it plays a significant role in reframing failure, the relationship between design thinking curriculum and motivation is largely unexplored. Motivation is rarely specified in frameworks of 21st century learning, but educating students to thrive in the real world necessitates more than equipping them with skills such as collaboration and creativity and content knowledge: students must be willing to persist at challenging tasks and be motivated to go beyond a “good enough” solution. How does design thinking, especially the act of iterative rapid prototyping, foster persistence or willingness to seek feedback and try again? More importantly, what implications does this have for students’ motivation in the classroom?

I propose that if K-12 students add design thinking to their academic toolbox, this mindset can affect a radical shift in motivation. While experiences of failure traditionally set in motion a cascade of negative motivational outcomes (Multon, Brown, & Lent, 1991; Schunk, Meece, & Pintrich, 2014), a design thinking curriculum has the potential to shift beliefs around failure and effort, resulting in increased persistence and engagement. This is due to the ways in which iterative rapid prototyping embodies an incremental theory of intelligence and entails specific, proximal learning goals.

Implicit Incremental Theory of Intelligence

One of the ways in which iterative rapid prototyping bolsters motivation is by providing the optimal environment for affecting students’ implicit theories. Implicit theories of intelligence are individual differences in the belief that intelligence can or cannot be developed through effort. Those with a fixed theory of intelligence view intelligence as relatively stable and unchanging over time. Difficulties are viewed as obstacles that lower self-efficacy and lead
students to give up or disengage from a task. Others hold an *incremental theory* of intelligence, believing that ability can change and grow from effort, experience, and learning. Research suggests that students with incremental theories embrace challenges, persist, see effort as necessary for mastery, learn from feedback, and attribute successes and failures to internal causes that they can control (Dweck, 2000). Furthermore, studies suggest that ability theory interventions can improve students’ motivation and academic performance (Blackwell, Trzesniewski, & Dweck, 2007; Good, Aronson, & Inzlicht, 2003), and educational environments employing incremental theory incentive structures show benefits for student persistence and perseverance (O’Rourke et al., 2014).

Design thinking, with its emphasis on iterative rapid prototyping, is essentially an incarnation of an incremental theory. In this paradigm, rather than viewing intelligence as malleable, students are taught that their designs are malleable. As students follow a design thinking process, they can witness the incremental improvement of their ideas. The very act of iterative rapid prototyping implies that a product can improve through effort, experience, and learning. Therefore, a design thinking mindset should show similar benefits as incremental theory of intelligence for persistence.

**Managing Uncertainty Through Proximal Learning Goals**

Moreover, the *structure* of the design thinking process facilitates persistence. Designers are tasked with solving complex, ill-defined problems, and therefore the ability to function in uncertainty is a requisite; numerous interview studies of professional designers have confirmed that coping with uncertainty and open-ended situations is an important design skill (Cross, 2011; Lawson, 2005; Michlewski, 2008). The design thinking process is geared towards enabling individuals to cope with uncertainty through the inclusion of goals. In general, student goals –
the behaviors or outcomes a student is aiming for – are the most motivating when they are proximal (close-at-hand), specific, and challenging (Locke & Latham, 2002; Schunk et al., 2014). Particularly for new complex tasks, the use of proximal goals helps students with error management, leading to higher success. Relating this to the design process, while the high-level goal in a design challenge is, of course, challenging, the various steps of prototyping serve as proximal, specific goals, facilitating motivation.

Furthermore, implicit theories of intelligence are related to student goals. There are two overarching types of goals students can have: learning goals and performance goals. Students with incremental theories generally hold learning goals, which are associated with a focus on learning or improving at a task, such as by trying to accomplish something challenging to gain understanding or insight (Pintrich, 2000). Students with learning goals are more likely to seek challenge and persist (Schunk et al., 2014). In contrast, entity theorists hold performance goals, focusing on demonstrating competence or high ability. According to the literature, performance goals can be detrimental during complex tasks, due to evaluative pressure and anxiety. Instead, complex tasks are best met by specific and challenging learning goals (Seijts & Latham, 2001). I propose that iterative rapid prototyping provides students with proximal, achievable learning goals in an otherwise open-ended and complex performance-focused problem space. Switching the focus away from perfection, prototyping emphasizes incremental improvement and learning from feedback.

Conclusion

In summary, design thinking is an umbrella term for the process, skills, and mindsets that designers use to innovate in ill-defined problem spaces. Increasingly, schools are incorporating design thinking into their curricula, and a nascent body of research suggests that this instruction
can facilitate the development of 21st century skills and provides a constructivist framework for
STEM learning. However, while research suggests that iterative rapid prototyping can reframe
failure and lead to performance benefits, few studies focus on iteration and assess whether
students can learn this mindset and regard mistakes as learning opportunities. Turning to the
motivation literature, I propose that the process of rapid prototyping facilitates ill-defined
problem solving by providing specific proximal learning goals as students encounter setbacks or
failures. This reframes failure by encouraging and normalizing the experience, characterizing
mistakes as learning opportunities. Students are encouraged to and expected to fail early and
often as they test, seek feedback, and revise their work to iteratively improve their designs.
Moreover, this prototyping process promotes an incremental theory of intelligence, whereby
students believe that their effort will affect learning gains. In the following chapters, I present a
design thinking intervention to teach the iterative rapid prototyping process and mindset in a way
that can transfer to future tasks and situations.
CHAPTER 3: DESIGN THINKING INTERVENTION: A DESIGN CASE

Abstract

This design case describes the development of a brief design thinking intervention for middle school students. Design thinking, the problem solving style and process traditionally involved in engineering and other design fields, is rapidly gaining traction in K-12 education, where studies suggest that it benefits students in a variety of ways: bolstering collaboration, creativity, metacognition, and learning. However, many educators are still confused about what design thinking is and how it might work in their classrooms. This intervention illustrates one way to teach design thinking and was developed as part of an empirical study to determine if the prototyping process and philosophy could be taught for transfer into the classroom. I developed a 6.5-hour intervention to teach middle school students design thinking, ultimately aiming to facilitate transfer of the iterative rapid prototyping process and change in attitudes towards failure. In the intervention, students learned about the prototyping process and how designers use mistakes to incrementally improve their work. They then practiced applying this knowledge in two design challenges. In this paper, I describe the intervention and explain the rationale behind design decisions, detailing the research-based strategies that drove the design of this curriculum. Additionally, I identify key factors to consider when selecting appropriate design challenges. Last, I discuss the tradeoff between developing ideal instruction and conducting quantitative research and suggest ways in which educators and researchers can adapt this curriculum to fit their own needs.
Introduction

Design thinking, the problem solving style and process traditionally involved in engineering and other design fields, has rapidly gained traction across many contexts beyond those traditionally associated with design. Used to improve everything from hotels (Lub et al., 2016), to chronic disease care (Johnson et al., 2016), to the management of multi-billion dollar corporations (Ignatius, 2015), the rationale is that the way designers solve problems is of value to anyone who is trying to innovate and problem solve in the context of ill-defined problem spaces.

Design thinking is characterized as a nonlinear, often collaborative process of development, involving rapid prototyping and iterative refinement through testing and feedback. It is a process that entails taking risks and using failure as a learning opportunity. Consequently, this process and philosophy promote innovation and empower individuals in the face of complex problems (Carroll et al., 2010; Gerber & Carroll, 2012).

In the realm of education, design thinking is in vogue, and is increasingly included in science standards as an essential skill for middle school students (NGSS Lead States, 2013). Lauded as a valuable component to incorporate into curriculum, it both aligns with and supports 21st century learning goals (Koh et al., 2015). As the world and job market have changed, many have called for a similar shift in our education system, and design thinking holds major promise for bringing education into the 21st century. Studies of design thinking in classrooms suggest that it benefits students in a variety of ways: bolstering collaboration, creativity, metacognition, and STEM learning by providing a meaningful context within which students can hone various proficiencies.

While teachers are excited about the promise of design thinking, there exists some confusion around what exactly design thinking is and what it might look like in their classrooms
Design thinking is an umbrella term for a variety of competencies, mindsets, and philosophies (Kimbell, 2011), and a recent review paper broke the paradigm down into a grand total of 26 subcomponents (Razzouk & Shute, 2012). Generally speaking, design thinking is a problem solving process used in the face of complex problems whereby designers identify a human need, clarify the problem, come up with many solutions, and iteratively test and refine their designed product. Embedded in this process are a set of skills (i.e., collaboration, risk-taking), and a series of broad approaches (i.e., experimentation, empathy). However, in order to promote clarity and facilitate its success in the classroom, it is important to extract and focus on sub-components of the term.

While numerous studies have demonstrated the ways in which design thinking fosters certain 21st century skills and STEM learning, less explored is the way in which students may benefit from the culture of prototyping and the permission to fail attitude embedded in the process. With this in mind, I developed a brief intervention for middle school students, focused on the process of rapid prototyping, as part of an empirical research study on the benefits of design thinking education. My research questions concerned if students who participated in the design thinking intervention would learn the rapid, iterative prototyping process and transfer it into novel situations and undergo a motivational shift in how they react to failure. In the intervention, students learned the process and philosophy of design thinking by participating in carefully selected hands-on design challenges, intended to normalize and facilitate practice of rapid iteration across different types of complex problems. Throughout, students engaged in both individual and group reflections, received a small amount of direct instruction, and ultimately created brochures explaining design thinking to a hypothetical future student.
In this paper, I detail the curriculum of the intervention and explain the rationale behind design decisions. First, I define design thinking and provide an overview of current K-12 design thinking curricula. Next, I discuss the various research- and process-based factors that influenced the intervention. Using best practices from the transfer literature, research on social-psychological interventions, and the iterative design process, I aimed to facilitate (a) transfer of the design thinking process onto novel design tasks and prospective new situations, and (b) attitude change in response to mid-task failure and mistakes. I then describe my own design process, as well as the struggle to select appropriate design challenges to meet these aforementioned aims. Next, I describe the intervention. Last, I consider the trade-offs between designing ideal instruction and designing for quantitative research and suggest ways in which educators can adapt pieces of this curriculum to their own classroom instruction.

**What is Design Thinking?**

Defining design thinking is difficult; in a recent news article, a design thinking expert explained that it is a “bundle of mindsets and philosophies all wrapped up in one term” (Lahey, 2017). The term is simultaneously used to characterize (a) what designers do, (b) what designers know, and (c) more broadly, how they approach and cognize the task at hand (Kimbell, 2011). Design thinking is used to solve ill-defined problems, or problems lacking clear goals, problem spaces, and/or expected solutions (Simon, 1973). Some authors focus on the physical process of design, highlighting the ways in which designers create, seek feedback, and revise (Razzouk & Shute, 2012). In terms of what designers physically do, design entails repeated, iterative transitions across often-nonlinear steps (Plattner, 2010). These steps include:

1. empathizing with the user or the target audience of the design,
2. defining the challenge or problem one aims to solve,
3. ideation, or the act of coming up with a breadth of ideas for possible solutions,
4. prototyping, or building out models of one or more solutions, and
5. testing one’s idea(s) to gather feedback and gain insight on their strengths and weaknesses.

Others emphasize the skills, such as collaboration and metacognition, that are involved as practitioners “frame, explore, and re-frame ill-structured problems to derive design solutions” (Koh et al., 2015, p. v). Still others ascribe a set of mindsets or philosophies to the term, such as human-centeredness, culture of prototyping, and bias toward action (Carroll et al., 2010). For example, human-centeredness is the philosophy that problem solving should focus on the needs of human users. Ultimately, design thinking is all of these things: it is a problem-solving process to use in the face of complex or difficult problems (what designers do) that necessitates a set of skills (what they know) and embodies a specific philosophy (how they approach and understand their work).

**Culture of Iteration**

The focus of this intervention is on a common movement through the space, iterative rapid prototyping, which involves repeated cycles of ideation, prototyping, and testing as one refines a design into a desired product over the course of incremental development (Cross, 2011, Barry, 2010, Figure 2). As expressed by Tim Brown, CEO of the renowned design firm IDEO, design thinkers “try early and often” and “create an expectation of experimentation and prototyping” (Brown, 2008, p. 8). This culture of iteration, or repeated design activity, is one of four key design thinking *mindshifts*, or “reorientations of […] worldviews, routes, and propensities in problem solving” (Goldman et al., 2012, p. 15). I chose to focus on this sub-component due to its documented performance benefits and the way in which it appears to effect
how designers perceive mistakes and failures. Numerous studies of K-12, higher education, and professional designers have found that individuals who iterate outperform those who do not (Apedoe & Schunn, 2013; Bayles & Orland, 2001; Dow et al., 2009; Looijenga et al., 2015). Furthermore, as detailed in the following section, research suggests that iterative rapid prototyping reframes failure as an opportunity for learning by minimizing the affective impact of mistakes or setbacks (Carroll et al., 2010; Gerber & Carroll, 2012; Sadler et al., 2000).

![Diagram of rapid prototyping process](https://dschool.stanford.edu/groups/k12/wiki/606dd/Process.html)

**Figure 2.** The rapid prototyping process entails nonlinear, iterative movement through three steps. (adapted from [https://dschool.stanford.edu/groups/k12/wiki/606dd/Process.html](https://dschool.stanford.edu/groups/k12/wiki/606dd/Process.html))

**Reframing Failure**

Interconnected to the culture of prototyping is the philosophy of *permission to fail*; designers are urged to fail forward, with the attitude that any product will be riddled with mistakes in its initial stages and iteratively improve through testing and refinement across iterations (Babineaux & Krumboltz, 2013; Cross, 2011; Maccoby, 1991). A number of studies, both in the K-12 context and beyond, have suggested that rapid iteration reduces investment in any one design and shifts the focus off of perfection (Carroll et al., 2010; Sadler et al., 2000). As designers participate in rapid cycles of iterative prototyping, they learn that failures are simply a part of the process.

Iterative prototyping is often overlooked in classroom engineering and design activities (Kolodner et al., 2003), and I propose that promoting an iterative disposition and reframing failure are understudied benefits of bringing design thinking into K-12 education. This process
and mindset involved in design thinking look very different from the typical motivational landscape of the classroom. While design thinking celebrates failures across prototypes as to-be-expected learning opportunities and involves an iterative process of trying again by seeking feedback and revising one’s work, failure is a motivation killer in the classroom. Students are given few opportunities to iterate, and when given the chance, struggle with the revision process. *Trying again* is often a difficult hurdle for students to overcome. In a traditional motivation paradigm, a student’s experience of failure leads to disengagement (Schunk et al., 2014) and a decrease in her self-efficacy (Bandura, 1977), which then leads to decreased effort, decreased persistence, and makes her less likely to take on challenging tasks (Multon et al., 1991; Zimmerman, 2000). Experiences of failure reverberate to create a chain of negative effects, ultimately affecting academic performance. Additionally, fear of failure, or the motivation to avoid failure due to shame or embarrassment, is predictive of disengagement in the classroom and decreased GPA (Caraway, Tucker, Reinke, & Hall, 2003). Moreover, failure tolerance and risk-taking appear to decline as students enter middle school (Clifford, 1988). However, if students develop an iterative disposition, they can reap both in-task performance benefits and more long-term motivational benefits, whereby iterative testing and refinement turns failures into stepping stones towards success. See Chapter 2 for more detail on the various motivational mechanisms behind design thinking.

**Design Thinking Instruction**

Available research and case studies about design thinking instruction measure 21st century skill acquisition or STEM content gains, but few have focused on the learning of the process or its corresponding philosophy. Research on 21st century skill cultivation suggests that design thinking curriculum can facilitate collaboration (Carroll et al., 2010; Ching & Kafai,
creativity (Barlex & Trebell, 2008), metacognition (Kolodner et al., 2003; Sabag et al., 2014), technological savvy (Beyers, 2010; Bower et al., 2014; Ching & Kafai, 2008), and give students opportunity to work on authentic problems (Casey et al., 2011; Kangas et al., 2013). Moreover, in a review of science education programs incorporating design, Fortus, Dershimer, Krajcik, Marx, and Mamlok-Naaman (2004) concluded that most programs used design as a vehicle for constructing science knowledge, rather than teaching design.

While some design challenge-focused curricula focus on the process, these curricula are mostly found in higher education and engineering programs (Berland et al., 2013). There are a few exceptions; for example, Goldman et al. (2017) taught a month-long design curriculum to middle school students and found that students learned the steps of the process and importance of human-centeredness from pre to posttest. However, among K-12 instruction, design challenge-based instruction often engages students in both design and STEM learning, but prioritizes “scientific inquiry.” For example, the Design-Based Science (DBS) pedagogy helps high school students learn both scientific understanding and real world problem solving skills, but its goal “is not to instruct students about Design; we want them to engage in Design in order to learn science” (Fortus et al., 2004, p. 1085). Likewise, Sadler et al.'s (2000) series of design challenges for middle school students taught students science process skills. Similarly, the LBD curriculum has demonstrated both learning and transfer but of scientific inquiry skills and deep content knowledge (Kolodner et al., 2003).

In the present intervention, STEM learning is not the goal. Instead, I focused on rapid prototyping and the design thinking attitude towards failure in a way that is far more explicit than in many existing curricula, particularly for K-12 students. As proposed by Goldman and
Kabayadondo (2017), design instruction can be used for more than traditional content learning; it can help students develop mindsets that enable them to “approach problems in new ways, to experiment in finding solutions, to learn from mistakes…” (p. 9). Therefore, in the present intervention, I chose to focus on the design process and shine a light on features such as iteration and learning from mistakes that, I believe, hold particular promise for students.

**Rationale**

As design thinking becomes a recommended component of middle school instruction, it is important that educators have resources on and exemplars of how to implement this new style of teaching in their classrooms. This design case presents a way of teaching design thinking to K-12 students that leads to learning, transfer, and internalization of the philosophy, and therefore contributes meaningfully to a fledging body of research examining the implications of design thinking education in K-12 education. I propose that if middle school students add the design thinking philosophy and process to their academic toolbox, this mindset can affect a radical shift in performance and motivation. Keeping students motivated and engaged in school, particularly in the face of challenging work, is a constant struggle in the classroom. Educating students to thrive in the real world necessitates more than equipping them with skillsets and content knowledge: students must be willing to engage in and persist at tasks, even in the face of failure or setbacks. While experiences of classroom failure traditionally set in motion a cascade of negative motivational outcomes, the iterative rapid prototyping process has the potential to shift beliefs around failure and effort.

**Designing for Lasting Impact**

The goal of this intervention was to facilitate deep learning of the iterative rapid prototyping process and mindset of *permission to fail* such that students could apply this new
way of thinking about and solving problems on future complex tasks both in the classroom and
throughout their lives. Therefore, I relied heavily on best practices from the transfer literature
and research on social-psychological interventions. Transfer, broadly speaking, is the theory of
how knowledge acquired in one situation applies in other situations (Singley & Anderson, 1989).
When we teach students content and skills in the classroom, we implicitly expect that they will
be able to apply this knowledge in new contexts, on different content, and across long spans of
time. However, the literature suggests that transfer must be actively facilitated. Social-
psychological interventions are also intended to have broad and enduring impact. They are short
periods of instruction targeted at motivational mechanisms that have long-lasting effects on
student achievement. As explicated in the next two sections and related throughout this paper,
these bodies of research informed the types of activities chosen and style of instruction used
throughout the intervention.

Facilitating Learning and Transfer

First, this curriculum aimed to facilitate the transfer of design principles to novel
situations and tasks, and this played a huge role in informing various design decisions. Transfer
occurs to the degree to which there are deep structural or conceptual similarities mapped across
two situations (Chen & Klahr, 1999; Gick & Holyoak, 1983; Singley & Anderson, 1989).
Students come to see these similarities through the process of abstraction, or the extraction of
“some generic or basic qualities, attributes or patterns of elements” that affords application to a
wider range of instances (Salomon & Perkins, 1989, p 125). Abstraction leads to transfer by re-
representing knowledge in a way that maps onto a greater number of contexts, and studies
confirm that students who develop robust abstractions are more successful at solving transfer
problems (Gick & Holyoak, 1983).
To promote abstraction, educators can use specific instructional techniques that help students extract a common deep structure from concrete situations (Gentner, Loewenstein, & Thompson, 2003; Salomon & Perkins, 1989). This intervention is designed to facilitate abstraction through two overarching strategies: (1) providing opportunity for varied practice of design principles through design challenges, and (2) facilitating mapping of concrete “raw” instances and students’ prior experiences onto the broad design principles through bridging activities. Varied practice, particularly across expanding contexts, helps students develop more generalizable and flexible skills by promoting schema induction (Gick & Holyoak, 1983; Perkins & Salomon, 1988; Salomon & Perkins, 1989). Moreover, providing students with multiple cases can enable them to focus on common structural similarities and leads to greater transfer, whereas learning just one case may leave students focused on idiosyncratic surface features (Gentner et al., 2003; Gick & Holyoak, 1983). Additionally, instruction can facilitate transfer by bridging connections between particular instances and general principles, either through expository instruction or by provoking students to make these connections themselves (Perkins & Salomon, 1988). Throughout the description of the intervention, I explain how this transfer literature informed design decisions.

A Social-Psychological Intervention

In addition to facilitating transfer of the process to novel contexts, this intervention aimed to shift students’ attitudes around mistakes and low-stakes mid-task failures, with the intention of creating long-term benefits for student achievement. Prior research on social-psychological interventions includes interventions targeting implicit theories of intelligence (Blackwell et al., 2007; Wilson & Linville, 1982), stereotype threat (Good, Aronson, & Inzlicht, 2003; Aronson et al., 2002), and attributions (Walton & Cohen, 2011), and these interventions have demonstrated
longitudinal beneficial effects: increasing student performance, happiness, and even health. The present intervention aimed to change students’ affective and behavioral responses to mistakes and low-stakes failures experienced during tasks. Specifically, I hoped that, by learning design thinking, students would reframe failure in a way that would reverberate throughout their lives, resulting in more adaptive reactions to setbacks and willingness to try again.

This intervention borrowed many best practices from similar programming to better facilitate this motivational shift. As outlined by Yeager and Walton (2011), effective interventions (a) rely on impactful delivery mechanisms, whereby students actively participate, generate ideas, and advocate persuasive messages about the learned content; (b) affect self-reinforcing recursive processes that are already present in the student’s life; (c) are “subtle and stealthy” in that they are brief with no link to academic performance or stigmatization; (d) occur during timely academic gateways or moments of important transitions where students are more malleable or open to change; and (e) are personalized and tailored to each context they are implemented within. Regarding the first principle, design challenges are inherently constructivist, facilitating a high level of active participation. In terms of reinforcing processes, this intervention is designed to change how students feel and what they do each time they encounter a complex problem. As students react more resiliently to mid-task failures and iterate, they can do better on those tasks and become more confident in their abilities, leading them to be better able to tackle problems in the future. Applications of the remaining three prescriptions are further explicated throughout the description of the intervention.

**Design Team, Context, and Process**

This curriculum was developed as part of a quantitative research study of whether or not middle school students could learn the design thinking process, transfer the process of iterative
rapid prototyping, and internalize its philosophy around failure. I led the design team and am a PhD candidate in Cognitive Science in Education, with an MA in Instructional Design and Media and experience as a design thinking consultant to promote teacher innovation. The developed intervention and final research study served as my dissertation. During the iterative prototyping stage, I was joined by four graduate students, all with prior science or design thinking teaching experience. A professor of Learning Sciences with middle school science teaching experience and a former science teacher with experience working in over 30 schools on curriculum design served as consultants on the project.

I developed the curriculum over two years and implemented it with designer-as-instructor in three urban, low-income, racially diverse middle schools, replacing typical science classroom instruction. In between each full run of the intervention, the team conducted rapid prototyping cycles during which various design activities and lessons were piloted on small groups of graduate and middle school students outside of class time. Using best practices and learning science theory, I first developed a 40-minute intervention involving one design activity and tried it as part of a weeklong study with 36 students across 4 classrooms. This pilot study was ineffective, which was ascribed to a number of protocol violations, its brevity, and the use of only one design challenge. However, the pilot helped me to understand which aspects of design thinking were difficult for students to comprehend and how an iterative design task would play out in the classroom. I then ran a 4-month research practicum with four graduate students that met weekly to (a) distill the learning goals to a feasible size and phrase them in kid-friendly language, (b) determine the essential qualities of design tasks, and (c) pilot these tasks among graduate students. Next, I conducted extensive piloting with middle school students in small groups. Two to three small groups of students would do a design activity or hear a lesson,
followed by group debriefing and discussion to obtain feedback from the students. Each week I tweaked the lessons and design challenges based on this feedback and then tested anew with fresh groups of students. After careful revision and consultation, I worked closely with a classroom teacher to develop and run a full 4.5-hour intervention with two design activities on 78 students across her three middle school classes. Students participated in the intervention in their intact classrooms, during class time. The results of this intervention, both quantitative data and feedback from students and teachers, were largely positive, suggesting that students learned the taught components of design thinking and became more iterative after participating in the intervention. The longitudinal nature and scale enabled me to glean more nuanced feedback on how to improve the effectiveness of the intervention. Finally, six months later, I ran the final 6.5-hour intervention on 89 students across 4 middle school classrooms, with the support of a small team of researchers. Results of these two studies are briefly discussed towards the end of this chapter, and both studies are presented in detail in Chapter 4.

Many aspects of this design context follow Yeager and Walton (2011)’s prescriptions for effective social-psychological interventions. As recommended, this intervention was not linked to academic performance but rather couched in a research study where students’ performance did not affect their class grades. Additionally, I targeted students at a well-studied academic gateway that is particularly relevant for student motivation: the beginning of middle school. The middle school transition is marked by declines in self-esteem, decreased school engagement, and reduced failure tolerance (Clifford, 1988; Simmons et al., 1987; Watt, 2004; Wigfield et al., 1991), making it a critical juncture for affecting motivational processes. Furthermore, I worked closely with classroom teachers to personalize the intervention, meeting with them on multiple occasions leading up to the study and shadowing them as they taught their classes in an effort to
replicate their behavior management techniques and co-opt the structure of their lessons. A number of design decisions were made at their suggestion. For example, I initially planned for students to design an advertisement as the culminating activity, but the students at my study sites had prior experience designing brochures in their science classrooms, so I decided to switch the product to a brochure.

In addition to a reliance on learning sciences literature and this larger design process in creating this intervention, countless hours were spent carefully selecting and prototyping the specific design activities students would complete during the intervention. As explicated in the next section, I considered and prioritized a number of competing factors, both practical and related to the transfer literature, in selecting the final design challenges.

**Choosing Design Challenges**

This design case centers on a curriculum created specifically for use in an empirical, quantitative research study. Therefore, production of scientific data was a foremost concern and access to students was limited by Department of Education Institutional Review Board policies and requirements. This introduced unique constraints on the duration of instruction. Moreover, the need to measure iteration and persistence limited the types of design challenges I could use. To facilitate data collection, I chose challenges with comparable, objective performance metrics that could be completed within 1-2 class periods.

In addition to these overarching logistical considerations, I considered many other factors when deciding upon the ideal situations for students to practice their prototyping skills. The chosen design challenges were the product of three key questions: (1) what does success look like?, (2) what does iteration look like?, and (3) what does failure and its corresponding feedback look like? In selecting challenges, I chose tasks that would emphasize the importance of iteration
and allow students to practice using mistakes as stepping-stones towards success. Additionally, I aimed to facilitate varied practice, ensuring each task differed across certain factors to promote transfer.

**What does success look like?**

As recommended by Sadler, Coyle, and Schwartz (2000) in their review of effective design challenges, performance goals must be clear and universally understood by students, and the best type of competition is internal (i.e., improvement on one’s own design). Therefore, when determining what success should look like for students, I aimed for tasks with clear objective performance goals. Moreover, I developed design challenge worksheets to focus students on incremental improvement, rather than competition across the class. Furthermore, I ensured that none of the chosen design challenges had a “success” state. Instead, there was always room for improvement, in order to encourage iteration. Additionally, there was no one “correct” answer for the challenges I used. Design thinking is intended for use on ill-defined problems. Therefore, I aimed for design tasks that would encourage multiple creative approaches and a variety of high-performing solutions.

**What do iteration and progress look like?**

Due to my focus on promoting iteration, how each attempt played out and how it related to progress on the task were critical factors in selection of tasks. In order for students to develop iterative habits, they must encounter situations in which iteration is both plentiful and beneficial to performance. Therefore, I sought out design activities where students would be able to immediately, frequently, and meaningfully iterate. One way to encourage iteration is by using tasks that involve “tests against nature” whereby the student can carry out a preliminary test at any time (Sadler et al., 2000). For example, tasks where the goal is to make an object go a certain
distance enable physical tests whereby students can launch their designs to gain perspective on their achievement. Therefore, I looked for tasks that allowed for this type of testing.

Prior research suggests that iteration has a variety of meanings, from mere task repetition to “mental” iteration based on changes in the scope or abstraction level of the design task (Costa & Sobek, 2003; Jin & Chusilp, 2006). To promote clarity both for students and for measurement within the study, I defined iteration as a cycle of design culminating in the physical testing of a designed item (i.e., seeking feedback, releasing the design in a physical test). Therefore, I looked for tasks where I could count iterations as the number of times a student tested a design in a clear specific way.

Additionally, I eliminated tasks where the physical construction of a prototype or the testing phase was tedious or time-consuming. On a practical level, this led me to choose building materials that were easy for children to quickly build with (e.g., gumdrops and toothpicks instead of straws and tape) and to move away from tasks where iteration involved tiny, less conceptually-meaningful alterations. For example, I tossed around the idea of creating Rube Goldberg machines but found that most iteration on this task involved minute adjustments (e.g., shifting a paper a millimeter to the left), rather than the reconceptualization of a design.

An equally important factor to consider is the benefit to iteration. If students took many tries on a task but did not perceive that this effort was leading to improvement, it would undermine the intervention. Therefore, throughout the design process, I measured both objective performance and students’ subjective experiences of whether or not iteration was “worth it,” and I chose tasks where students could perceive their own improvement when asked to reflect upon it. For example, certain Rube Goldberg machine objectives were so difficult that students could
not improve despite making many changes to their designs. When asked, many believed that luck played a large role in their success, rather than meaningful and strategic design decisions.

**What does feedback look like?**

In addition to finding tasks where iteration was prevalent and led to improvement, I was concerned with students’ experiences of mistakes and the feedback provided within each task. The second objective of this curriculum, to shift students’ beliefs around failure, necessitated experiences where students were able to leverage their mistakes into learning opportunities. I considered various types feedback including physical, peer-judged, criterion-judged, and stakeholder-judged. Keeping with my requirement for more objective measures of performance, I aimed for tasks where feedback was physical, criterion-judged, or based on stakeholder feedback (i.e., time until device hits the floor; advice given by the “user”/experimenter). Additionally, in selected challenges, I intended for the feedback to be transparent (i.e., the way something falls through the air, the effect of math on an outcome). Not all design challenges have clear-cut feedback, with prescriptions for the next try. For example, I considered including a task to design a cooler that could keep an ice cube cold when exposed to heat from a blow dryer for 1 minute. Yet the feedback in this task was quite literally a “black box” (or silver, when students used aluminum). Without being able to view the ice cube melting, students were unable to understand how to change their designs.

**The Intervention**

Ultimately, my own iterative design process combined with learning sciences research informed the development of 6.5 hours of instruction, across 7 days. Conceptually, this intervention involved four components: (a) an initial anchoring design challenge (i.e., tower challenge), (b) a lesson on design thinking, (c) two contrasting design challenges where students
could practice applying content from the lesson (i.e., drop and playground design challenges), and (d) a culminating writing project for students to abstract and summarize their learning (i.e., brochure activity). All components served the joint goals of facilitating learning of design thinking, transfer of iterative habits, and attitude change in the ways students reacted towards mid-task mistakes or failures. Figure 3 shows the full timeline of the intervention. These components are explained in more detail in the following subsections.

![Timeline](image)

**Figure 3.** The intervention procedure is conducted over 6.5 hours across 3 weeks.

**Baseline Design Challenge**

Prior to any formal instruction about design, students were given an initial design challenge to build the *tallest* tower that would support a juice box, using a 50 gumdrops and 100 toothpicks (adapted from TryEngineering IEEE, n.d.). Students worked individually with no guidance and were given 30 minutes to build their towers and test them using juice boxes, as many times as desired (Figure 4). This baseline challenge served an empirical purpose by providing us with individual baseline information about students’ natural inclinations towards iteration and their design abilities. However, it served an additional function as an engaging introduction to design and an anchoring activity to refer back to during the future lessons on design thinking. Drawing on the factors to consider when choosing design challenges, this activity had a clear objective performance goal, multiple routes towards success, no “ideal” answer, and facilitated iteration since students were able to quickly assemble their towers using
the materials and conduct quick tests with a juice box. In this task, iterations were counted as each time a student asked to test with a juice box. Without any lessons on iteration, 28% of students did not iterate at all and only tested once at the end of the challenge, 24% tested twice, 24% tested three times, and the remaining 22 students (24%) tested from 4 to 12 times. Feedback was physical; in addition to seeing the height of a tower, students could watch how their towers stood strong or contorted in response to the weight of the juice box.

![Tower Challenge](image)

**Figure 4.** Tower challenge (a) goals and rules, (b) materials, and (c), sample designed towers (adapted from TryEngineering IEEE, n.d.)

**Introducing the Design Process**

Next, during the initial design thinking lesson, students were taught a set of key terms. Students learned a process-focused definition of design as *a way to take action to solve a tricky problem*. Tricky problems were defined as problems that are new to you, with many ways to solve and/or multiple solutions. I then introduced *design thinking* as what designers think and do...
in the face of tricky problems. I distilled the philosophy into three components: (1) Try early and often, (2) Make mistakes and learn from them, and (3) Go through cycles of *Make, Test, Think* (Figure 5). Students learned that design thinkers dive in and try something quickly, followed by many more tries. While trying to solve the problem, design thinkers make lots of mistakes. However, design thinkers welcome these mistakes because they can learn from them. Moreover, the process design thinkers use is called *Make, Test, Think*: designers *make* something, *test* it to see their mistakes and learn what could be better, and then *think* about what happened in the test to decide what to do next. Importantly, design thinkers do this process *early* and *often* in order to make their designs the best they can be. As will be explicated across the rest of this section, students reviewed, applied, and reflected on these three components throughout the intervention. By repeatedly connecting the three components to concrete instances, instruction aimed to bridge understanding, facilitating abstraction and transfer.

**Figure 5.** Three design thinking principles taught through the intervention

Instruction involved a lecture alongside a PowerPoint presentation, with frequent pauses for discussion questions and reflection. Throughout, the instructor strived to encourage active participation and facilitate connections between this content and what students already knew.

After defining design, the instructor briefly talked about *who* designs, naming varied and diverse
everyday designers such as architects, teachers, programmers, researchers, and students. When going over the three key things that design thinkers do, each point was elaborated through a story, discussed in small groups, and then reviewed as a class. For example, when discussing how designers make mistakes and learn from them, the class started with a quote from Michael Jordan: “I’ve failed over and over again in my life and that is why I succeed.” Students volunteered their own interpretations of the quote, and then, as a group, went over the concept of learning from mistakes. Next, students turned and talked to a partner about a time in their lives when they learned from a mistake. Then, they shared out as a class, and the instructor provided students with additional strong and varied examples of ways to learn from mistakes.

The class ended by applying design thinking in three contexts. First, students viewed a short StoryBots video about the Wright brothers and discussed how the Wright brothers were design thinkers, referencing all three components (StoryBots, 2014). Next, instruction circled back to the set of everyday designers and discussed how they use design thinking. For example, a video game programmer debugs her software, thereby making mistakes and learning from them and taking many tries. Last, instruction connected the lesson to the gumdrop towers students made earlier that week. The instructor brought out a very tall tower and told an anecdote that was true for many students in the classroom: a student spends the entire 30 minutes building a very tall tower. At the end of the 30 minutes, she puts a juice box on the tower and it collapses. Students then discussed, in small groups and as a class, how this student might have done this task differently, using their new knowledge of design thinking. As in all discussions, the instructor brought the class to an understanding that included all three key ideas in design thinking.
Design Challenges

During week two of the intervention, students worked in pairs or trios on two distinct design activities to practice iteration and witness the ways in which early failures lead to learning and better outcomes. Students first completed a more physical and engineering-like design task: the drop challenge. Next, students participated in a more school-like task where they were tasked to design the optimal playground space using graph paper. In the drop challenge, students worked for 40 minutes, in groups of three, to create a device to keep an index card in the air as long as possible, using a variety of materials (based on an activity designed by Carpinelli, Kimmel, & Rockland, 2014, Figure 6). For the playground challenge, students worked in pairs to design the most “fun” paper playground comprised of varying sized equipment with different fun star ratings (Figure 7). “Fun” was a multiplicative relationship between the total number of “fun stars” in one’s playground and the diversity of included equipment (based on a task from DefinedSTEM, n.d.). Large items were worth more fun stars, but importantly, the smallest items had a greater density of stars, such that using smaller playground pieces resulted in a higher score. This task was spread over two class periods, for a total of 55 minutes. Students were randomly assigned to groups for these activities, and their classroom teacher suggested minor alterations based on her knowledge of students’ peer relationships to ensure that students in each group would be able to adequately work together.
**Drop Challenge**

(a) **GOAL:** Design a device that will keep ONE INDEX CARD in the air as long as possible after you let it go.

**SCORE:** The time your device is in the air to the moment any part of it touches the floor

**RULES:**
- You must include 1 index card in the design
- You can use AS MUCH OR AS LITTLE
- One team member will RELEASE your device

(b) **MATERIALS**:
- Scotch Tape
- Scissors
- 10 straws
- 10 rubber bands
- 5 index cards
- 5 8.5x11 paper
- 3 11x17 paper

*each device may include no more than the above amounts. Students are able to request more materials as needed to create multiple devices.

**Figure 6.** Drop challenge (a) goal and rules, (b) materials, and (c), sample designed drop devices with their scores on the challenge (adapted from Carpinelli, Kimmel, & Rockland, 2014)

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**Playground Challenge**

(a) **GOAL:** Design a playground with the highest FUN SCORE.

**FUN SCORE:** # of different types of equip. x total fun stars

**RULES:**
- You can use AS MANY OR AS FEW of the playground cut-outs
- All equipment MUST fit inside the fence and cannot overlap
- Can rotate pieces and put them next to each other

(b) **EQUIPMENT OPTIONS:**

**Figure 7.** Playground challenge (a) goal and rules, (b) five equipment options, each with a different “star” value, and (c) sample designed playgrounds with their calculated fun scores (adapted from DefinedSTEM)
As students completed each design challenge, they were scaffolded through three “macro” iterations of the process Make, Test, Think, using guided worksheets (Figure 8). At each Make, students crafted their designed items. During this time, students were able to engage in “micro” iteration, defined as spontaneous test-retest iterations which are common in design activities (Barlex & Trebell, 2008). For the drop task, this involved testing out a device by releasing it and gauging its descent time. For the playground task, this involved calculating a fun score. To encourage students to conduct their own “tests against nature” and make the iteration process more salient, students were told to note these micro-iterations by tallying them in the Make section of the worksheet. At each Test, an experimenter came around to give feedback or test the designed item and students recorded their scores. In the drop challenge, instructors used a stopwatch to time the descent of the designed device. In the playground challenge, instructors helped students calculate a fun score and then provided two pieces of feedback from a list of six options (e.g., If you reorganize, could you fit more equipment?, Try adding more different TYPES of equipment and see how that changes your score.).

In the first two Think periods, students were pushed to think about what went wrong in the test and how they might improve the design (Figure 8a). On the final Think, students explained how their design processes followed the tenets of design thinking (Figure 8b). Each design challenge culminated in an instructor-led discussion, expanded upon in the following section.
Figure 8. Drop design challenge worksheets. Students completed three rounds of Make, Test, Think. They recorded micro-iteration “tries” during each Make, received a score during each Test, and reflected during each Think.

As with the tower challenge, both of these tasks employed objective performance goals. The worksheets pushed students to focus on incremental improvement, rather than competition across groups. The drop challenge had no clear success state and many solution paths, and while the playground challenge technically has an optimal solution, no student reached this solution and there are multiple layouts that would result in the highest score. Both tasks provided ample opportunity for iteration, which was delineated by the test of a design. Macro-iterations involved more “official feedback,” were enforced, and were structured by the worksheets while micro-iterations involved tests the students could do on their own (i.e., students could drop their devices at will in the drop challenge and use multiplication to check on their fun scores in the playground challenge), were merely encouraged, and were tallied in the Make sections of students’ worksheets. Ultimately, students in the two studies of this intervention tested an average of 16
times throughout the drop challenge and 4 times during the playground challenge (in addition to the three larger cycles of iteration enforced in each task). Both tasks facilitated students’ abilities to practice trying early and often. Moreover, students benefitted from and tended to see benefit to iteration. Data from both studies indicated that, across the tasks, 50% of groups improved, such that their final prototype was their best out of the three rounds, and 60% perceived improvement when asked if their designs got better over time. Last, feedback on these tasks was intentionally transparent. The drop task feedback was physical and criterion-judged (i.e., time until the device hits the ground) while the playground task feedback was criterion-judged with stakeholder feedback (i.e., fun score and two pieces of feedback from the experimenter). The former is rather typical for an engineering design challenge, and the latter was designed to resemble how a student might receive feedback in the classroom.

To facilitate transfer, this intervention leveraged the initial design challenge and the two design thinking process challenges as opportunities for varied practice and analogs for fruitful abstraction. In both challenges, students were able to practice iteration and witness the ways in which testing and revealing one’s mistakes earlier in a timed design challenge (rather than waiting until the end) can lead to learning and better outcomes. As students moved from the more playful drop and tower challenges towards the math-heavy and school-like playground challenge, I aimed to expand their understanding of the conditions under which design thinking can apply. Students practiced the same iterative process and used the same reflective language (i.e., make, test, think, try early and often) across both tasks. However, the challenges involved different contexts (physics vs. math) and relied on different types feedback (physical, immediate feedback vs. mathematical and human feedback). Additionally, the iterative design process provided ample opportunity for practice both within each challenge and across the two
challenges; students were able to practice trying early and often, using *Make, Test, Think*, and learning from their mistakes. Moreover, reflection opportunities during each challenge served as bridging activities. Students were guided to map concrete instances of design onto the broader design concepts during the final *Think* period. This connected the lessons to each challenge and reminded students of the overarching principles they were practicing.

**Individual Reflection and Class Discussions**

In addition to *Think* sections of the design challenges, a number of individual reflections and classroom-wide discussions were peppered throughout the intervention to facilitate learning and transfer. Students participated in written individual *Do Now* reflections, which asked them to elaborate on material learned the prior day (e.g., *How did you practice being a good designer during the drop challenge?*). Additionally, each design challenge ended with a class discussion led by the head experimenter, who used a bulleted script with target discussion goals that she summarized for each class at the end of the discussions. To facilitate abstraction through bridging, the reviews and reflections bookending each intervention day tied the day’s activities to the design thinking principles. The guiding questions pushed students to talk about their design experiences using the common design thinking vocabulary (i.e., *How has design thinking helped you today?; Can you think of a time today when you made a mistake? What happened next?*).

**Brochure**

After the second playground challenge, students began the brochure activity. In this, the goal was to teach hypothetical future students how to be design thinkers. Students were provided with a cover story: *We cannot run this study next year, but we want to make sure that future students will also know about this great way to solve problems. It is up to you to make brochures that can teach future students about everything you have learned!* The instructor gave a 10-
minute review of the key concepts and activities students had done thus far. Then, students spent the rest of the class using worksheets to plan out their answers to the brochure questions. The following day, students were given a structured worksheet with sentence starters and a variety of images to cut and paste into their brochures (Figure 9). These eight prompts asked students to define key terms and the key components of design thinking, explain how they used design thinking in the drop and playground challenges, and come up with a novel scenario in which design thinking might be useful. Students had one hour to develop their own brochures.

This summative brochure activity was the pièce de résistance of efforts to facilitate transfer and attitude change. It facilitated abstraction by explicitly asking students to develop a schema for situations where rapid iteration applies. Moreover, students were required to draw connections between the activities and the principles of design thinking. As students applied design thinking to a new context, they bridged understanding to aspects of their own lives. The goal of the brochure activity was this active schema construction and ultimately a robust understanding of the applicability conditions of design thinking. From the social-psychological perspective, this activity was based on writing activities done in other interventions where students advocate a persuasive message to a new audience (e.g., Good, Aronson, & Inzlicht, 2003; Walton & Cohen, 2011). This type of delivery mechanism is considered a powerful way to induce deep processing and transfer (Yeager & Walton, 2011).
Figure 9. Brochure design challenge. Students responded to a set of 8 prompts aimed at facilitating comparison across design experiences and abstraction of key principles of design thinking.

Results: Transfer and Attitude Change

Our two studies – one of a preliminary version of the intervention (Study 1) and one of the final curriculum (Study 2) – found behavioral and self-report evidence of transfer and attitude change (Chapter 4). Students in these studies participated in either this design thinking mindset intervention or a comparison STEM-focused (STEM) intervention where students did the same activities but were focused on science and math content rather than the design thinking process.

The key transfer measure was a new engineering design challenge, given after the intervention, where students were tasked with building a boat that could float and support as many nickels as possible out of a paper, straws, and tape (adapted from Kornoelje & Roman, 2012). Unlike the intervention design challenges, iteration was optional on this task and measured as each time a student tested a boat in a tub of water. Students were given 30 minutes to build and test as many boats as desired, and were measured on (a) time to first iteration (try early), (b) number of iterations (try often), and (c) maximum number of nickels held by a given boat (performance).
found strong evidence of transfer of the design thinking process. Compared to students in the STEM condition, students in the intervention iterated earlier and more frequently on the transfer design challenge, and in the final study, they demonstrated higher performance on the task.

Additionally, a number of survey measures suggested that students were internalizing this process in ways that would facilitate future transfer. In both studies, pretest and posttest measures assessed iterative disposition, measured as the number of “attempts” students requested on eight future design and classroom tasks (e.g., You are doing a really hard math problem on your math homework and you can tell that the answer looks wrong. How many times would you retry the problem?). On these items, students in the intervention asked for significantly more attempts at posttest, compared to students in the STEM condition. Additionally, during the Brochure activity, students were asked to identify a scenario in which design thinking would be useful, and 42% (Study 1) and 66% (Study 2) of students in the intervention were able to generate an adequate novel context. Additionally survey measures from both studies found that students in the design thinking intervention learned the vocabulary and key components of design thinking (STEM students did not), while students in the STEM condition learned relevant science and math concepts taught before their design tasks (design thinking students did not).

Moreover, in Study 2, survey measures assessed students’ abilities to apply the design thinking process in two novel contexts. Students were given “mid-task failure scenarios” (i.e., a student is in the middle of a design challenge and is doing terribly, a student turns in the first draft of an essay and the teacher covered it in red pen) and asked what to do next. As measured on these survey items, students in the intervention became better at using the design process in the face of a mid-task failure, compared to STEM students. Taken together, this data suggests that students internalized design thinking knowledge, could map it onto new prospective
scenarios, and were able to transfer the process by iterating earlier and more frequently on novel design challenges.

Moreover, results from Study 2 suggest, at least in the short-term, the intervention was effective at shifting how students perceived failure. Pretest and posttest survey items measured students’ affective reactions to design failure, derived from Clifford’s (1998) *School Failure Tolerance scale*. Adapting 9 of his affect items, the 5-point Likert scale asks students how much they agree with various maladaptive affective responses to failure during a design challenge (e.g., *While designing something in a design challenge, I would feel terrible if I made a mistake*). I found that students in the intervention developed significantly more adaptive affective reactions to failure, as measured from pretest to posttest, while students in the STEM condition did not change on this measure.

**Limitations and Future Directions**

While the results of both studies of this intervention are promising, there are a few limitations to the instruction I developed. As mentioned earlier, the essential affordance of producing quantitative scientific data was limiting in a number of ways, necessitating a shorter, less integrative curriculum than would have been ideal. The length of the study was limited to 9 hour-long class periods across three weeks, which was the maximum time allotted to disrupt the everyday routine of students’ science classes. The longest challenge lasted one hour. However, the multi-faceted nature of true iterative design is often far more longitudinal. In a typical classroom, a single design challenge can take a month or more to complete (Fortus et al., 2004; Kolodner et al., 2003). Furthermore, the transfer literature calls for extensive varied practice, and, while varied, this intervention would likely be more effective if it were extended over time with an increased dosage.
Moreover, the necessity of measurement led us to give students short design challenges with clear objective performance criteria. While educators recommend challenges with a diversity of target goals to increase interest (e.g., design *anything* that uses a chemically-based heating or cooling system, Schunn, 2011), these sorts of challenges are inherently more complex, requiring more hours of work and making it difficult to compare performance across students. While I could not use highly complex tasks in this intervention, I would encourage classroom teachers to consider making target goals more flexible.

Another limitation to this intervention is that it focuses on iterative rapid prototyping at the expense of integrating target skills into a more holistic curriculum or full design process. As an isolated event taught by teacher-researchers rather than their usual classroom teacher, the design thinking unit was not connected to any larger learning units or integrated into future science curriculum after I left the school. While study results showed learning gains on design knowledge and performance benefits, students did not learn any specific science content from this intervention. Future work should integrate design thinking instruction with STEM instruction. Additionally, in narrowly defining the scope of design thinking, I chose to use fairly artificial design tasks, removing human-centeredness and authenticity from the equation, which are often characteristic of design thinking. While I maintain that there is value in focusing on the iteration subcomponent, many proponents of design thinking focus on its emphasis on empathizing with the user, and educators suggest that challenges to help others are authentic and motivating (Schunn, 2011). Ideally, design activities would be lengthier, involve more complex, authentic, intrinsically motivating challenges, include the whole process, and be integrated more fully into students’ yearlong curriculum.
Although this curriculum was developed with research in mind, I have detailed a quick way to introduce the main ideas of design thinking into a middle school classroom. Without the burden of measurement, the present curriculum could be co-opted piecemeal or in its entirety and integrated into normal classroom practice, both within and outside of STEM domains. In fact, this is the type of implementation I would most recommend. As elucidated by Carroll et al. (2010), “Teachers face a struggle to teach students all they need to learn, and if they are asked to integrate design thinking into their classrooms it needs to be done in a way that synergizes instruction that is already in place” (p. 51). Beginning with the framework proposed here (i.e., initial design challenge to anchor, lesson on three components, two contrasting challenges, activity where students write a message to a new audience) and taking into consideration the important factors to consider when selecting design challenges, teachers could develop a modified curriculum that relates more closely to the content taught in their classrooms.

There are an increasing number of exemplars illustrating how to teach specific content through design thinking. Rather than add to that pot, I instead propose including an emphasis on iterative rapid prototyping and reframing failure that could lead to more broad benefits for students’ persistence and willingness to try again when problem solving. Future work on this sort of intervention should seek to integrate instruction more thoroughly within existing classroom curriculum. Additionally, educators should explore how to teach multiple design thinking competencies within a single design challenge.

**Conclusion**

The present design case illustrates one way to teach design thinking to middle school students, through a brief intervention teaching the process of iterative rapid prototyping and mindset around failure. Using my own iterative design process, I created 6.5 hours of instruction,
including three carefully crafted design challenges. By enabling varied practice, promoting abstraction through bridging instruction, and using impactful delivery mechanisms such as the brochure activity, I aimed to promote both transfer of the iteration process and internalization of the philosophy around failure, such that students reframed mistakes as learning opportunities. Results of two studies demonstrated its effectiveness: students transferred the iterative disposition to a new design challenge and shifted their attitudes towards failure. While this curriculum was effective, there are aspects that could be improved. Presenting students with more holistic, longitudinal, and integrated design challenges that have greater flexibility would likely increase engagement and lead to more robust transfer.

The present design case adds meaningfully to the nascent, growing body of work exploring how to teach design thinking to K-12 students. I focused on just one aspect of design: iterative rapid prototyping, and aimed for students in the intervention to learn the process and its corresponding philosophy surrounding failure. Hopefully, as educators and instructional designers begin to document and detail their forays into design thinking, it will shift from being a trendy buzzword to a meaningful constructivist pedagogy implemented throughout K-12 education.
CHAPTER 4: EMPIRICAL INVESTIGATION

Abstract

Design thinking, with its emphasis on iterative rapid prototyping, portrayal of mistakes as learning opportunities, and mantra of “fail early and often,” stands in stark contrast with the typical high-stakes, failure-averse culture of the classroom. However, few studies have examined the potential motivational benefits for students who learn design thinking. In two quasi-experimental studies with 78 and 89 students, respectively, I explored the effectiveness of a brief design thinking intervention, intended to teach students the iterative process of design and its unique philosophy surrounding failure, whereby mistakes are natural and expected learning opportunities as students work towards increasingly better solutions to tricky problems.

Students in an iterative design mindset condition (Mindset) learned about iterative rapid prototyping, employed the process on two different design challenges, and developed brochures about design thinking. In a comparison STEM-focused condition (STEM), students participated in an analogous intervention focused on the importance of using science and math in design.

Results from both studies indicated that Mindset students learned the philosophy and process of iterative rapid prototyping from the brief intervention and were able to transfer the process to a target design task. Furthermore, results confirmed a performance benefit to iterating early and often. Moreover, Study 2 results suggested that students in the Mindset condition developed more adaptive attitudes to failure, compared to students in the STEM condition. These studies provide compelling evidence that design thinking education has the potential to instill persistence in the face of ill-defined problems, reframe failure, and improve task performance for middle school students. This work also presents a model for evaluating the design thinking process using quasi-experimental studies and quantitative methods.
Introduction

Design thinking, the cyclical problem solving process traditionally involved in engineering and design, has become a buzzword in a variety of fields. The term has gained traction in contexts beyond those traditionally associated with design, with the general reason being that the way designers solve problems is of value to anyone who is trying to innovate and problem solve in the context of ill-defined problem spaces. The design thinking process entails repeated, iterative transitions across nonlinear steps of (a) empathizing with the user, (b) defining the challenge, (c) ideation, (d) prototyping, and (e) testing (Plattner, 2010). Design thinking is on its way to becoming a required skill for middle school students; the Next Generation Science Standards’ (NGSS) engineering design performance expectations for middle school state that students should be able to define a design problem, develop an iterative process for testing it, and analyze feedback to evaluate their solutions (i.e., participate in the design thinking process, NGSS Lead States, 2013). However, while researchers have begun studying how design thinking interactions play out in the classroom, there is still little experimental or quasi-experimental research on the explicit benefits of design thinking for K-12 students (Razzouk & Shute, 2012).

How can this process help students succeed in the classroom and beyond? In the present research, I investigate how learning design thinking may benefit students’ motivation and performance. Particularly, I explore how a brief design thinking intervention can affect students’ attitude towards failure and proclivities towards “trying again” or iterative dispositions, as they encounter complex problems.
Background and Rationale

Design Thinking in K-12 Education

Design thinking is a complex umbrella term simultaneously used to characterize what designers do, what designers know, and more broadly, how they approach and cognize the task at hand (Kimbell, 2011). Some definitions focus on the physical process of design, highlighting the ways in which designers create, seek feedback, and revise (Razzouk & Shute, 2012). Others emphasize the skills, such as collaboration and metacognition, that are involved as practitioners “frame, explore, and re-frame ill-structured problems to derive design solutions” (Koh et al., 2015, p. v). Still others ascribe a set of mindsets or philosophy to the term, such as human-centeredness, culture of prototyping, and bias toward action (Carroll et al., 2010). The present research views design thinking as a problem-solving process to use in the face of complex or difficult problems that embodies a specific philosophy around failure and prototyping.

This focus on failure and prototyping is relatively unexplored in design thinking research, particularly in K-12 populations. Rather, the nascent body of studies on design thinking in K-12 education suggests that it is often used as a means to cultivate 21st century skills (Koh et al., 2015), incorporated into science education programs as a vehicle for constructing science knowledge (Fortus et al., 2004), or leveraged to interest students in engineering careers (Bottoms & Anthony, 2005). Research on 21st century skill cultivation suggests that design thinking curriculum can facilitate collaboration (Carroll et al., 2010; Ching & Kafai, 2008; Kangas et al., 2013; Kolodner et al., 2003), creativity (Barlex & Trebell, 2008), metacognition (Kolodner et al., 2003; Sabag et al., 2014), technological savvy (Beyers, 2010; Bower et al., 2014; Ching & Kafai, 2008), and give students opportunity to work on authentic problems (Casey et al., 2011; Kangas et al., 2013). Moreover, much current design education focuses on scientific inquiry skills and
knowledge. For example, the Design-Based Science (DBS) pedagogy helps high school students learn both scientific understanding and real world problem solving skills, but its goal “is not to instruct students about Design; we want them to engage in Design in order to learn science” (Fortus et al., 2004, p. 1085). Likewise, Sadler et al.'s (2000) series of design challenges for middle school students taught students science process skills. Similarly, the Learning By Design (LBD) curriculum has demonstrated both learning and transfer of scientific inquiry skills and deep content knowledge (Kolodner et al., 2003). This existing research demonstrates many benefits of using design thinking in education, but few studies focus on learning the process of design or its corresponding philosophy explicitly. Moreover, while some research suggests that students can learn the design process from these types of instructional units (Lachapelle & Cunningham, 2007), other research suggests that without explicit focus on the process, students are left with only superficial understanding of design (Berland et al., 2013).

Rather than using design thinking to teach STEM content or foster the traditional set of 21\textsuperscript{st} century skills, the present research teaches prototyping and the design thinking attitude towards failure in a way that is far more explicit than in many current curricula. As explicated in the next section, a growing body of qualitative evidence suggests that this prototyping process and permission to fail mindset change the way designers perceive mistakes. However, little formal empirical work has been conducted on design thinking, especially with K-12 populations or through quasi- or experimental study designs, and the field has called for more quantitative and focused research (Koh et al., 2015; Razzouk & Shute, 2012). Moreover, while existing 21\textsuperscript{st} century skill frameworks do not highlight motivational constructs, a “try again” attitude and resilience in the face of mistakes are undoubtedly important skills for the ill-defined problems of the 21\textsuperscript{st} century. Therefore, the present research includes two quasi-experimental intervention
studies where students received explicit instruction on the iterative design process and its corresponding mindset around failure. My research explored how teaching these components to middle school students could change the ways they engage with complex problems, reframe how they perceive failure, and ultimately, affect classroom performance.

Iterative Rapid Prototyping and Reframing Failure

Iterative rapid prototyping, or repeating the design process to incorporate new information, is a key element of the design thinking process that illustrates persistence or willingness to try again, affects performance on design tasks, and shifts how designers perceive mistakes and failures. Design thinking emphasizes rapid cycles of developing prototype solutions early in the process, testing them to receive feedback, creating a new prototype based on that feedback, and so on. In fact, this culture of iteration is one of four key design thinking mindshifts, or “reorientations of […] worldviews, routes, and propensities in problem solving” (Goldman et al., 2012, p. 15). This culture is important for performance; numerous studies of K-12, higher education, and professional designers have found that individuals who iterate outperform those who do not (Apedoe & Schunn, 2013; Bayles & Orland, 2001; Dow et al., 2009; Looijenga et al., 2015). Yet importantly, the choice to iterate and therefore seek out feedback that could potentially be negative is a difficult one; it is easier to consider an initial solution “good enough” and call it quits (Schunn, 2011), and qualitative evidence from studies of prototyping suggest that individuals feel anxiety when pushed to iterate early and frequently (Dow et al., 2009). More broadly, studies of adolescents have documented that students do not actively seek out feedback (Good et al., 1987; Newman & Goldin, 1990). Therefore, students’ decisions to iterate across mistakes demonstrate overcoming a motivational hurdle, to try again with the determination to improve.
Furthermore, research suggests that the process of iterative rapid prototyping reframes failure as an opportunity for learning by minimizing the affective impact of mistakes or setbacks (Carroll et al., 2010; Gerber & Carroll, 2012; Sadler et al., 2000). Interconnected to the culture of prototyping is the philosophy of permission to fail; designers are urged to fail forward, with the attitude that any product will be riddled with mistakes in its initial stages and iteratively improve through testing and refinement across iterations (Babineaux & Krumboltz, 2013; Cross, 2011; Maccoby, 1991). Studies, both in the K-12 context and beyond, have suggested that rapid iteration reduces investment in any one design and shifts the focus off of perfection (Carroll et al., 2010; Sadler et al., 2000). As designers participate in rapid cycles of iterative prototyping, they learn that failures are simply a part of the process. Consequently, a student’s choice to iterate in the face of a complex problem both illustrates a tenacity and more broadly, may alter how students view failures or mistakes.

Iterative rapid prototyping is often overlooked in classroom engineering and design activities (Kolodner et al., 2003), but I propose that promoting an iterative disposition and reframing failure are understudied benefits of bringing design thinking into K-12 education. This process and mindset involved in design thinking look very different from the motivational landscape of the classroom. While design thinking celebrates failures across prototypes as to-be-expected learning opportunities and involves an iterative process of trying again by seeking feedback and revising one’s work, failure is a motivation killer in the classroom. Students are given few opportunities to iterate, and when given the chance, struggle with the revision process. Trying again is often a difficult hurdle for students to overcome. However, if students develop an iterative disposition, they can reap both in-task performance benefits and more long-term motivational benefits, whereby iterative testing and refinement turns failures into stepping stones.
towards success. As described in detail in Chapter 2, iteration interacts with motivation in many ways. Ultimately, the iterative rapid prototyping process gives students a framework for how to overcome mistakes and can help them internalize the belief that their effort and energy is worthwhile.

To my knowledge, there is only one systematic study of K-12 students that assesses the connection between design thinking, iteration, and performance. Conlin et al. (2015) taught middle school students to either seek feedback or create many prototypes at once. On an assessment using computer-based games, the authors found that, for low achieving students, learning a specific design thinking strategy led them to implement that strategy in the game. Furthermore, both of these strategies led to increased learning. The present study differs from Conlin et al. (2015) in that it focuses on fostering incremental prototyping (as opposed to parallel), and my assessments involve future design tasks and traditional classroom tasks, rather than games. Additionally, my study explores the ramifications of how learning this philosophy and process will affect students’ attitudes towards failure. To my knowledge, there is no quantitative work on this connection thus far.

**Teaching For Transfer**

As the goal of my instruction is to help students develop iterative habits and attitudes towards failure that extend beyond the timeframe of the study and into other contexts, the present research is concerned with teaching students design thinking in a way that will lead to transfer. Transfer, broadly speaking, is the theory of how knowledge acquired in one situation applies in other situations (Singley & Anderson, 1989). When we teach students content and skills in the classroom, we implicitly expect that they will be able to apply this knowledge in new contexts, on different content, and across long spans of time. However, the literature suggests that transfer
must be actively facilitated. Transfer occurs to the degree to which there are deep structural or conceptual similarities mapped across two situations (Chen & Klahr, 1999; Gick & Holyoak, 1983; Singley & Anderson, 1989). Students come to see these similarities through the process of abstraction, or the extraction of “some generic or basic qualities, attributes or patterns of elements” in some internal manner than affords application to a wider range of instances (Salomon & Perkins, 1989, p 125). Abstraction leads to transfer by re-representing knowledge in a way that maps onto a greater number of contexts, and studies confirm that students who develop robust abstractions are most successful at solving transfer problems (Gick & Holyoak, 1983). Two ways in which instruction can enhance abstraction and thereby transfer are by providing opportunities for extensive varied practice and by facilitating mapping of concrete “raw” instances to decontextualized concepts (Salomon & Perkins, 1989). Applying this research, the present intervention is designed to facilitate transfer by giving students numerous design challenges, in a variety of contexts, and by encouraging mapping of aspects of each concrete design task and their own life experiences onto abstract design components through reflection activities peppered throughout instruction.

The Present Research

Overview

The present research used a quasi-experimental design to evaluate how design-thinking education can promote an iterative disposition and reframe failure. The developed curriculum explicitly taught design thinking for its own sake and its motivational repercussions, rather than using it as a means to an end. The connections between design thinking education, willingness to iterate, and attitudes towards failure are largely unexplored, particularly for K-12 students or through quantitative research methods. Therefore, this work stands as an important contribution
to the growing body of quantitative work on design thinking. By promoting an iterative disposition and reframing failure for early middle school students, can instruction in design thinking change how students think about mistakes and failures, and increase students’ willingness to iterate and persist in the face of mistakes or setbacks?

This paper presents the results of two studies. In both studies, students in the iterative design mindset (Mindset) condition participated in a brief design thinking intervention where they were taught the core philosophy of the process, used this process to complete two design challenges, and illustrated their understanding by creating a brochure about the topic. Comparison classrooms participated in an analogous STEM-focused (STEM) intervention where they were instructed to “use what you’ve learned in school” when developing their designs and were taught relevant science and math content to employ in each design challenge. This comparison is ecologically valid in that the goal of many traditional design and engineering activities is to help students deeply learn and apply specific science content (Fortus et al., 2004). I chose to teach a design curriculum in both conditions, rather than compare to “business as usual,” to increase control and target the effects of teaching the process and philosophy of design thinking, rather than the effects of introducing design activities.

Between Study 1 and Study 2, I fortified the study design and revised the curriculum to strengthen the intervention. Study 1 was conducted over eight one-hour class periods in three classrooms of end-of-year fifth-grade students. Study 2 was conducted over nine one-hour class periods in four classrooms of mid-year fifth- and sixth-grade students. In both interventions, students completed written pretest and posttest measures of motivation and content knowledge. In Study 1, students completed a near transfer design task and a far transfer riddle task where they were assessed on iteration and performance. In Study 2, students completed the near transfer
design task as well as a baseline design challenge to better account for pre-existing individual differences in iteration and performance. For both studies, the philosophy of design thinking was condensed for students to three key components of age-appropriate language and complexity: (1) Make mistakes and learn from them, (2) Go through multiple cycles of *Make, Test, Think*, and (3) Take many tries (Study 1) or Try early and often (Study 2).

**Research Questions**

This work aimed to assess if teaching middle school students the process of design thinking could incite them to be more iterative problem solvers and reframe failure as an opportunity for learning. For both studies, research questions assess if the design thinking philosophy can be learned, can transfer, and can benefit the performance of students who practice it:

1. **Can a brief intervention teach students the process and philosophy of design thinking?**

   I hypothesized that students in the Mindset condition would demonstrate growth in design thinking knowledge and beliefs, as measured by performance on questions about the design process and philosophy on pretest and posttest surveys, while students in the STEM condition would not show any difference in performance on these items from pretest to posttest. Conversely, students in the STEM condition would demonstrate growth in STEM content knowledge, as measured by performance on questions about science and math content on pretest and posttest surveys, while Mindset students would not show growth on these items.

2. **Will students who participate in a design thinking intervention develop an iterative disposition?**

   I predicted that Mindset students would learn to rapidly iterate, measured by earlier and
greater iteration (i.e., testing) on the transfer tasks and greater desire to take multiple attempts on tasks, as self-reported on pretest and posttest surveys, compared to students in the STEM condition.

3. Will early and frequent iteration lead to performance benefits on tasks?

In addition to predicting that students in the Mindset condition would iterate more and earlier, I hypothesized that students across all conditions that iterated more and earlier on the transfer tasks would perform better on these tasks than those who did not. Prior research suggests a performance benefit to iteration (Apedoe & Schunn, 2013; Bayles & Orland, 2001; Dow et al., 2009; Looijenga et al., 2015), and these studies aimed to replicate this finding.

4. How do the intervention, students’ iterative dispositions, and performance on design challenges relate to one another?

I hypothesized that students in the Mindset condition would outperform those in the STEM condition on transfer tasks. Moreover, I predicted that the relationship between condition and performance would be partially mediated by iteration such that being in the Mindset intervention would lead to more and earlier iteration and more and earlier iteration would lead to greater performance.

5. How does expressed design knowledge relate to demonstrated design behaviors?

Last, I sought to explore the relationship between learning as measured on pretest and posttest survey measures and design knowledge as demonstrated through performance on the transfer tasks.
Study 1 Method

Participants

A total of 78 fifth-grade students (46 female, 32 male) at a racially diverse, low-income public charter middle school in New York City participated in the study, near the end of the school year. The school population was 44% African American and 55% Hispanic, with 95% of the student body receiving free or reduced lunch. Students were divided among three science classrooms, all taught by the same teacher. The study was conducted at the school during scheduled class time. A lead experimenter taught all classes, with support from both the standard classroom teacher and a number of experimenters. This study employed a quasi-experimental design, with random assignment of intact science classes to one of two conditions. Two of the classes were randomly assigned to the iterative design mindset (Mindset) condition and the remaining class served as the STEM condition. Both conditions participated in eight 1-hour class periods of the “Design to Learn” study.

Procedure

On Day 1, students first took a 30-minute paper pretest, followed by instruction on either design thinking (Mindset) or design (STEM). One week later, students participated in the two design challenges, the drop challenge on Day 2 and the playground challenge on Days 3 and 4. After three class periods of design challenges, on Day 5 students were tasked with designing a brochure to teach future students about design. The final three days of the study included a near transfer measure (the boat challenge, Day 6), a 40-minute paper posttest (Day 7), and a far transfer measure (the bridge riddle, Day 8). Figure 10 shows the full timeline of instruction and assessment throughout the 4-week intervention. The intervention and assessments are discussed in further detail in the following sub-sections.
Figure 10. Study 1 procedure. This is an 8-hour study conducted across 4 weeks, involving 4.5 hours of intervention and 3.5 hours of assessment.

Design Intervention and Experimental Manipulation

Students in both conditions participated in an intervention that included a lesson on design, two small group design challenges, and a brochure activity. The curriculum was iteratively developed over two years by a team of graduate students with backgrounds in STEM education and with input from educators, Learning Sciences professors, and curriculum designers. It was extensively piloted with adults and students. See Chapter 3 for more details on the development of the intervention.

The design challenges provided students with two, contrasting “learning-by-doing” experiences with design thinking, drawing on best practices of constructivist pedagogy and the transfer literature. Students used the same process and language across both tasks. However, they involved different contexts (physics vs. math) and relied on different types feedback (physical, immediate feedback vs. mathematical and human feedback). In the drop challenge, students worked in groups of three to create a device to keep an index card in the air as long as possible, using a variety of materials (based on an activity designed by Carpinelli, Kimmel, & Rockland, 2014, Figure 11). For the playground challenge, students worked in pairs to design the most “fun” paper playground comprised of varying sized equipment with different fun star ratings.
“Fun” was a multiplicative relationship between the total number of “fun stars” in ones playground and the diversity of included equipment (based on a task from DefinedSTEM, n.d., Figure 12).

Instruction for both conditions involved a lecture alongside a PowerPoint presentation with frequent pauses for discussion questions and reflection. While all classrooms learned that design is “a way to solve a tricky problem,” students in Mindset classrooms were given a process focus and told that good designers use design thinking to make their designs. Mindset students learned, used, and reflected upon the condensed design thinking philosophy of (1) Make mistakes and learn from them, (2) Go through cycles of Make, Test, Think, and (3) Take many tries. In contrast, students in the STEM classroom had a content focus, learning that good designers use what they learn in school to make their designs. When these students completed their design challenges, they first learned relevant science or math content to employ in the designs. Before the drop challenge, STEM students had a brief lesson on gravity and air resistance. Before the playground challenge, STEM students had a brief lesson on area.
Drop Challenge

(a) GOAL: Design a device that will keep ONE INDEX CARD in the air as long as possible after you let it go.
SCORE: The time your device is in the air to the moment any part of it touches the floor

RULES:
- You must include 1 index card in the design
- You can use AS MUCH OR AS LITTLE
- One team member will RELEASE your device

(b) MATERIALS*:
- Scotch Tape
- Scissors
- 10 straws
- 10 rubber bands
- 5 index cards
- 5 8.5x11 paper
- 3 11x17 paper

*each device may include no more than the above amounts. Students are able to request more materials as needed to create multiple devices.

Figure 11. Drop challenge (a) goal and rules, (b) materials, and (c) designed drop devices with their scores on the challenge

Playground Challenge

(a) GOAL: Design a playground with the highest FUN SCORE.
FUN SCORE: # of different types of equip. x total fun stars

RULES:
- You can use AS MANY OR AS FEW of the playground cut-outs
- All equipment MUST fit inside the fence and cannot overlap
- Can rotate pieces and put them next to each other

(b) EQUIPMENT OPTIONS:

Figure 12. Playground challenge (a) goal and rules, (b) equipment options, and (c) designed playgrounds with their scores on the challenge
During each challenge, Mindset students completed three cycles of the iterative *Make, Test, Think* process (Figure 13) and were supported through this process with guided worksheets (See Chapter 3, p. 43). During each *Make*, students crafted their designed items. At each *Test* an experimenter came around to give feedback or test the designed item, and students recorded their scores. At each *Think*, students completed written reflections, where they were pushed to think about what went wrong in the test, how they might improve the design, and how their design process followed the tenets of design thinking.

![Figure 13. Design process by condition.](image)

**Figure 13.** Design process by condition. Students in the Mindset condition participated in three cycles of *Make, Test, Think* during the two design challenges, while students in the STEM condition followed a process of one long *Make*, followed by a standard *Test* and *Think*.

In contrast, STEM students were given an unstructured body of time during which to apply the new concepts they had learned, during which iteration (i.e., testing) was *possible* but not required or made salient in any way (Figure 13). After this block of time, experimenters tested the item, and then students reflected in the *Think* period about how they applied STEM content to their designs. While iterative rapid prototyping is a key part of the design thinking process, it is often disregarded in classroom engineering and design activities, to make room for a focus on content (Kolodner et al., 2003). Therefore, the STEM condition is both ecologically valid as it is what often happens in schools and ideal for assessing the effects of learning iterative design on future iterative behaviors.

Notably, students in both conditions were able to engage in “micro” iteration, defined as spontaneous test-retest iterations which are common in design activities (Barlex & Trebell,
2008). For the drop task, this involved testing out a device by releasing it and gauging its descent time, and for the playground task, this involved calculating a fun score. To encourage Mindset students to iterate and make this iteration process more salient, students in this condition were required to note the micro-iterations they made during the Make by tallying them on their worksheets. The large team of experimenters spread across the room ensured that all micro-iterations were recorded by each group. In summary, both tasks provided Mindset students with ample opportunity for iteration, which was delineated by the test of a design. Enforced macro-iterations involved more “official feedback” and were structured by the worksheets while spontaneous micro-iterations involved tests the students could do on their own, were merely encouraged, and were tallied in the Make sections of students’ worksheets.

Last, the brochure activity corresponded to the learned content of each condition. Mindset students’ goal was to teach students how to be design thinkers. In the STEM condition, the goal was to teach students how to be good designers by using what they learn to design. Students were given a checklist of content to include and a blank sheet of paper with which to create the brochure. Mindset students were asked to (a) define design thinking, (b) explain how they used design thinking in each challenge, and (c) propose a new context in which design thinking would be useful. STEM students (a) defined design, (b) explained how they used STEM content in each challenge, and (c) proposed a new design context in which STEM content would be useful. These prompts pushed students to compare their design experiences and abstract key ideas about design. This activity is similar to writing activities done in other interventions where students advocate a persuasive message to a new audience (see Good, Aronson, & Inzlicht, 2003; Walton & Cohen, 2011). This type of delivery mechanism is considered a powerful way to induce deep processing and transfer (Yeager & Walton, 2011). While students spent about 90 minutes on this
activity and generally were able to generate content (see Appendix 2 for analyses of Mindset brochures), the study team noted that many students had difficulty following the checklist and finishing their brochures in the allotted time. Therefore, I added structure to this task in Study 2.

**Reflection and Class Discussion.** In addition to *Think* sections of the design challenges and brochure activity, a number of individual reflections and classroom-wide discussions were peppered throughout the intervention, to help students deeply process the learned material. Students participated in written individual reflection *Do Now* activities at the beginning of each day, relating to material learned the prior day. These worksheets posed identical questions to students in each condition (e.g., *What is design and who designs?*; *How did you practice being a good designer during the drop challenge?*). Additionally, each of the intervention activities culminated with class discussion led by the head experimenter. Striving for consistency across classes, the head experimenter used a bulleted script in leading each classroom, with target discussion goals that she summarized for each class at the end of the discussions.

**Assessments**

A number of survey and behavioral measures assessed students’ learning and attitude changes in response to the intervention. To ensure that students were learning the main content taught in each condition, survey measures assessed both science/math and design knowledge. To measure attitude change in the ways students perceive failure, survey measures assessed how students felt and chose to act in the fact of mistakes or setbacks during a task.

Addressing research questions 2, 3, and 4, I included both survey and behavioral measures to measure the construct of iterative disposition. Iteration was defined as the iterative cycle of making, testing, and then making again to incorporate new information (Costa & Sobek, 2003). Therefore, each iteration was delineated by a clear test of a designed item, with the
assumption that students would revise their designs based on feedback from each test, either by reworking an existing design or developing an entirely new designed product. Survey measures of iteration asked students how many attempts they would like to take on prospective tasks, and behavioral measures of iterative disposition assessed how early (i.e., time to first iteration) and frequently (i.e., number of iterations) students tested within the target design task. For the bridge riddle, iterative disposition was measured by frequency (number of iterations) and persistence (how long students chose to work on the task). Moreover, we measured final performance on each task.

Last, to begin to understand students’ experiences during the intervention design challenges, we gathered information from their worksheets on performance (all students) and improvement across iterative cycles (Mindset students only).

**Learning Outcome Assessments.** Learning outcome measures included two kinds of questions: design knowledge items and science/math content knowledge items. Design item were three free-response questions about design (e.g., *What do you think it means to think like a designer?*). Science/math content items were four science (i.e., air resistance, gravity) and math (i.e., area) content questions relevant to the design tasks, two of which were multi-part questions with a multiple-choice response followed by a short-answer question (e.g., *Which of these two objects will hit the ground first if I drop them at the same time, a heavy ball or a basketball? Why?*). Free-response and multi-part questions were coded for accuracy and thoroughness of answer and agreement between coders was satisfactory, with all kappa values .79 or greater.

Scores on design-focused items were averaged together to create a *design thinking knowledge* score. Items relating to air resistance, gravity, and area (the relevant science and math material taught to STEM students) were averaged to create a *science/math knowledge* score. All items
were scored from 0 to 1. See Appendix 1 for the coding manual and list of items included in these assessments.

**Attitude Towards Failure.** Students answered a 5-point Likert *Reframing Failure* scale of three items relating to student beliefs about failure: making mistakes, feedback seeking, and taking many tries (e.g., *I should only show my teacher work that is complete and correct*). This scale was inspired by Mosborg, Adams, and Kim's (2005) *Definition of Design* scale, which assessed design beliefs in adults. Item #3 (i.e., *People who take a lot of tries to do something well are bad at it*) was removed from analysis due to ceiling effects and pretest condition differences, $t(76) = 2.58, p = .01$. The remaining two items were averaged together for a composite *Reframing Failure* score, out of 5. The scale was highly unreliable ($\alpha < .01$) and, I believe subject to response bias, and therefore was dropped from Study 2.

**Survey Iterative Disposition.** At posttest only, I included a measure of iterative disposition, asking how many attempts students would desire to take on two prospective future tasks (e.g., *Your teacher assigns you an essay for a big homework assignment. It is due in 1 month. How many DRAFTS of the essay would you want to turn in for feedback before turning in your final essay?*).

**Near Transfer Task.** The near transfer task was a behavioral measure of students’ iterative dispositions and performance on an engineering activity where students were tasked with building a boat that could float and support as many pennies as possible out of paper, straws, and tape (adapted from Kornoelje & Roman, 2012, Figure 14). Unlike the intervention design challenges, students had to work alone on this task. Additionally, iteration was optional for both conditions and defined as each time a student tested a boat in a tub of water. To test, students would raise their hands and an experimenter motioned them to the back of the
classroom where water tubs were located. Students were measured on (a) time to first iteration (iterative disposition), (b) number of iterations (iteration disposition), and (c) maximum number of pennies held by a given boat (performance). Students were given 30 minutes to build and test as many boats as desired.

**Far Transfer Task.** The far-transfer design challenge tasked students with solving an “impossible” bridge riddle adapted from a TED-Ed video (Gendler, Outis, & Misirioglu, 2015, Figure 15). Impossible tasks have been used to measure persistence in prior research (e.g., Malkiewich, Lee, Slater, Xing, & Chase, 2016; Ventura, Shute, & Zhao, 2013). Similar in nature to the classic “Cannibals and Missionaries” riddle (McCarthy, 1980), this riddle asked students to come up with the fastest way to get a team of individuals across a bridge, with a variety of constraints limiting how and the time it takes to cross. In this task, students watched a modified version of the video and attempted to solve the riddle using a packet of identical worksheets (Figure 15C). Again, students worked independently on this task. When a student came up with an answer, she raised her hand and the experimenter examined the sheet and told the student that there was a better answer possible, regardless of whether or not this was true. After each of these attempts, students had the opportunity to stop and play educational computer games or to try again. If a student wanted to try again, she turned the page to continue. Students were measured on (a) persistence time (i.e., time until they chose to play computer games), (b) number of iterations (i.e., number of worksheet pages filled out), and (c) best answer (i.e., the shortest time to cross the bridge) that the student came up with during the task.
Boat Float Challenge

(a) **GOAL:** Design a boat that can hold THE MOST NICKELS without sinking

**SCORE:** the number of coins your boat holds before it is completely submerged or touches the bottom of the water tank

**RULES:**
- You can use AS MUCH OR AS LITTLE of your supplies
- You can build more than one boat and can try a boat out at any time during the challenge
- Whenever you want to see how many coins a boat can hold, raise your hand and an adult will bring you to a water tank to try it out

(b) **MATERIALS***:
- Scotch tape
- Scissors
- 10 straws
- 5 sheets of paper

*each boat may include no more than the above amounts. Students are able to request more materials as needed.

Figure 14. Boat challenge (a) goal to design a boat that can hold the most coins without sinking, (b) materials, and (c) sample designed boats

Bridge Riddle Challenge

(a) **GOAL:** Find the fastest way to get all four people across the bridge

**SCORE:** the “time” it takes to get all four people across the bridge

**RULES:**
- One or two people can cross the bridge at the same time
- Crossers move as fast as the SLOWEST person
- Crossers need the lamp, so whenever anyone crosses to safety, somebody must bring the lamp back until everyone is on the other side.

(b)

Figure 15. Bridge riddle challenge (a) goal of the task, (b) situation and instructions, and (c) most typical solution on worksheets (adapted from Gendler, Outis, & Misirioglu, 2015)
**Intervention Design Task Measures.** In addition to pretest and posttest survey data and the transfer tasks, I measured iteration and performance during the two instructional tasks (i.e., drop and playground challenges). For Mindset students, their design challenge packets were coded for number of tries (i.e., micro-iterations) recorded during the Make period and scores at each Test period. Performance was measured as the final score on the task. Improvement was coded as a binary measure of whether or not the group’s third test was their best performance. Additionally, an open-ended reflection question of perceived improvement (i.e., *Did your design get better over each try or round?*) was coded on a binary yes/no scale, and agreement between coders was satisfactory, kappa = 0.91. Students in the STEM condition completed much shorter worksheets at the end of each design challenge. These worksheets were coded for performance (i.e., students’ final score) only.

**Study 1 Results**

The majority of the following analyses were conducted using MANOVA and ANOVA models. For measures that were identical at pretest and posttest, I used RM ANOVA, and where measures were different at pretest and posttest, I use ANCOVA. In situations where measures are not theoretically connected or refer to separate research questions, I used separate ANOVAs. To explore the complex relationships between key variables, I used a set of linear regression models. For count data (i.e., number of tests), I initially used Poisson regression models and switched to ANOVA when results were highly similar.

While my research questions concern condition differences, due to the incomplete nesting of class within condition, I was concerned about accounting for class effects. Therefore, I initially conducted each analysis by class and ran a custom contrast comparing the STEM classroom to the average of the two Mindset classroom means. The results of these analyses were
near identical to those of my by-condition analyses, with one exception, which I note in a footnote on page 79. Therefore, for clarity, I report the results of condition analyses alone.

Analyses were conducted using the maximum number of students with data who completed each day of the study prior to the given measure. The majority of analyses use a sample size of 78, which includes all students who were present for pretest and all of the days of the intervention. Analyses of the Mindset condition include 49 students. Additionally, since the intervention design challenges (i.e., drop and playground) were performed in random groups of two or three students, corresponding analyses were conducted with group as unit of analysis, where each design challenge involved a different dataset of groups. Due to this, no statistical tests were run comparing or including both challenges at once.

**Learning Outcomes**

Students in both conditions learned their condition-specific target knowledge from pretest to posttest. A three-way repeated measures ANOVA, with time (pre vs. post) and target knowledge (design vs. science/math content) as within-subjects factors and condition as the between-subjects factor, confirmed a significant three-way interaction between time, target knowledge, and condition, $F(1,75) = 43.75, p < .01$, with a large effect size, $\eta^2_p = .37$. Students in both conditions performed poorly at pretest for both types of target knowledge (Figure 16). By posttest, only Mindset students improved at design knowledge and only STEM students improved on science/math knowledge. Showing that each condition learned what it was taught, this result addresses my first research question by demonstrating that Mindset students learned about design thinking, and further confirms the adequacy of STEM instruction.
Figure 16. Estimated marginal mean score (+/- 1 SE) on content and design knowledge items at pretest and posttest by condition.

Attitude Towards Failure

For the 2-item Reframing Failure scale, a RM ANOVA by condition confirmed that pre and posttest scores differed significantly, $F(1,76) = 22.74, p < .01, \eta^2_p = .23$ but found no interaction of condition and time, $F(1, 76) = 0.40, p = .53$. On average, students scored .5 points higher from pretest ($M=2.08, SD=0.75$) to posttest ($M=2.57, SD=0.91$). Both Mindset and STEM students reported more beneficial ideas about failure after participating in the design study.

Survey Iterative Disposition

The written posttest included two items asking students how many attempts they would choose to take on future tasks: a new design challenge and writing an essay. An independent samples t-test confirmed a significant difference between conditions for average requested attempts on these items, $t(76) = 2.32, p = .02$, Cohen's $d = 0.56$ (Figure 17). This evidence
suggests that the Mindset group gained more of an iterative disposition in that they reported a willingness to engage in more iteration in two novel tasks.

![Figure 17. Mean score (+/- 1 SE) on future iteration items at posttest by condition.](image)

**Near Transfer Boat Task**

Overall, students’ best boats held an average of 85 pennies (SD=58) and a maximum of 247. They tested boats an average of 1.8 times (SD=1.0) and a maximum of 8 times. A student’s first test was, on average, 21.5 minutes (SD=7.5) into the 30-minutes challenge. Unsurprisingly, there was a significant correlation between first test time and the number of tests, $r = -.67$, $p < .01$. The earlier a student started testing her boats, the more tests she was likely to do.

**Effect of Condition on Iteration and Performance.** To test the hypothesis that students in the Mindset condition would demonstrate more iterative behaviors than STEM students on the
near transfer task, an initial MANOVA examined time to first test and number of tests as dependent variables and condition as the fixed factor. While the multivariate effect for condition was not significant, $F(2,74) = 2.32, p = .11^1$, univariate analyses revealed that students in the Mindset condition tested their boats significantly earlier than students in the STEM condition, $F(1, 75) = 4.55, p = .04, \eta^2_p = .06$, and tested marginally more than students in the STEM condition, $F(1, 75) = 3.02, p = .09, \eta^2_p = .04$ (Table 1). There were no significant differences in performance (maximum pennies held) by condition, $t(75) = .72, p = .47$ (Table 1). Taken together, these results suggest that students in the Mindset condition demonstrated more of an iteration disposition than students in the STEM condition, particularly as measured by time to first iteration, but there was no effect of condition on performance.

**Table 1.** Mean (with SD) and range of scores on near transfer iteration measures by condition.

<table>
<thead>
<tr>
<th>Condition</th>
<th>$n$</th>
<th>Minutes to first test *</th>
<th>Number of Tests</th>
<th>Maximum Pennies Held</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Mindset</td>
<td>51</td>
<td>20.2 (0.8)</td>
<td>3.4-30</td>
<td>2.0 (1.2)</td>
</tr>
<tr>
<td>STEM</td>
<td>26</td>
<td>23.9 (5.8)</td>
<td>10.6-30</td>
<td>1.5 (0.7)</td>
</tr>
</tbody>
</table>

*Significant difference in scores, $p < .05$

**Relationship between Condition, Iteration, and Performance.** Regression analysis was used to investigate the complex relationship between performance, iterative measures, and condition (Table 2). There were no interactions between condition and either of the iterative measures, so these coefficients were removed from presented analyses. Confirming the previous

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1 Running this analysis by class with a contrast by condition, the multivariate effect was significant, $F(2,73) = 3.25, p = .04$, contrast estimate = .45, $\eta^2_p = .08$. The univariate effects were similar: time to first test, $F(1,74) = 6.57, p = .01, \eta^2_p = .08$ was significant and number of tests, $F(1,74) = .69, p = .41$, contrast estimate = 11.55, was marginal.
analysis, I found no effect of condition on performance (Model 1). However, I did find an overall effect of iteration on performance, particularly for time to first test, such that each minute earlier a student tested resulted in about 4 more pennies held by her boat (Model 2). Model 3, regressing performance on condition and both iterative measures, was significant as well. Adding the two iterative measures to the model accounted for significantly more variance than a model with condition alone, $F(2,73) = 7.28$, $p < .01$, $\Delta R^2 = .17$. However, adding condition to a model with both iteration measures accounted for no additional variance in performance, $\Delta R^2 < .01$. Taken together, these results suggest that performance was affected by iteration, particularly time to first test, such that students who iterated earlier performed better on the task. However, while MANOVA analyses indicated that students in the Mindset condition gained more of an iterative disposition, regardless of condition, students who tested earlier did better on the challenge.

Table 2. Regression models of near transfer task performance on iteration measures and condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>SE B</td>
<td>B</td>
<td>SE B</td>
</tr>
<tr>
<td>Time to first test</td>
<td>-4.15*</td>
<td>1.15</td>
<td>-0.07*</td>
</tr>
<tr>
<td>Number of tests</td>
<td>-12.02</td>
<td>8.39</td>
<td>-12.01</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.00</td>
<td>.17</td>
<td>.17</td>
</tr>
<tr>
<td>$F$</td>
<td>0.52</td>
<td>7.69</td>
<td>5.05</td>
</tr>
<tr>
<td>$p$</td>
<td>.47</td>
<td>&lt;.00</td>
<td>&lt;.00</td>
</tr>
</tbody>
</table>

$\Delta R^2$ for Model 1 to 3: 0.17*

To assess whether the relationship between iterating early and performance was due to a third variable of prior boat building expertise (i.e., expert boat builders quickly build excellent boats), I added the number of pennies held on the first boat test to Model 3, regressing
performance on condition, time to first iteration, number of iterations, and pennies held on first iteration. This covariate was, as expected, significant, since many students only test one boat and therefore their best score is their first score, $B = .75$, $t(70) = 7.82$, $p < .01$. However, time to first test was still a significant predictor of performance, $B = -1.95$, $t(70) = -2.2$, $p = .03$. A closer look at the data confirms that students who iterate early are not immediately creating their best boats: the earliest tester, a student who tested 8 times, began with a boat that held 18 pennies and only by his 8th try, over 25 minutes later, did he get his maximum score of 99. The second-earliest tester similarly got his best score 11 minutes later on his third attempt.

**Far Transfer Bridge Riddle Task**

On average, students persisted on the bridge riddle for 17 minutes (SD = 8.27, range = 5.4-30) and completed 4 attempts at the riddle (SD = 3.46, range = 1-20). Unsurprisingly, these two iterative disposition measures were highly correlated, $r = .748$, $p < .01$, such that students who spent more time on the task were also making more attempts at solving it.

**Effect of Condition on Iteration and Performance.** A MANOVA with persistence time and number of attempts as dependent variables and condition as the fixed factor revealed no significant difference between conditions for iteration on the far transfer task, $F(2,73) = .01$, $p = .99$. Due to the strange distribution of final answers on the problem, I chose to analyze performance as binary. The goal of the task was to come up with the “fastest time” a group of individuals could cross a bridge, given a number of constraints. While I structured the task to be impossible, the best possible answer was, in fact, 17 minutes, and the second-best answer which individuals often reach an impasse on was 19 minutes. Therefore, I categorized the 52 students who came up with 17 minutes (N=5, 6%) or 19 minutes (N= 47, 60%) as **High** performers and 26 students as **Low** performers who either came up with a longer time for their answer (N=10,
13%) or could not use the worksheet correctly and did not calculate a time (N=16, 21%). A chi-square test of independence confirmed no significant differences in performance on this task by condition, χ²(1, N = 78) = .12, p = .80,

Relationship between Iteration, and Performance. As there were no condition effects on this task, I explored only the relationships between iterative disposition and performance. I ran a binomial logistic regression to determine whether performance could be predicted by persistence time or number of attempts on the task. The logistic regression model was statistically significant, χ²(2) = 29.73, p < .01. The model explained 32% (Cox & Snell R²) of the variance in performance and correctly classified 72% of cases. Increasing number of iterations was associated with an increased likelihood of high performance, Wald = 10.97, p < .01, but persistence time did not significantly predict performance. These results suggest that while the intervention did not affect students’ performance or iterative dispositions on the far transfer task, there was a performance benefit to iterating more on the task.

Design Knowledge vs. Design Behaviors (Mindset only)

In order to determine what factors may have contributed to iterative behaviors and success on the transfer tasks, I explored the association between these measures with measures of students’ design thinking knowledge, focusing only on students in the Mindset condition. Correlations between a student’s score of posttest design knowledge and performance on the boat task, controlling for pretest design knowledge, revealed an interesting pattern: the more a student learned about design thinking as demonstrated on a written survey, (a) the less that student iterated on the boat task and (b) the later that student began testing his or her boats (Table 3). Controlling for pretest score, scores on posttest design knowledge and tests on the boat challenge were negatively correlated, and scores on posttest design knowledge and the time of
first boat test were positively correlated. However, there were no significant correlations between scores on the posttest design knowledge and any of the far transfer task measures (best score on task, persistence time, or total number of tries), controlling for pretest score. These results are unexpected and suggest that students who were able to demonstrate learning via the near transfer design task were not the students who demonstrated their learning on survey measures and the more school-like far transfer challenge.

**Table 3.** Correlations between design thinking knowledge and near and far transfer performance (Mindset condition)

<table>
<thead>
<tr>
<th></th>
<th>Near Transfer Boat Task</th>
<th>Far Transfer Bridge Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max. Pennies Held</td>
<td>Time to 1st Test</td>
</tr>
<tr>
<td>Posttest Design Knowledge (Controlling for Pretest Design Knowledge)</td>
<td>-.22</td>
<td>.36*</td>
</tr>
</tbody>
</table>

*Correlation is significant at the .05 level (2-tailed).

**Intervention Design Task Measures (Group-level Analyses)**

Intervention design tasks were analyzed at the group level. There were no significant differences between Mindset and STEM groups on performance on either the drop challenge, $F(1,25) = 0.43$, $p = .52$, or the playground challenge, $F(1,38) = 0.55$, $p = .46$. On average, groups created drop devices that stayed in the air for 1.43 seconds (SD = .57) (1.33 STEM, 1.48 Mindset), and their final playgrounds scored 182 fun points (SD = 30.5) (177 STEM, 184 Mindset). Exploring the data collected for Mindset groups across both challenges, groups documented almost three times more tries on the drop challenge than the playground challenge (Table 4). In regards to demonstrated improvement across iterations and perceived improvement across iterations, approximately half of the groups demonstrated improvement (i.e., their third test was their best test) or perceived improvement (as coded on their reflection sheet) on each task.
Table 4. Mean tries, demonstrated improvement (%), and perceived improvement (%) by design task with group as unit of analysis (Mindset condition)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Drop (n=20) M (SD) / %</th>
<th>Playground (n=28) M (SD) / %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tries</td>
<td>14.25 (7.33) 45%</td>
<td>4.79 (2.90) 61%</td>
</tr>
<tr>
<td>Demonstrated Improvement</td>
<td>50%</td>
<td>62%</td>
</tr>
</tbody>
</table>

**Study 1 Discussion**

**Learning Design Thinking**

These results largely support my first hypothesis; I found that students who participated in the design thinking intervention acquired design thinking knowledge and beliefs, while STEM students acquired math and science knowledge. Mindset students significantly outperformed STEM students on the design knowledge component of the posttest, while STEM students outperformed Mindset students on math/science content knowledge. Mindset students did not learn STEM content from this intervention.

**Attitude towards Failure**

Students in all conditions improved on the *Reframing Failure Scale* from pretest to posttest. This result suggests that merely participating in the design activities may have altered student’s beliefs about mistakes and failure, regardless of whether or not the process was explicitly taught or whether iteration was made salient.

**Iterative Disposition**

Results were more tenuous for the second hypothesis: the design thinking intervention will teach students to be more iterative. On the posttest, Mindset students asked for significantly more attempts on future tasks than STEM students, suggesting that an iterative disposition could transfer to new activities. However, analyses of the near transfer boat task revealed that while
Mindset students tested *earlier* than STEM students, they tested only marginally *more*. This could be due to the generally low average number of iterations and restricted range (M=1.8 times, SD=1.0). Only 12 students (15%) iterated 3 or more times, while 33 (43%) tested twice and 32 (42%) students tested just once. Compared to the greater range in the time to first iteration variable, it is harder to find statistical significance with this narrow range of values. Moreover, there were no significant differences between conditions on the far transfer task for either of the iterative measures.

Overall, this pattern of results suggests that Mindset students did learn that iteration was important and, to some extent, applied this to a new design challenge. However, a more robust iterative disposition did not transfer to the bridge riddle task. Ultimately, this task may not have been ideal for evaluating far transfer. Design thinking is not intended for problems that can be solved by exhaustive analysis, with one correct solution (Goldman & Kabayadondo, 2017), and therefore students may have had trouble applying their newfound knowledge to the bridge riddle.

**Iteration and Performance**

My third hypothesis was that students who iterated more and earlier on the transfer tasks would perform better on these tasks than those who did not. On the near transfer task, while I did not find support for the number of iterations, I did find that the timing of first iteration was highly predictive of performance on the near transfer task. This does not appear to be a result of prior boat building knowledge; adding performance on the first boat to a regression did not change the significance of time to first test, and a closer look at the data suggests that earliest testers created their best boats much later in the task. These results suggest that the “fail early” component of design thinking is perhaps more important than the actual number of iterations a student completes. While “fail early” was not explicitly taught in this intervention, these results
imply that teaching students to begin testing designs earlier may be more productive than teaching them to simply test many times. On the far transfer task, I found that students who persisted longer performed better on the task.

**Condition, Iteration, and Performance**

I did not find evidence for my fourth hypothesis, that students in the Mindset condition would outperform those in the STEM condition, as mediated by iterative disposition. On the near transfer task I found that Mindset students iterated earlier and marginally more, and students who iterated earlier did better on the task, but I did not find any direct effect of condition on performance. A plausible interpretation of these findings is that I simply lacked power, perhaps through the dosage of the intervention, to see the overarching condition effect. On the far transfer task, I found no evidence that my intervention affected students’ performance or iterative habits at all. However, I did still find a connection between iteration and performance. Overall, I replicated prior research on the benefit of iterations for performance on design tasks, extended the benefits of iteration to non-design tasks, and highlighted an aspect of iteration that is rarely measured – time to first iteration. Moreover, I found that my intervention affected students’ actions on the near transfer task but did not transfer to the far transfer task.

**Design Knowledge and Behaviors**

Last, I found that design thinking knowledge as measured by paper-based pretest and posttest surveys was either not related at all (i.e., the far transfer task) or even inversely related to iterative behaviors (i.e., the near transfer task). The inverse relationship between design knowledge score and iterative behavior on the boat task was unexpected. In this study, it appears the students who excelled at reflective activities and written work, which we would generally
consider to be “good students,” were not the same students who excelled at tinkering and trying many ideas in a design paradigm.

Limitations and Future Directions

The biggest limitation in Study 1 stemmed from its design. Due to real-world constraints of the school structure, I was unable to randomize within classroom and only had one class in my STEM condition. Additionally, due to time constraints, I did not give a design challenge at pretest to determine baseline iterative disposition or design performance, which could increase my explanatory power by decreasing some within-subject variation in my data. Therefore, in Study 2, I aimed to corroborate these findings and employ a study design more conducive to finding condition differences in iterative behaviors. Study 2 included two classes per condition as well as a baseline design task in order to ascertain prior iterative disposition and design prowess. In doing this, I chose to drop the far transfer task from the study design. The intervention appeared to have no effect on this riddle task, and, with limited access to students, I aimed to utilize that precious time more effectively.

In addition to fortifying the study design, I aimed to increase the effectiveness of the intervention itself in Study 2, since I found a number of marginally significant relationships. Studies of transfer suggest that instruction should bridge understanding from one context to another by emphasizing deliberate abstraction, mindfulness, and reflection (Chen & Klahr, 1999; Perkins & Salomon, 1988). Therefore, I strengthened the curriculum by increasing its dosage and including more bridging activities and structure to promote abstraction and transfer of the design thinking philosophy and process.

Additionally, one new idea born from these results was the importance of testing early, not just testing frequently. While a common design thinking tenet is “fail early, fail often,” I only
taught students the second half of this phrase. However, my results imply that the first half is perhaps even more important for performance on a task. Therefore, Study 2 of this intervention taught early testing as an important component of design thinking and integrated it into the process students used in design challenges.

**Study 2 Method**

Study 2 involved a revised curriculum and study design. Based on the results of Study 1, I (a) fortified the study design by including two classes per condition and adding a baseline measure, (b) revised the curriculum by highlighting the importance of beginning the iteration process *early*, (c) amended survey measures by adding new scales and additional items, and (d) strengthened the intervention by adding an additional hour of instruction and including more abstraction components to facilitate transfer. The second study aimed at replicating and strengthening the findings of the first study; I posed the same research questions and made the same hypotheses. Unless specified below, all other aspects of the intervention were the same as those in Study 1.

**Participants**

A total of 89 mid-year fifth- and sixth-grade students (38 female, 51 male; 55 fifth, 34 sixth) at another diverse, low-income public middle school from the same charter participated in the study. The school population was 60% African American and 37% Hispanic, with 88% of the student body receiving free or reduced lunch. Students were divided among four science classrooms, all taught by the same teacher. As in Study 1, I randomly assigned intact science classes to one of two conditions. Two of the classes (one fifth-grade and one sixth-grade) were randomly assigned to the Mindset condition and two of the classes served as STEM comparisons.
Procedure

The procedure for Study 2 was very similar to Study 1. The primary differences between these studies are the four-class structure, the inclusion of a baseline design task, and the removal of the far transfer task. These changes fortify the experimental design by enabling me to parse class and condition effects as well as account for pre-existing individual differences in design strategy and ability. Additionally, I added a full day of instruction to lengthen the expository lesson on design thinking. Figure 18 shows the full timeline of instruction and assessment throughout the intervention. The intervention and assessments are discussed in further detail in the following sub-sections.

Figure 18. Study 2 procedure. This was a 9-hour study conducted across 3 weeks, involving 5.5 hours of Intervention and 3.5 hours of assessment.

Design Intervention and Experimental Manipulation

The design intervention and experimental manipulation are those of Study 1, with minor changes. Due to Study 1 results which suggested particular importance to testing early in the design process, in Study 2 the design thinking philosophy taught to Mindset students was modified to: (a) Make mistakes and learn from them, (b) Go through cycles of Make, Test, Think, and (c) Try early and try often. For both conditions, the brochure activity included a more structured format with sentences starters in order to support students in completing the task (See
Chapter 3, p. 47). This change was made in reaction to observation that many students had difficulty completing the brochure task in Study 1.

Additionally, the curriculum in Study 2 was designed to increase abstraction through more extensive use of comparisons (i.e., across different design tasks, iterations within a design task, types of designers) and guided bridging between concrete and abstract design thinking ideas, both during introductory instruction and embedded in reflections. During the lecture, reflections, and brochure activity, I focused more heavily in Study 2 on the definition of design thinking as *a way to take action to solve a tricky problem*, and went on to define and discuss different types of tricky problems. Throughout the intervention, the students used the baseline design challenge as an example of a tricky problem and it served as an additional experience on which to build their understanding of design thinking.

Additionally, for the STEM condition, I decided to alter the content taught in relation to the Playground challenge. Due to high baseline performance on Study 1’s area items (68% of students could correctly calculate area at pretest), I changed this lesson in Study 2 to teach something students would not already be so familiar with. Therefore, I taught a brief conceptual lesson about density, focused on controlled comparisons of varying amounts of “stuff” in a given amount of “space,” with the rationale that if students shift their thinking about the playground equipment such that they focus on “density” of stars rather than number of stars, they would be more successful at the task.

**Assessments**

Assessments include a variety of paper-based and behavioral measures. Many of these measures are similar to those in Study 1. However, as outlined below, items deemed ineffective
were revised and replaced and new scales were added to better assess students’ response to failure. All items and their coding schemes are included in Appendix 1.

**Learning Outcome Assessments.** As in Study 1, learning outcomes were assessed through free-response questions and the measures were aggregated into two separate knowledge scores: a design thinking knowledge score and a science/math knowledge score. All free-response learning outcome questions were coded and agreement between coders was satisfactory, with all kappa values .76 or greater. I changed the design example for one item, since the Study 1 item was about a tower challenge and students actually do this challenge in Study 2. Due to fairly high baseline performance on the Are mistakes good or bad? item in Study 1 (64% of students answered “yes” at pretest, and half of these students explained that they are good for learning), I replaced it with a different item about trying early and often in Study 2. Additionally, corresponding to the STEM condition’s content change for the playground task, I revised the two items relating to area to instead relate to density and ratio.

**Survey Iterative Disposition.** As in Study 1, students were asked how many attempts they desired to take on certain tasks. I made this measure more robust by including it at pretest with four classroom-related items (e.g., You are doing a hard math problem... how many times would you retry the problem?), and at posttest, adding four design-related items for a total of eight items (e.g., If I gave you a new design challenge to design a toy car... how many designs would you want to create?). This iterative disposition scale was reliable, particularly at posttest (pre: $\alpha = .45$, post: $\alpha = .69$).

**Attitude towards Failure.** Instead of the Reframing Failure scale, which yielded conflicting results in Study 1, I employed three new measures to assess students’ affect, expectancies, and actions in reaction to failure scenarios. The affective reaction to failure scale,
given at pretest ($\alpha = .67$) and posttest ($\alpha = .82$), was derived from Clifford’s (1998) School Failure Tolerance scale. Adapting 9 of his affect items, the 5-point Likert scale asked students how much they agree with various maladaptive affective responses to failure during a design challenge (e.g., “While designing something in a design challenge, I would feel terrible if I made a mistake), where 1 indicated “Strongly disagree” and 5 indicated “Strongly Agree”. This scale was then reverse coded such that higher scores indicated more adaptive affective responses to failure.

Next, students read short paragraphs about another student who experienced mid-task failure in either a school (pretest) or design (pretest and posttest) task. Students were asked to imagine that they were the hypothetical student (e.g., If you were Jordan, how well do you think you would do in class this year?). The expectancy to succeed in reaction to failure scale, given at pretest ($\alpha = .74$) and posttest ($\alpha = .85$), was derived from Eccles and Wigfield (1995)’s ability/expectancy-related items of their Children’s Self- and Task- Perceptions in the Domain of Mathematics scale and adapted to fit the scenarios. Students answered five items on a 5-point Likert scale concerning their self-perceptions and expectancies to do well on the task and in the course, based on the paragraph.

Last, action in reaction to failure items, given at pretest and posttest, were free-response questions connected to each of the aforementioned failure scenarios, asking students what they would do in the time before the final report or design was due. These were coded and agreement between coders was satisfactory, with kappa = .76.

**Near Transfer Boat Task.** As in Study 1, the near transfer boat task served as a behavioral measure of students’ iterative dispositions and performance on design challenges. In
Study 2, students weighted the boats with nickels, which are twice as heavy as the pennies used in Study 1, in order to cut down on tedious testing time.

**Baseline Tower Task.** Additionally, to assess baseline iterative disposition and design ability, students participated in an initial design challenge (Figure 19). In this challenge, students worked alone to build the *tallest* tower that would support a juice box, using gumdrops and toothpicks (adapted from TryEngineering IEEE, n.d.). As on the transfer boat task, iteration was optional and measured as each time a student asked for the juice box to test her tower. Iteration metrics included number of iterations (i.e., number of times student used the juice box to test) and time to first iteration. Performance was calculated as the height of final *successful* towers, such that those students whose towers could not support a juice box received a score of zero. Students were given 30 minutes to build and test as many times as desired.

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**Tower Challenge**

(a) **GOAL:** Design the TALLEST tower you can that can hold ONE JUICE BOX for 5 seconds  
**SCORE:** The height of your tower up to where the juice box sits IF the tower does not fall.  
**RULES:**  
- You can use AS MUCH OR AS LITTLE of your supplies  
- Whenever you want to see if the tower can hold a juice box, raise your hand and an adult will give you a juice box to try it out.

(b) **MATERIALS*:  
- 100 toothpicks  
- 50 gumdrops

*each tower may include no more than the above amounts. Students are able to request more materials as needed.

(c)

---

**Figure 19.** Tower challenge (a) Goals and Rules, (b) Materials, and (c), Sample designed towers
**Intervention Design Task Measures.** As in Study 1, data from the design challenges included performance (both conditions) and micro-iterations, improvement, and perceived improvement (Mindset only).

**Study 2: Results**

This study recruited from two grades, and one class from each grade was nested within condition. Therefore, Study 2 analyses include grade as a factor in order to test for grade and interaction effects. The majority of analyses were conducted using the 89 students with data who completed at least one day of all components of the study, although missing data resulted in an analysis set of 88 for a few analyses. Analyses of the Mindset condition include 44 students. As with Study 1 data, I initially used Poisson models for total tests, found similar results, and report ANOVA models instead in this section.

**Learning Outcomes**

In accordance with the Study 1 and including the new factor of grade, I calculated a RM ANOVA, with time (pretest vs. posttest) and target knowledge (design vs. science/math content) as within-subjects factors and condition and grade as between-subjects factors. As in Study 1, this revealed a significant three-way interaction between time, target knowledge, and condition, $F(1,84) = 174.10, p < .01$, with a very large effect size, $\eta^2_p = .68$. Students in the Mindset condition learned the design philosophy and STEM students learned about relevant science and math. Students in both conditions performed poorly at pretest for all types of target knowledge, and, by posttest, only Mindset students improved at design knowledge and only STEM students improved on science/math knowledge (Figure 20). As in Study 1, this result demonstrates that Mindset students learned about design thinking and confirms the adequacy of STEM instruction.
Figure 20. Mean score (+/- 1 SE) on content and design knowledge items at pretest and posttest by condition.

Attitude Towards Failure

For the affective reaction to failure scale, a repeated measures ANOVA confirmed a main effect of time, $F(1, 84) = 15.26, p < .01, \eta_p^2 = .15$, and an interaction of time and condition, $F(1, 84) = 7.90, p < .01, \eta_p^2 = .09$. There were no main effects or interactions with grade, $p$-values < .16. Confirmed by Bonferroni pairwise comparisons, Mindset students improved their affective reactions to failure from pretest to posttest, $F(1,84) = 22.53, p < .01$, while STEM students’ scores did not change, $F(1,84) = 0.60, p = .44$ (Table 5).

For expectancy to succeed in reaction to failure, I calculated an ANCOVA on posttest expectancy, by condition and grade, co-varying pretest expectancy. I found no effects of condition, $F(1,82) = 0.04, p = .96$, grade, $F(1,82) = 0.78, p = .46$, or interaction of condition and grade, $F(1,82) = 1.60, p = .21$. Results indicate that neither condition changed from pretest to posttest on this scale (Table 5).
Last, for action in reaction to failure, I calculated an ANCOVA on posttest actions, by condition and grade, co-varying pretest score. I found a main effect of condition, $F(1,84) = 7.42$, $p < .01$, $\eta_p^2 < .08$. There were no main effects of grade or interaction of grade by condition, $p$-values > .14. Mindset students significantly outperformed STEM students, controlling for baseline performance (Table 5). Overall, these results suggest that the intervention made Mindset students develop more adaptive affective reactions to failure and taught them to apply the design process as a way to take action in the face of a setback. However, the intervention did not affect students’ expectancy to succeed if they experienced a mid-task failure.

**Table 5.** Estimated marginal mean score (with SE) on attitude towards failure measures by condition (out of 5).

<table>
<thead>
<tr>
<th>Condition</th>
<th>n</th>
<th>Pre</th>
<th>Post*</th>
<th>n</th>
<th>Expectancy</th>
<th>n</th>
<th>Action*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mindset</td>
<td>43</td>
<td>3.32 (.11)</td>
<td>3.85 (.13)</td>
<td>44</td>
<td>3.06 (.10)</td>
<td>44</td>
<td>1.80 (.09)</td>
</tr>
<tr>
<td>STEM</td>
<td>45</td>
<td>3.13 (.11)</td>
<td>3.22 (.13)</td>
<td>44</td>
<td>3.00 (.10)</td>
<td>45</td>
<td>1.44 (.10)</td>
</tr>
</tbody>
</table>

*Significant difference in scores, $p < .01$

**Survey Iterative Disposition**

For the self-report iterative disposition scale, I calculated an ANCOVA on posttest iteration, by condition and grade, co-varying pretest iteration. I found a significant effect of condition, $F(1,84) = 7.69$, $p = .05$, $\eta_p^2 = .05$, such that students in the Mindset condition requested more attempts on future tasks than those in the STEM condition, accounting for baseline requested attempts (Figure 21). There was no effect of grade or interaction of condition and grade, $p$-values > .29. As in Study 1, these results suggest that the intervention made Mindset students more iterative, as measured by reported desire to take many attempts on future tasks.
Baseline Tower Task

On the initial gumdrop tower task, included to ascertain students’ pre-existing iteration habits and design performance, 39 (44%) students were able to design gumdrop towers that could hold a juice box at the end of 30 minutes. Among those that stood, the average height was 9.6 inches (SD = 3.7). They tested their towers an average of 2.8 times (SD = 2.0) and a maximum of 12 times. A student’s first test was, on average, 21.6 minutes (SD = 8.1) into the challenge. A preliminary MANOVA on time to first test, total tests, and performance found no significant differences at baseline, by grade or condition, $p$-values > .35.

To test the hypothesis that students who iterate more or earlier will perform better on the task, I explored the association between iteration measures and performance on the baseline task. A regression of performance on total tests and time to first test was significant, $F(2,86) = 3.31$, $p = .04$, $R^2 = .07$. Minutes to first test was a significant predictor of performance on the baseline task, controlling for total tests, $B = -.22$, $t(86) = -2.26$, $p = .03$, such that for each minute earlier a
student tested, her tower was almost a quarter of an inch taller. Total number of tests did not significantly predict performance, controlling for time to first test, $p > .54$. These results suggest that, prior to intervention, there is a performance benefit to iterating early on design tasks.

**Near Transfer Boat Task**

Overall, students’ best boats held an average of 33.7 nickels (SD = 28.5) and a maximum of 120 (equivalent to 67 and 240 pennies). They tested boats an average of 2.3 times (SD=1.7) and a maximum of 9 times. A student’s first test was, on average, 21.15 minutes (SD= 8.1) into the challenge. Again, there was a significant correlation between first test time and the number of tests, $r = -.75$, $p < .01$. The earlier a student started testing her boats, the more tests she was likely to do.

**Condition Effects on Iteration and Performance.** To test the hypothesis that Mindset students would demonstrate more iterative behaviors compared to STEM students, a MANCOVA examined time to first test and number of tests as DVs, with condition and grade as fixed factors and baseline time to first test and number of tests as covariates. The model showed significant multivariate effects of condition, $F(2,81) = 12.77$, $p < .01$, $\eta^2_p = .24$, grade, $F(2,81) = 16.45$, $p < .01$, $\eta^2_p = .29$, and a significant interaction of condition and grade, $F(2,81) = 4.19$, $p = .02$, $\eta^2_p = .09$. Univariate analyses revealed that, compared to students in the STEM condition, students in the Mindset condition tested their boats significantly earlier, $F(1,82) = 14.24$, $p < .01$, $\eta^2_p = .15$, and tested their boats significantly more, $F(1,82) = 24.70$, $p < .01$, $\eta^2_p = .24$. Moreover, older students were more iterative: compared to students in fifth grade, students in sixth grade tested their boats significantly earlier, $F(1,82) = 21.84$, $p < .01$, $\eta^2_p = .21$, and tested their boats significantly more, $F(1,82) = 30.00$, $p < .01$, $\eta^2_p = .27$. Analyses
of the condition and grade interaction revealed significant interactions for both time to first test, $F(1,82) = 6.97, p = .01, \eta_p^2 = .08$, and number of tests, $F(1,82) = 6.45, p = .01, \eta_p^2 = .07$.

To explore these interactions, I ran follow-up Bonferroni pairwise comparisons on the marginal means. These revealed a clear condition effect for sixth-graders and a messier story for fifth-graders (Table 6). Mindset sixth-grade students tested their boats significantly earlier than STEM sixth-grade students, $F(1,82) = 16.80, p < .01, \eta_p^2 = .17$, and significantly more than STEM sixth-grade students, $F(1,82) = 23.08, p < .01, \eta_p^2 = .22$. Among fifth-grade students, while Mindset students tested significantly more than STEM students, $F(1,82) = 3.97, p = .05, \eta_p^2 = .05$, they did not differ from STEM students on time of first test, $F(1,82) = .89, p = .35, \eta_p^2 = .01$.

To test the hypothesis that Mindset students would demonstrate higher performance on the transfer task, an ANCOVA examined maximum nickels held by condition and grade with baseline performance as a covariate. This model revealed significant main effects of condition, $F(1,83) = 14.05, p < .01, \eta_p^2 = .15$, such that students in the Mindset condition outperformed students in the STEM condition, and grade, $F(1,83) = 4.91, p = .03, \eta_p^2 = .06$, such that students in the sixth grade outperformed students in the fifth grade, with no significant interaction, $p = .76$. Bonferroni pairwise comparisons revealed that Mindset students in both grades performed better (i.e., created boats that held more nickels) than their same-grade STEM counterparts, $F(1,83) = 10.78, p < .01, \eta_p^2 = .12$ (fifth) and $F(1,83) = 4.73, p = .03, \eta_p^2 = .05$ (sixth, Table 6). Taken together, these results suggest that Mindset students transferred their iterative disposition to the boat task, and these effects were somewhat stronger for sixth graders than fifth graders. However, regardless of grade, Mindset students outperformed STEM students.
Table 6. Estimated marginal mean scores (with SE) on near transfer measures by condition and grade, accounting for corresponding baseline measures.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Condition</th>
<th>n</th>
<th>Minutes to first test</th>
<th>Number of Tests*</th>
<th>Maximum Nickels Held*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean (SE)</td>
<td>Range</td>
<td>Mean (SE)</td>
</tr>
<tr>
<td>Fifth</td>
<td>Mindset</td>
<td>25</td>
<td>23.0 (1.3)</td>
<td>3.0-30.0</td>
<td>2.0 (0.3)</td>
</tr>
<tr>
<td></td>
<td>STEM</td>
<td>29</td>
<td>24.7 (1.2)</td>
<td>2.8-30.0</td>
<td>1.3 (0.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minutes to first test*</td>
<td>Number of Tests*</td>
<td>Maximum Nickels Held*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean (SE)</td>
<td>Range</td>
<td>Mean (SE)</td>
</tr>
<tr>
<td>Sixth</td>
<td>Mindset</td>
<td>18</td>
<td>12.5 (1.5)</td>
<td>6.3-29.0</td>
<td>4.4 (0.3)</td>
</tr>
<tr>
<td></td>
<td>STEM</td>
<td>16</td>
<td>21.7 (1.6)</td>
<td>15.3-30.0</td>
<td>2.2 (0.3)</td>
</tr>
</tbody>
</table>

*Significant difference in scores, \( p < .05 \)

**Relationship between Condition, Iteration, and Performance.** Regression analysis was used to investigate the complex relationships between condition, iteration, and performance (Table 7). There were no interactions between condition and either of the iterative measures or condition and grade, so these coefficients were removed from presented analyses. As shown through the analyses in the prior section and reiterated below, both grade and condition were significant predictors of performance, such that being in 6th grade predicted an increase in performance (Model 1) and being in the Mindset condition, controlling for grade, significantly predicted and accounted for significantly more variance in performance than a model with grade alone, \( F(1,85) = 14.49, \ p < .01 \), \( \Delta R^2 = .14 \) (Model 2).

Next, to understand the effect of iteration on performance, I first ran a regression of performance on grade, time to first test, and total tests (Model 3) and found that this model predicted significantly more variance than a model of performance on grade alone, \( F(2,84) = 3.27, \ p = .04, \ \Delta R^2 = .07 \). Due to the collinearity of time to first test and total tests, neither predictor was significant in this model. Therefore, I ran two separate models to parse out their unique effects and found that both time to first test (Model 3b) and total tests (Model 3c) were significant predictors of performance, when controlling for grade. Last, to test my mediation hypothesis, I
ran a regression of performance on grade, condition, time to first test, and total tests (Model 4).

While this model predicted a significant amount of variance in performance, the only significant predictor was condition. An R² change test confirmed that this model accounted for no additional variance in performance than a model with condition and grade alone, \( p = .29, \Delta R^2 = .02 \). Taken together, these results show that condition affected both iteration and success on this task.

Students in the Mindset condition iterated more, iterated earlier, and performed better on the task. However, when controlling for condition, there were no benefits to iteration for performance.

**Table 7. Regression models of near transfer task performance on iteration measures and condition**

<table>
<thead>
<tr>
<th>Model</th>
<th>( B )</th>
<th>SE</th>
<th>( B )</th>
<th>SE</th>
<th>( B )</th>
<th>SE</th>
<th>( B )</th>
<th>SE</th>
<th>( B )</th>
<th>SE</th>
<th>( B )</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>21.55*</td>
<td>5.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>19.51*</td>
<td>5.94</td>
</tr>
<tr>
<td>Time to first test</td>
<td></td>
<td></td>
<td>-68</td>
<td>.54</td>
<td>-96*</td>
<td>.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-68</td>
<td>.51</td>
</tr>
<tr>
<td>Number of tests</td>
<td>1.96</td>
<td>2.59</td>
<td>4.19*</td>
<td>1.89</td>
<td>-55</td>
<td>2.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( R^2 )</td>
<td>.06</td>
<td>.21</td>
<td>.13</td>
<td>.13</td>
<td>.12</td>
<td>.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( F )</td>
<td>5.83</td>
<td>11.15</td>
<td>4.22</td>
<td>6.08</td>
<td>5.52</td>
<td>6.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( p )</td>
<td>.02</td>
<td>&lt;.00</td>
<td>.01</td>
<td>&lt;.00</td>
<td>.01</td>
<td>&lt;.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( \Delta R^2 \) for Models:

- Model 1 to 2: .14**
- Model 1 to 3: .07*
- Model 2 to 4: .02

* \( p < .05 \)

**Note:** I tested for and found no interactions of condition, grade, or either iteration measure, so these were not included in the models.

**Design Thinking Knowledge vs. Design Behaviors (Mindset Only)**

In an effort to replicate the inverse relationship between reported and demonstrated design thinking knowledge found in Study 1, I ran similar correlations on my Study 2 data, comparing Mindset students’ posttest scores, and boat task measures, controlling for pretest score. There were no such correlations found in the Study 2 data (Table 8).
Table 8. Correlations between design thinking knowledge and iterative disposition on near transfer task (Mindset condition)

<table>
<thead>
<tr>
<th></th>
<th>Max Nickels Held</th>
<th>Time to 1st Test</th>
<th>Total Tries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest Design Knowledge (controlling for Pretest Design Knowledge)</td>
<td>.09</td>
<td>.16</td>
<td>-.17</td>
</tr>
</tbody>
</table>

**Intervention Design Task Measures (Group-level Analyses)**

As in Study 1, intervention design tasks were analyzed at the group level. An ANOVA by condition and grade confirmed there were no effects of grade, condition, or interaction of grade and condition on performance for either the drop challenge or the playground challenge, $p$-values >.10. On average, groups created drop devices that stayed in the air for 1.68 seconds (SD = .61), (1.56 STEM, 1.79 Mindset), and their final playgrounds scored 207 fun points (SD = 40) (206 STEM, 208 Mindset). In the Mindset condition, groups documented about five times more tries on the drop challenge than the playground challenge Table 9. In regards to demonstrated improvement across iterations and perceived improvement across iterations, approximately half of the groups demonstrated improvement (i.e., their third test was their best test) while around 70% perceived improvement (as coded on their reflection sheet) on each task.

Table 9. Mean tries, demonstrated improvement (%), and perceived improvement (%) by design task with group as unit of analysis (Mindset condition)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Drop ($n=18$)</th>
<th>Playground ($n=23$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M (SD) / %</td>
<td>M (SD) / %</td>
<td></td>
</tr>
<tr>
<td>Tries</td>
<td>16.61 (9.63)</td>
<td>3.30 (2.18)</td>
</tr>
<tr>
<td>Demonstrated Improvement</td>
<td>50%</td>
<td>52%</td>
</tr>
<tr>
<td>Perceived Improvement</td>
<td>67%</td>
<td>70%</td>
</tr>
</tbody>
</table>
Study 2 Discussion

Learning Design Thinking

As in Study 1, Study 2 found that students who participated in the design thinking intervention significantly outperformed STEM students on the design knowledge component of the posttest, while STEM students significantly outperformed Mindset students on science and math content knowledge. Together, this set of findings supports my first hypothesis: a brief design thinking intervention can successfully teach middle school students both the process and philosophy of design thinking. Importantly, the goal of the Mindset intervention was to affect learning of the design thinking process and increase performance on tasks, rather than enhance STEM learning, and results suggest that I met this aim.

Attitude Towards Failure

Additionally, new promising results from Study 2 were those around students’ attitudes towards failure. Study 2 results suggest that the design thinking intervention promoted more positive affective responses to failure and taught students to act in reaction to failure by employing the design thinking process. Students in the Mindset condition performed significantly better than STEM students on both of these posttest measures, accounting for pretest performance. It seems that, in Study 2, Mindset students internalized the messages about failure and iterative prototyping. These findings provide compelling evidence that rapid prototyping can shift students’ responses to failure in meaningful ways.

However, Study 2 found no effects of the design thinking intervention on expectancy to succeed in the face of failure. I believe that this is likely due to the complex and confusing nature of the measure. Students were given a scenario in which “Jordan” failed and then asked to take the perspective of Jordan. Unfortunately, these scenarios neglected to mention if Jordan knew
about design thinking, and it is reasonable that a student may have thought that Jordan was not taught the same lessons as she was. In fact, studies suggest that individuals are motivated to think of themselves are better than most other people (Hoorens, 1995), such that students in this study may have believed that Jordan was a typical student who would expect to and might actually do terribly after experiencing failure (unlike themselves, who would of course persevere and ultimately succeed). Additionally, these scenarios dealt with rather catastrophic mid-task failures, rather than slight setbacks or mistakes, which was largely the type of failure that was discussed during the intervention. It is possible that students were unable to transfer the design thinking philosophy to such extreme cases.

**Iterative disposition**

Corroborating Study 1 findings, Study 2 found that Mindset students asked for significantly more attempts on future tasks than STEM students at posttest, accounting for their pretest iteration scores, suggesting that students in the Mindset condition consider iteration an important process step across a variety of tasks. More importantly, analyses of the near transfer boat task revealed condition differences in on iteration and performance measures, such that students in the Mindset condition iterated earlier, iterated more frequently, and scored higher on the task than those in the STEM condition, co-varying baseline iterative measures. I did find an interaction of grade and condition for the iteration measures, such that sixth grade students in the Mindset condition tested their boats significantly earlier and more than their STEM counterparts, while fifth graders in the Mindset condition tested more than fifth-grade STEM students but did not test significantly earlier. These results suggest that mid-year fifth graders may not be developmentally or behaviorally ready for this type of quick instruction. Perhaps younger students would benefit from longer or more heavily scaffolded instruction. However, the pattern
suggests that the intervention had an effect across both grades, despite it not always reaching statistical significance.

Overall, results from these studies largely supported my second hypothesis: students in the Mindset condition adopted an iterative disposition, measured both via survey and behavioral measures. Both studies found condition differences in the time to first iteration on the near transfer design challenge (controlling for baseline iterative disposition in Study 2), and Study 2 found condition differences in number of iterations as well. Moreover, timing of iteration took on greater importance across both studies than expected. Due to the way it minimizes investment in any one idea, rapid early prototyping is a staple of design thinking. While there exists no research to my knowledge that formally explores the effects of iterating early, this measure was most sensitive to condition effects and, as discussed below, appears to be highly related to performance.

**Iteration and Performance**

Adding to Study 1 findings, Study 2 findings present more evidence that students who iterate earlier on design tasks perform better on these tasks than those who do not. Across the two studies, three separate tasks show a relationship between iteration (either early or often) and performance. Early iteration predicted performance on both the Study 1 near transfer boat challenge and the Study 2 baseline tower challenge. Moreover, number of tries predicted performance on the Study 1 far transfer bridge task. However, Study 2 regression models for the near transfer task suggested that, while condition was a major predictor of performance and iterative disposition, there was no effect of iteration on performance, controlling for condition. This differs from Study 1, where performance was not significantly different across conditions.
on the boat task. Overall, these results generally support my third hypothesis: iterative habits lead to greater performance on a task.

**Condition, Iteration, and Performance**

For Study 2, while I did find that condition affected performance, such that students in the Mindset condition outperformed those in the STEM condition, I did not find evidence of mediation. In fact, iterative disposition did not affect performance when controlling for condition. In Study 2, I increased the dosage and revised the curriculum of the intervention, and it appears it had a strong effect on student performance. These results suggest that an additional component of the Mindset intervention, beyond “try early and often,” benefits performance. One interpretation is that students in the Mindset condition were benefitting from multiple aspects of design thinking as they designed their boats, in addition to trying early and often. For example, students may have reflected on feedback in more beneficial ways, such that the number or timing of iterations was less important than what these students did with the feedback they gleaned from iterations. Alternatively, Mindset students in Study 2 may have been more resilient in the face of uncertainty and failure and used the iterations more productively, while STEM students mentally disengaged after experiencing any setbacks. Overall, I did not find evidence of mediation. Study 1 found that students in the Mindset condition iterated earlier than those in the STEM condition and that iterating earlier was linked to increased performance, but did not demonstrate an overarching relationship between condition and performance. Study 2 found large condition effects, such that students in the Mindset condition iterated more and earlier than those in the STEM condition and outperformed them, but regression analyses indicated that, when controlling for condition, there was no relationship between iterative measures and performance.
Design Knowledge and Behaviors

One unexpected finding was that design thinking knowledge as measured by the more traditional school-like task of completing a posttest was either not related at all (Study 2) or even inversely related (Study 1) to iterative performance on the near transfer task. These findings suggest that the students who are able to demonstrate learning on posttest measures are not the same students who are able to demonstrate iterative disposition on a transfer task. This result indicates that we might need to find a better way to reach the conscientious “good student” who has trouble letting go of the desire to do something slowly, once, and perfectly, and instead dive in with permission to fail. More optimistically, these findings imply that design thinking might tap into the non-traditional students’ needs and serve as a powerful way to engage students who may not shine in the traditional classroom. Prior research suggests that design thinking curriculum may provide a specific benefit to low performing students (Conlin et al., 2015; Kolodner et al., 2003), and one interpretation of these results is that the students who succeeded most at the design tasks were not traditionally good students.

Limitations and Future Directions

I have demonstrated that students were able to learn and transfer the process and philosophy of design thinking after participating in a brief intervention that explicitly teaches these components. Moreover, the intervention reframed failure, such that Mindset students reacted less negatively to failure and were able to apply design thinking in reaction to a mid-task failure. Future research should explore whether or not these effects transfer into more traditional classroom contexts. Can students apply this iterative process across a variety of ill-defined problems in the classroom (e.g., a tricky math problem, an essay), and, if so, does the connection between iteration and performance hold? Additionally, future work could explore the extent of
this motivational shift around failure. How do students who have learned design thinking react to mid-task failures on non-design tasks? Furthermore, one new idea born from these results is the importance of testing *early*, not just testing frequently. While a number of studies show links between quantity of iteration and performance, future work should explore this relationship between timing of iteration and performance.

One limitation of this work is the narrowly defined definition of iteration. In each task, I used a specific type of test as a proxy for an iteration, which assumes that (a) students are refining their designs between each test and (b) students are only testing in this way. It is likely that there was a great deal of variance in how much students reworked their ideas or designs between each test as well as how much feedback they gleaned from a test, both across and within students. Moreover, it is likely students were physically testing their designs in a variety of other ways that were less involved than asking for a juice box or using a water bin in the back of the classroom (i.e., testing a tower’s strength with one’s hand). Additionally, this measurement entirely discounts mental iteration, or the way in which designers reason about and change their designs in the absence of physical testing (Jin & Chusilp, 2006). In reality, iteration is far less clear-cut and trickier to define. My choice to count iterations this way reflects the constraints of quantitative data acquisition in the midst of a classroom study. However, future work, perhaps using micro-genetic techniques, could explore the messier ways in which students iterate upon ideas during design challenges. Furthermore, future studies should aim to assess the different ways in which students refine designs across iteration and determine the importance of *meaningful* iteration. For example, how does a student conducting trial-and-error tests differ from one who is reflecting deeply on feedback? How does a student who makes slight tweaks to an existing design differ from one who develops an entirely new designed item? In Costa and
Sobek's (2003) work on engineering design, the authors frame iteration in terms of abstraction level (concepts vs. details). How do iterations of concepts differ from iterations of minor details? Exploring the varying impacts and importance of different types of iteration could be a fruitful next step.

Additional limitations concern the short duration of instruction and its lack of embeddedness in typical classroom instruction. A full-fledged design-thinking curriculum that is integrated into the whole school year may affect greater change in students’ behaviors and beliefs. Furthermore, in order to highlight the effects of teaching design, I chose study conditions where students learned either STEM content or design principles, rather than integrating the two into a more holistic curriculum. The Mindset intervention was aimed at inducing learning of design thinking components and enhancing performance, rather than affecting learning of science or math content. Ideally, students would learn both relevant content and design principles in an integrated curriculum. Future studies should explore how best to integrate these types of instruction.

Another limitation is its feasibility. This intervention relied on a team of up to five researchers during design challenges, to ensure that students received timely feedback. While this level of support was required to collect data, it also facilitated the effectiveness of the intervention, and a 6:1 student to teacher ratio is rare in a typical middle school classroom setting. Therefore, future work should explore how to facilitate design thinking challenges with fewer coaches or instructors in the room.

Furthermore, this study isolated the iterative rapid prototyping component of design thinking and its corresponding philosophy around failure. Future work should evaluate the additional benefits of teaching the full design process, including the *empathy* and *defining the*
problem stages, as well as dealing with more authentic, so-called wicked problems. Complex design challenges that revolve around a human need can be personally motivating and engaging for students, and therefore may result in even greater willingness to iterate. Therefore, future work should consider the ways in which more authentic and relevant design tasks will affect iterative dispositions. Additionally, future work should further investigate the complex relationship between knowing about design thinking and employing it in both design and non-design contexts. In these studies, there was a disconnect between performance on survey measures and demonstrating iterative disposition on the design challenges. Do these tasks tap into very different skillsets for students?

**Conclusion**

This research sought to explore how a brief design thinking intervention could impact students’ proclivities towards iteration and mindsets around failure. Overall, I found that students in a design thinking intervention learned from the intervention and were able to demonstrate increased design thinking knowledge by posttest. While Study 1 results were inconclusive regarding students’ attitudes towards failure, results from the second study suggested that students in the Mindset condition internalized the design thinking philosophy, as measured by their affect and actions in the face of failure. Furthermore, survey and behavioral measures confirmed that Mindset students developed an iterative disposition. Additionally, data across the baseline tower challenge, near transfer boat challenge, and far transfer bridge riddle triangulated on the performance benefits of going through iterative cycles of design both earlier and frequently. Moreover, the second study suggested the Mindset intervention had broader benefits for student performance, beyond encouraging them to iterate early and often.
My findings add to the growing body of work regarding the use of design thinking curriculum in K-12 education. While many studies of design thinking in middle schools focus on facilitating skills such as collaboration and creativity or use the process in service of a larger STEM agenda, this work shows unique motivational benefits of learning iterative rapid prototyping. Moreover, the vast majority of design thinking research involves case studies or employ qualitative designs. Therefore, the present research adds quantitative evidence for the use of design thinking in schools and presents a novel way to quantify iterative dispositions during design tasks. Armed with the process of iterative design and the mentality that a good product should take many tries and will often involve a number of mistakes or setbacks, I propose that design thinking education can provide students with the tools and resilience necessary to succeed in the face of the myriad ill-defined problems that define our modern world.
CHAPTER 5: CONCLUSION

Design thinking is a complex construct, and we are only just beginning to conduct rigorous research on how it fits into the K-12 educational landscape. While research does suggest that design thinking education promotes 21st century skill acquisition and STEM learning, motivational implications have been largely unexplored. The present research focused on teaching a subcomponent of design thinking, iterative rapid prototyping, and assessing the ways in which it affected individuals’ iterative habits, attitudes towards failure, and performance on design tasks. Chapter 2 provided a brief overview of design thinking literature and connected it to motivational theory. Chapter 3 detailed the intervention I developed in a design case, illustrating how both research and my own iterative design practice informed its development. Chapter 4 presented the results of two classroom studies of the intervention, which demonstrated that students learned about design thinking, internalized its message about failure, and could transfer the iterative process onto novel design tasks. After learning design thinking and practicing the principles in two design challenges, students developed iterative dispositions and shifted their attitudes towards failure. These studies confirmed the performance benefits of iterative rapid prototyping and highlighted the importance of early iteration. This dissertation adds to a larger discussion on how to integrate design thinking into the classroom, and more importantly, provides new evidence for why one would want to incorporate this process in the first place. In using quantitative research methods and a quasi-experimental study design, I add meaningfully to the body of largely qualitative design thinking research. Moreover, this work raises important questions about how the process affects motivation. As K-12 education shifts to support the needs of the 21st century, I believe design thinking is an ideal pedagogy for cultivating the mindsets and skillsets that will enable students to thrive.
REFERENCES


Gentner, D., Loewenstein, J., & Thompson, L. (2003). Learning and transfer: A general role for analogical encoding. Journal of Educational Psychology, 95(2), 393–405.


Francis.


### APPENDICES

**Appendix 1. Assessment Measures and Coding Manuals**

#### Design Knowledge

<table>
<thead>
<tr>
<th>Item</th>
<th>Desired Response</th>
<th>Coding Scheme*</th>
<th>Study</th>
</tr>
</thead>
</table>
| **What do you think it means to think like a designer?** | 1. Make Mistakes / Failure is okay  
2. Make test think / Iterative prototyping  
3. Try often (Study 2: and often) | 1 – 3 of the answer  
.75 – 2 of the answer  
.5 – 1 of the answer  
.25 – “solve a problem”  
0 – None of the above | Both |
| Pretend that I gave you a new design challenge, where you had to build a tower to support a heavy weight. Do NOT explain what you would design. Instead, **explain the STEPS or PROCESS you would take to solve this challenge.** | Iterative process of Make, Test, Think. | 1 – Iteratively Make, Test, Think  
.75 – Make, Test, Think  
.5 – [Make + Test] or [Make + Iterate]  
.25 – Make + Think  
0 – None of the above | Study 1 |
| **Part 1:** Do you think mistakes are good or bad? (circle one) **Good Bad I’m not sure** | Part 1: Yes | 1 – Correct Part 1 + Correct Part 2  
.5 – Correct Part 1 + Partial Part 2  
(You can learn from them)  
0 – Incorrect Part 1 or [Correct Part 1 + Incorrect Part 2] | Study 1 |
| **Part 2:** Explain your answer in 1-2 sentences. | Part 2: You can learn from them and fix your mistake on the next try | | |
| A designer has a challenge to build a bridge out of pasta that will support a weight without breaking. Explain the steps or process a designer should take to solve this challenge. | Iterative process of Make, Test, Think. | 1 – Iteratively Make, Test, Think  
.75 – Make, Test, Think  
.5 – [Make + Test] or [Make + Iterate]  
.25 – Make + Think  
0 – None of the above | Study 2 |
| **When should designers try their designs during a design challenge** | Early and Often | 1 – Early and often  
.5 – Early OR often  
0 – None of the above | Study 2 |

*Similar responses to these were given credit*
## Content Knowledge

<table>
<thead>
<tr>
<th>Item</th>
<th>Desired Response</th>
<th>Coding Scheme*</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1: Which of these two objects will hit the ground first if I drop them at the same time from very high up? (circle your answer)</td>
<td>Part 1: (c) They will land at the same time</td>
<td>1 – Correct Part 1 + Correct Part 2</td>
<td>Both</td>
</tr>
<tr>
<td>(a) [Image of 15lb medicine ball]</td>
<td></td>
<td>.5 – Correct Part 1 + Incorrect Part 2</td>
<td></td>
</tr>
<tr>
<td>(b) [Image of 2lb basketball]</td>
<td></td>
<td>0 – All Incorrect</td>
<td></td>
</tr>
<tr>
<td>(c) They will land at the same time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 2: Why did you pick this answer?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 2: Gravity acts the same on all objects / The air resistance is the same because they are the same shape / It doesn’t matter how much something weighs for how fast it falls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part 1: Which of these two sheets of paper will STAY IN THE AIR longest if I drop them at the same time from very high up? (circle your answer).</td>
<td>Part 1: (b) [Image of flat sheet of paper]</td>
<td>1 – Correct Part 1 + Correct Part 2</td>
<td>Both</td>
</tr>
<tr>
<td>(a) [Image of crumpled ball of paper]</td>
<td></td>
<td>.5 – Correct Part 1 + Incorrect Part 2</td>
<td></td>
</tr>
<tr>
<td>(b) [Image of flat sheet of paper]</td>
<td></td>
<td>0 – All Incorrect</td>
<td></td>
</tr>
<tr>
<td>(c) They will land at the same time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 2: Why did you pick this answer?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part 2: The flat sheet will have more air resistance than the crumpled sheet due to its shape</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| My garden is 4 feet wide by 6 feet long. I want to plant tomatoes. Each tomato plant needs a space 2 feet wide by 2 feet long to grow. How many tomato plants can I put in my garden? (show your work) | 4 * 6 = 24 2 * 2 = 4 24 / 4 = 6 tomato plants | 1 – Correct answer .5 – Wrong answer BUT calculated area of garden (24) or tomato plant (4) 0 – Wrong answer + did not calculate area | Study 1      

* Similar responses to these were given credit
<table>
<thead>
<tr>
<th>Item</th>
<th>Desired Response</th>
<th>Coding Scheme</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1: Jenna made the designs for a new playground below. The <strong>GRAY</strong> lines outline each thing she plans to put in her playground. <strong>Can Jenna fit another sandbox of the same size in her playground?</strong> (Circle your answer) (a) Yes   (b) No</td>
<td>Part 1: Yes</td>
<td>1 – Correct Part 1 + Correct Part 2</td>
<td>Study 1</td>
</tr>
<tr>
<td>Part 2: If NO, explain WHY. If YES, how would you do it? (Optional: Show work on blank grid)</td>
<td>Part 2: Illustration with second sandbox (a common solution was shifting and rotating the monkey bars next to the park bench and putting a sandbox in the upper left corner) or Short answer explaining this new layout</td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamara wants to fill her sticker book page so that she has as many stars as possible on the page. She has an unlimited supply of the three below types of stickers. Without overlapping, how would you design her sticker book page so that it has the MOST stars on it?</td>
<td>32 (using all of sticker type 2)</td>
<td>1 – Correct</td>
<td>Study 2</td>
</tr>
<tr>
<td>Part 1. At the school bake sale, Tasha and Victor are both selling cookies. Tasha is selling bags of 10 cookies for $5. Victor is selling bags of 9 cookies for $3. If you want to get the BEST DEAL for your money, which student would you buy cookies from? (Circle one) (a) Tasha (b) Victor (c) Either one – it doesn’t matter</td>
<td>Part 1: (b) Victor</td>
<td>0 – All Incorrect</td>
<td>Study 2</td>
</tr>
<tr>
<td>Part 2. Why?</td>
<td>Part 2: Tasha’s cookies are 2 for $1 and Victor’s cookies are 3 for $1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Study 1 Iterative Disposition (Posttest Only, circle a number 0, 1, 2... 11 or more)

1. If I gave you a NEW design challenge to build a tower that could support a heavy weight, how many designs would you want to create before you had your final design?
2. Your teacher assigns you an essay for a big homework assignment. It is due in 1 month. How many DRAFTS of the essay would you want to turn in for feedback before turning in your final essay?

Study 1 Reframing Failure (Likert-Scale 1 [Strongly Disagree] to 5 [Strongly Agree])

1. I should only show my teacher work that is complete and correct. (Reverse code)
2. When I face a new challenge, I am excited to FAIL at it.
3. People who take a lot of tries to do something well are bad at it (Reverse Code, item dropped from analysis)

Study 2 Iterative Disposition (circle a number 0, 1, 2... 11 or more)
* indicates posttest only

1. *If I gave you a NEW design challenge to make a flying device that will go the farthest, how many designs would you want to create before you had your final design?
2. Your teacher assigns you an essay for a big homework assignment. It is due in 1 month. How many DRAFTS of the essay would you want to turn in for feedback before turning in your final essay?
3. *If I gave you a NEW design challenge to design the best backpack for students, how many designs would you want to create before you had your final design?
4. You are giving a speech to run for Class President. How many times would you want to practice your speech before giving it to the class?
5. You are doing a really hard math problem on your math homework and you can tell that the answer looks wrong. How many times would you retry the problem?
6. *If I gave you a NEW design challenge to design a toy car that would go the furthest when dropped down a ramp, how many designs would you want to create before you had your final design?
7. If I gave you an assignment to make a poster about your favorite historical figure, how many times would you sketch out your plan before making the final poster?
8. *You are doing a design challenge to come up with a safer and faster way to get students out of the building in case of a fire or other emergency. How many ideas would you want to consider before presenting your final design?
**Study 2 Expectancy in Reaction to Failure (5-point Likert Scale)**
(* indicates posttest only)

Tell us how you would feel if you were Jordan. There are NO right or wrong answers!

*Jordan is writing a big report for class and it is due in one month. The teacher said that students can turn in rough drafts of their reports as many times as they want before they turn in the final report, and the teacher will give them advice. Jordan turns in a report for feedback after working on it for one week and when Jordan gets it back it is COVERED in red marker. There are a LOT of things the teacher wants Jordan to change.*

1. If you were Jordan, based on the paragraph, how well would you expect to do on this report compared to other students? (1 – Much worse than other student to 5 – Much better than other students)
2. If you were Jordan, based on the paragraph, how well do you think you would do in this class this year? (1- Very Poorly to 5 – Very Well)
3. If you were Jordan, based on the paragraph, how good at writing reports are you? (1- Not at all good to 5 – Very good)
4. If you were Jordan and were to order all of the students in your class from the worst to the best at writing reports, where would you put yourself? (1 – The worst to 5 – The best)
5. If you were Jordan, based on the paragraph, how confident would you feel about doing well on the final report? (1 – Not confident at all to 5 – Very Confident)

*Tell us how you would feel if you were Morgan. There are NO right or wrong answers!

*Morgan is doing a design challenge in science class where students have to design an egg drop container that stops a raw egg from cracking when it is dropped from the ceiling to the floor. Morgan has one week to design the egg drop container and lots of raw eggs to play with. On the first day, Morgan makes a container and drops the egg from the ceiling. The egg flies OUT of the container and cracks ALL OVER THE FLOOR.*

1. If you were Morgan, based on the paragraph, how well would you expect to do on this design challenge compared to other students? (1 – Much worse than other student to 5 – Much better than other students)
2. If you were Morgan, based on the paragraph, how well do you think you would do in this class this year? (1- Very Poorly to 5 – Very Well)
3. If you were Morgan, based on the paragraph, how good at designer egg drop containers are you? (1- Not at all good to 5 – Very good)
4. If you were Morgan and were to order all of the students in your class from the worst to the best at designing egg drop containers, where would you put yourself? (1 – The worst to 5 – The best)
5. If you were Morgan, based on the paragraph, how confident would you feel about doing well on the final egg drop challenge? (1 – Not confident at all to 5 – Very Confident)

**Study 2 Action in Reaction to Failure (2 items, referring to expectancy scenarios)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Desired Response</th>
<th>Coding Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>If you were Jordan/Morgan what would you do for the next three weeks before the report/design challenge is due?</td>
<td>1. Make Mistakes / Failure is okay</td>
<td>1 – 3 of the answer</td>
</tr>
<tr>
<td></td>
<td>2. Make test think / Iterative</td>
<td>.75 – 2 of the answer</td>
</tr>
<tr>
<td></td>
<td>3. Try early and often</td>
<td>.5 – 1 of the answer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 – None of the above</td>
</tr>
</tbody>
</table>
Study 2 Affect in Reaction to Failure (Likert-Scale 1 (Strongly Disagree) to 5 (Strongly Agree))

*Design is a way to take action to solve a tricky problem. Design challenges are tricky problems where there is no one right answer. For these questions, tell us how much you agree with each sentence. There are NO right or wrong answers!*

1. I would feel terrible if I made a mistake.
2. If my design were poor, I would try not to let anyone know.
3. Bad feedback would make me feel very sad.
4. The first thing I think about is that I might fail.
5. I worry about making errors.
6. I would feel like hiding if I got bad feedback.
7. If I make a lot of mistakes, I feel very moody or angry.
8. I really dislike making mistakes.
9. I get sad if I make errors when I am trying to learn.

Brochure Coding (Mindset only)

<table>
<thead>
<tr>
<th>Item</th>
<th>Desired Response</th>
<th>Coding Scheme</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is Design?</td>
<td>A way to take action to solve a tricky problem</td>
<td>1 — Correct 0 — Incorrect</td>
<td>Study 2</td>
</tr>
<tr>
<td>What is a tricky problem?</td>
<td>1. Something new 2. You don't know the correct answer right away 3. You don't know HOW to find the answer 4. There are many ways to solve the problem OR no one correct answer</td>
<td>1 — 3 or 4 of the answers .5 — 1 or 2 of the answers 0 — none of the answers</td>
<td>Study 2</td>
</tr>
<tr>
<td>What are the three things good designers do?</td>
<td>1. Make mistakes and learn from them 2. Make, Test, Think 3. Take Many Tries (Study 2: Try early and often)</td>
<td>1 — 3 of the answers .5 — 1 or 2 of the answer 0 — none of the answers</td>
<td>Both</td>
</tr>
<tr>
<td>How did you use design thinking in the drop challenge?</td>
<td>Applies one of the following in the context of the challenge: 1. Make mistakes and learn from them 2. Make, Test, Think 3. Try early and often</td>
<td>1 — Applies one or more in context of challenge 0 — Does not apply design thinking to challenge</td>
<td>Both</td>
</tr>
<tr>
<td>How did you use design thinking in the playground challenge?</td>
<td>Applies one of the following in the context of the challenge: 1. Make mistakes and learn from them 2. Make, Test, Think 3. Try early and often</td>
<td>1 — Applies one or more in context of challenge 0 — Does not apply design thinking to challenge</td>
<td>Both</td>
</tr>
<tr>
<td>How could you use design thinking in your life (give a SPECIFIC example)</td>
<td>Any context where making mistakes can lead to feedback that you can learn from, take many tries, and ultimately succeed (e.g., when taking a hard math class, when designing a new video game)</td>
<td>1 — Novel valid context 0 — No novel valid context</td>
<td>Both</td>
</tr>
</tbody>
</table>
Appendix 2: Additional Results

Brochure Coding (Mindset condition Only)

Mindset students’ brochures were coded to assess how well students were able to explain, synthesize, and abstract their new design thinking knowledge. Brochures were coded on three parameters: thoroughness of design thinking information included, ability to connect design thinking tenets to design challenges, and adequacy of proposed future use of design thinking. Agreement between coders was satisfactory, with all kappa values > 0.70. These parameters were then combined to create an overall Brochure quality score, out of 1. This coding manual is included in Appendix 1.

Study 1. Overall, Mindset students demonstrated a thorough understanding and satisfactory application of design thinking. The majority (N=30, 58%) of students included all three of the key tenets of design thinking in their brochures, and all but one student included at least one of these key ideas. When asked to explain how these ideas applied to the design challenges, 62% of students were able to do so for at least one of the three key ideas. Proposing a new context in which design thinking could be useful proved slightly more difficult; only 42% of students were able to do so.

Study 2. Again, Mindset students demonstrated a thorough understanding and satisfactory application of design thinking. All but two students (96%) included all three of the key tenets of design thinking in their brochures. When asked to explain how these ideas applied to the design challenges, 67% and 50% of students were able to apply at least one tenet of design thinking to the drop or playground challenges, respectively. Furthermore, 66% of students were able to apply design thinking to a new context. This high performance replicates that of Study 1.
Study 1 and Study 2 Comparison Analyses

**Learning Outcomes.** To compare how students did on the learning measures across both studies, I calculated a MANOVA, with time (pre vs. post) and target knowledge (design vs. content) as within-subjects factors and condition and study as between-subjects factors. I found a four way interaction of time, target knowledge, condition, and study, $F(1,161) = 6.28, p = .01$. Follow-up Bonferroni pairwise comparisons revealed that, at pretest, Study 1 students scored significantly higher on both types of target knowledge compared to Study 2 students, $F(1,161) = 31.95, p < .01$. At posttest, Study 1 STEM students scored significantly higher than Study 2 STEM students on both types of target knowledge, $F(1,161) = 8.23, p < .01$, while Study 1 Mindset students scored significantly lower on design knowledge than Study 2 Mindset students $F(1,161) = 4.07, p = .04$, and did not differ on content knowledge $F(1,161) = 3.41, p = .07$. In summary, Study 1 students scored generally higher on both types of target knowledge than Study 2 students, with the exception of posttest design knowledge for the Mindset condition. These findings likely reflect the revisions from Studies 1 to 2 that increased the difficulty of surveys as well as those changes intended to increase the efficacy of the Mindset intervention.

**Transfer Boat Task.** To compare the transfer boat task across both studies, I calculated a MANOVA on time to first test, number of tests, and maximum nickels held by condition and study. For Study 2, I computed “maximum nickels held” by dividing the number of pennies held by two (pennies weigh half as much as nickels). There was a significant interaction of study and condition, $F(1,159) = 3.67, p = .01$. Follow-up Bonferroni pairwise comparisons, revealed that Study 1 STEM students’ boats held significantly fewer nickels than Study 2 STEM students’ boats, $F(1,161) = 5.82, p = .02$, and Study 1 Mindset students tested significantly fewer times than Study 2 Mindset students, $F(1,161) = 12.78, p < .01$. There were no differences across
studies for time to first test for either condition. Overall, Study 1 students tested fewer times and performed worse than Study 2 students on this task.

**Brochure Task.** In Study 1, Mindset students, on average, scored 70% on the brochure task (SD = 22), while Study 2 Mindset students scored an average of 75% (SD = 19). To compare brochure task performance across both studies, I calculated an ANOVA by study and found no significant differences, $F(1,93) = 1.59, p = .21$.

**Gender Differences**

**Study 1.** Main analyses from Study 1 were calculated including gender as a factor, in order to ensure no gender effects. I ran the appropriate ANOVA models for learning outcomes, the *Reframing Failure Scale*, the iterative disposition scale, performance and iteration on the near transfer boat task, performance and iteration on the far transfer bridge riddle, and performance on the brochure. All Study 1 gender analyses revealed no effects of gender or interactions with gender on any of the key outcome variables.

**Study 2.** To account for gender effects, I ran the appropriate ANOVA models for learning outcomes, iterative disposition, all three measures of attitude towards failure, performance and iteration on the transfer boat task, and brochure score. Among all these measures, the ANOVAs for learning outcomes and the *affective reaction to failure* scale were the only analyses that showed gender effect, and these effects are discussed below.

For learning outcomes, an RM ANOVA with time (pretest vs. posttest) and target knowledge type (design vs. science/math content) as within-subjects factors and condition, grade, and gender as between-subjects factors found no main effect of gender ($p = .34$). However, I did find a two-way interaction of knowledge type and gender, $F(1,80) = 9.10, p < .01$ and a three-way interaction of time, condition, and gender, $F(1,80) = 4.98, p = .03$. Follow-up
Bonferroni pairwise comparisons of the knowledge type and gender interaction revealed that, overall, males outperformed females on the content knowledge pretests and posttests, $F(1,80) = 5.23, p = .03$. Exploration of the three-way interaction of time, condition, and gender revealed that across all knowledge types, Mindset condition males outperformed Mindset condition females at pretest, $F(1,80) = 4.75, p = .03$. There were no other gender differences by time and condition. As these measures are within subject in this study, students act as their own controls and therefore gender was not included in main analyses.

For the affective reaction to failure scale, an RM ANOVA found an interaction of time, grade, and gender, $F(1,80) = 5.97, p = .02$. Follow-up Bonferroni pairwise comparisons showed that while there were no differences by grade or gender at pretest, fifth grade males outperformed sixth grade females at posttest, such that the fifth grade males had more adaptive reactions to failure than the females, $F(1,80) = 5.22, p = .03$. Again, this measure is within subjects, and gender was therefore not included in main analyses. Male students were outperforming female students on science and math items, especially at pretest. The gender effect at posttest on the affective reaction to failure scale suggests that males may have benefitted more from the intervention.