Design Thinking Instructional Problems (DTIP):

Exploring the Perspectives of K-14 STEM Teachers on the DTIP Approach to Developing Instructional Lessons

by

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ABSTRACT

A reform movement in the United States has focused on STEM education and 21st century soft skills such as critical thinking, communication, collaboration, and creativity. This spotlight on STEM instruction provided an opportunity to explore how K-14 STEM teacher participants perceived a Design Thinking Instructional Problems (DTIP) approach to developing instructional lessons. The study used a convergent parallel mixed-methods design with a survey instrument and a multiple case study focused on K-14 in-service STEM teachers. Data were collected from teacher participants during two five-week summer Research Experience for Teachers (RET) programs as part of two separate National Science Foundation (NSF) funded Engineering Research Centers (ERC) located at a large southwestern university in the United States (n=16). The study was conducted over three phases. During Phase I and II, teacher participants experienced a Design Thinking Overview workshop and weekly DTIP professional development sessions to facilitate the development of an RET instructional lesson. Pre- and post-program DTIP surveys and background interviews were conducted with all teacher participants (n=16). From this original group, teacher participants were selected as cases. Implementation observations and post-implementation interviews were conducted with these case-teachers (n=10). The study included frequency analysis and descriptive statistics of survey data. Qualitative data were analyzed using direct interpretation, thematic analysis, and open coding with the constant comparative method. A variety of arrays, summaries, and matrices were used to visualize patterns across and within individual case-teacher results. All 16 teacher participants viewed themselves as designers solving complex instructional problems. All 16 teacher participants found the

DTIP professional development sessions to have *somewhat* to *very much* provided additional value during their RET summer programs. Six of the 10 case-teachers perceived the DTIP model graphic as *mostly* to *completely* corresponding to the way in which they developed their RET instructional lesson. Lastly, eight of the 10 case-teachers chose to embed a Design Thinking student learning strategy into the RET instructional lesson they developed.

DEDICATION

This dissertation is dedicated to my family and friends who have encouraged and supported me. To my husband Stan who acted as my sounding board throughout this process and who spoke with joy about one day having letterhead that read Dr. and Mr. Elwood. To my son Nolan who decided to introduce me to several popular Internet games, which I then had to resist all through my dissertation. He was always patient whenever I needed to shut out the world to finish a paper for a deadline; however, even during those deadlines, we always made sure to sneak in family time. To my mother and sister, two powerful women who never cease to amaze me and who have helped me past those times of uncertainty. To my extended family and friends who bravely understood—smiled and took a rain check—when I could not participate because I was working on my dissertation—still. You will never know how much your support has and will always mean to me.

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I would also like to thank the faculty, staff, and administrators of the Engineering Research Centers through which I was able to conduct my study. Each of you has my eternal gratitude for your support and direction.

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CHAPTER 1

INTRODUCTION

In 2007, the Carnegie Foundation created a commission to address growing concerns about the ability of the United States to continue to be a competitor in today's global economy (Griffiths & Cahill, 2009). Their report asked the nation to shift the way in which our children were taught toward a more relevant inquiry and design-based science and math curricula. In 2011, the National Research Council, National Science Teachers Association, and the American Association for the Advancement of Science joined together with the departments of education from 26 states to create the Next Generation Science Standards. This effort led to the creation of *A Framework for K-12 Science Education* (National Academies of Sciences, 2018), a set of standards focused on the intersection of engineering and design practices, crosscutting concepts, and core ideas. By 2016, 18 states and the District of Columbia had officially adopted this framework, and several others followed suit (National Association of State Boards of Education, 2016). While the reevaluation of educational objectives is something that regularly occurs within K-12 education, science has rarely been the focus. Instead, the last few decades of reform have focused primarily on language arts and math (Core Standards, 2016).

This education reform not only changed educational curricula, but it also changed the professionalism standards for teachers. In a description of earlier teacher reforms experienced in her own country of Sweden, Dr. Ingrid Carlgren (1999) noted the following concerning the teaching profession:

> The aims and purposes of schooling change as society changes. During the second half of this century, there has been a permanent reforming of schools and, as a result, a permanent redefinition of teachers' tasks and competencies. In our times, teachers' work is characterized by ruptures rather than continuities. Teachers' knowledge will, therefore, be out-of-date more often than not. Every reform implies a loss of competence from the teacher's perspective.

This shift in the nation’s educational focus toward scientific inquiry, therefore, also necessitates a shift in teacher professional development and support. Carlgren recommended that one possible way to better support and strengthen teacher professionalism would be to foster teachers as designers.

Koehler and Mishra (2005) used a learning by design approach to provide in-service teachers problem-solving experiences with technology. They found that learning about design seemed to be most effective by actually doing the design. This suggests that there could be value in facilitating a design approach with teachers for the development of instructional lessons. Other researchers support this suggestion by recommending that a shift in the nature of how teachers are viewed and supported must also occur. For example, Jordan, Kleinsasser, and Roe (2014) described the complex and ambiguous issues today’s teachers face as *wicked problems*. They suggested that rigid, linear thinking resulting in right or wrong solutions is inappropriate for the multifaceted nature of learning. Instead, they posited that teachers must begin to view themselves as designers of learning environments. This was also supported by Svihla, Reeve, Sagy, and Kali (2015), who suggested that teachers need a reflective, iterative approach to help them facilitate creative problem-solving as they design learning experiences for their students.

Background

This study used a convergent parallel mixed-methods design (Creswell, 2014) with a survey and a multiple case study that explored how K-14 STEM teacher participants perceived a Design Thinking Instructional Problems (DTIP) approach to the development of instructional lessons. To provide context for this study, I first give an overview of the literature on Design Thinking as used to creatively problem-solve. Then I provide literature which suggests a need for a DTIP approach to the development of creative instructional learning experiences. I follow this with a section outlining the DTIP study context. I then conclude this chapter by describing the purpose of the study and presenting the research questions.

Design Thinking

Design Thinking can be considered a process or method through which a designer solves ill-defined problems (Cross, 2011; Kimbell, 2011); however, the term *process* can be associated with a linear step-by-step procedure. I therefore prefer the term *approach*, which more fully encapsulates the way in which Design Thinking is used to "characterize what individual designers know, how they approach and make sense of their own work, as well as how they actually do it" (Kimbell, 2011, p. 296). I will therefore refer to Design Thinking throughout this study as a creative problem-solving *approach* (Cross, 2011). This approach involves a fluctuating divergence and convergence of information that allows the designer to adapt and reimagine how they frame or see the problem (Cross, 2006). As they shallowly explore initial solutions, they may gather more data, more perspectives, and more knowledge to quickly determine their efficacy. During this framing process, certain solutions are abandoned while others may be nurtured.

Cross (2006, 2011) showed that student design teams who spent too much time gathering initial data, as scientists would, ran out of time to explore solutions and this resulted in more traditionally derived solutions. On the other hand, some novice design teams were able to move away from initial data collection, but brainstormed so many solution concepts that they became—much like those who spent too much time gathering data—wrapped up in the testing of each of those permutations and were never able to move forward. The expert design teams who were the most successful, based on the level of innovation of their final solution, used initial data to propel them forward to a few solution ideas which they rapidly tested through visualization methods. Then they gathered more data to either propel those ideas forward or disqualify them, in which case they would then forge a new path towards the solution.

While similar in some ways to scientific inquiry, one key differentiation is the satisficing nature of Design Thinking. Scientists use two main methods of reasoning: (1) deductive reasoning to apply a general theory to a group and then use specific instances within that group to test hypotheses, and (2) inductive reasoning to observe and gather data from specific instances to generalize to the whole group. On the other hand, Designers cannot build something and then let individual groups test it one at a time. This can lead to catastrophic harm. They also do not have the luxury of time to continue to gather data until they absolutely know their theory is correct for all groups in all instances.

Instead, designers use abductive reasoning (Cross, 2006), which allows them to gather the data at hand and begin to develop solutions while continuing to reach for new data as needed. However, at some point the designer must satisfice the solution. Satisficing is the act of being satisfied that a design is good enough to present to a client; it may still need ongoing revision in the future, but it will work for the moment (Lugmayr, Stockleben, Zou, Anzenhofer, & Jolonen, 2014). Is the solution going to be the BEST possible solution? Probably not. It is merely the best one for those users at that time in that context. This satisficing separates designers from scientists: “Unlike the scientist, who searches for many cases to substantiate a rule, and then one case to falsify it, the designer can be gratified in being able to produce just one satisfactory case that gives an appropriate result” (Cross, 2011, p. 28). This supports Buchanan’s (1992) claim that the Design Thinking approach is best utilized with ill-structured problems that have several possible solutions for one problem, and no stopping rules—only good or bad solutions.

Though Design Thinking researchers agree that certain assumptions define this approach—such as ambiguity, iteration, production, visualization, collaboration, empathy, situation, and satisficing—the abductive, non-linear nature of the approach does not suggest a simple process model (Cross, 2006; Buchanan, 1992; Rittel & Webber, 1973). Design Thinking’s fuzziness of construct might suggest a whimsical nature in which only those attuned to some magical internal force can use it successfully. Yet, research demonstrates that while it involves creativity of thought and a willingness to accept uncertainty and risk failure, Design Thinking is most often conducted in an extremely systematic way (Cross, 2001, 2006; Lawson, 2006; Rowe, 1991). This suggests that utilizing a Design Thinking model could provide foundational understanding for those new to the Design Thinking approach.

Traditional Design Thinking Models

Designers may have been taught a traditional linear process model for their specific design field; however, in practice they often do not follow these models step-by-discrete-step. Instead, they purposefully use a recursive approach to diverge from one step to return to an earlier one, often picking up new information in the process (Cross, 2006; Lawson, 2006; Schön, 1983). This affords designers the opportunity to change and reconstruct this frame over and over. This suggests that they begin by developing many mini solutions, then diverge from the traditional to follow certain aspects of those solution paths—often building or sketching models—until the rationale they are following collapses and leads them to converge again. Teal (2010) even relates the Design Thinking approach to the growth of a rhizome with its variety of root paths, as contrasted to the linear root of a tree.

As part of this approach, most designers define the problem, seek empathy through discovering stakeholder perspectives, explore solutions through prototyping, test those prototypes, and revise through reflection (Cross, 1990; Kimbell, 2011; Schön, 1983). However, note that Design Thinking researchers have refrained from developing their own Design Thinking process model, perhaps fearing that such a model would imply sequential, discrete stages to be followed in a rigid way, which would defeat its very assumptions (Buchanan, 1992). At the same time, Cross (2006) has strongly conveyed the importance of sketching and visualization as a method for increased insight.

The Stanford University d.School and IDEO Design Thinking models utilize discrete stages, which seem to suggest that Design Thinking is a five-stage linear creative problem-solving process (see Figures 1 and 2).

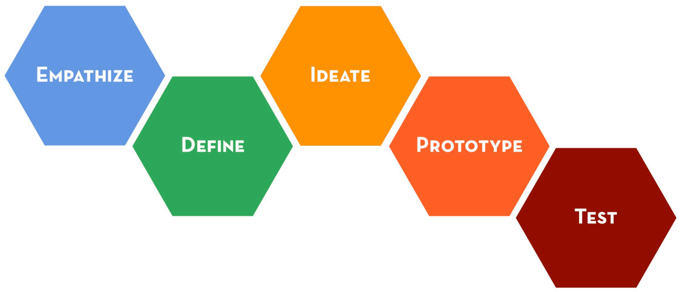

Figure 1.1. Stanford University Design Thinking Model (d.School, 2017).

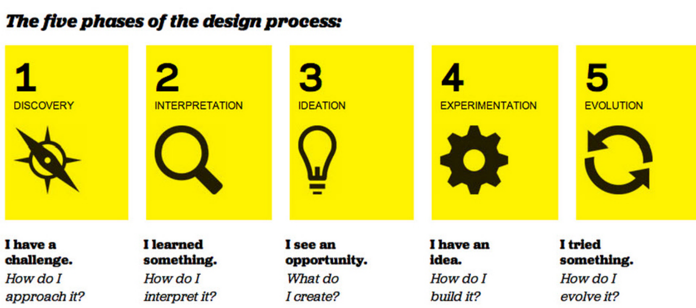

Figure 1.2. IDEO Design Thinking Model (IDEO, 2017).

The parsimonious nature of these models has made them extremely popular in design, engineering, and business fields. However, these models do not fully represent the inherent tension between the analytical and the creative that designers must navigate (Cross, 2011; Donar, 2011; Lugmayr et al., 2014; McKenney, Kali, Markauskaite, & Voogt, 2015).

Design Thinking Instructional Problems Approach

Design Thinking is both a set of principles and an approach (Kimbell, 2011) by which designers solve wicked problems—those that are ill-defined and difficult to solve (Buchanan, 1992; Rittel & Webber, 1973). The Design Thinking approach to solving a wicked problem involves a fluctuating divergence and convergence in which designers concurrently understand the problem as they solve it (Cross, 2006; Lawson, 2006). Because of the inherently indeterminate and ever-changing nature of education, the design of effective learning curricula, materials, and programs can represent a type of wicked problem (Jordan et al., 2014). Some researchers suggest a Design Thinking Instructional Problems (DTIP) approach—in which the general Design Thinking approach is used to solve wicked instructional problems in the field of education—could be an effective way to promote higher critical thinking and problem-solving patterns for teachers (Jordan, 2016; Kali, McKenney, & Sagy, 2015; Svihla et al., 2015). This further suggests that a DTIP approach could lead teachers toward ever deepening and more meaningful ways of developing learning experiences for students.

Wicked Instructional Problems

Buchanan (1992) suggests that the Design Thinking approach is most effective for solving wicked problems. Rittel and Webber (1973) define wicked problems as ones that are ill-defined and inherently complex. Head (2008) further expanded this definition by suggesting that wicked problems involve the highest levels of complexity, uncertainty, and divergence of viewpoints.

If design problems are wicked problems, using a linear scientific method to solve them would fail to encompass Design Thinking assumptions. By combining the Design

Thinking approach with Dewey's (1986) pragmatism and Rittel and Webber's (1973) notion of ill-defined wicked problems, Buchanan also develops a connection between Design Thinking and teacher education, a field known for its ambiguous and at times contradictory constraints. This discourse was furthered by Mishra and Koehler's (2006) technological pedagogical content knowledge framework (TPCK), in which they attempt to better understand the wicked problems inherent in technology integration in education. The TPCK framework provides teacher educators and researchers with a common language for discussing these complexities. Now teacher education researchers are further linking the wicked problems discourse to teacher education by recommending that teachers see themselves as professional designers of learning experiences (Jordan et al., 2014; Leverenz, 2014; Southgate, Reynolds, & Howley, 2013).

Some education scholars have begun to explore how Design Thinking might foster the development of innovative and creative learning design. Jordan et al. (2014) applied the wicked problems lens to better understand challenges in education and more specifically literacy learning. They found evidence in the literature that the common problems in teaching were often best defined as wicked, which further suggested that research into professional development integrating a DTIP approach to instructional problems could be a valuable first step. In addition, Henriksen and colleagues conducted an interview with Buchanan in which he further suggested that Design Thinking can be a type of creative inquiry (Henriksen, Mishra, & Deep Play Research Group, 2018). This suggests that even if a given instructional problem does not seem wicked or complex, the Design Thinking approach could still be valuable as a creative procedure that helps "melt the categories where we think we know what is, and they show us what could be" (p. 2).

Scholars have argued that teaching is a design science (Bower, Highfield, Furney, & Mowbray, 2017); however, the term science suggests a rigid process that if followed will seemingly lead to successful outcomes. However, Design Thinking—as a creative approach to problem-solving—involves challenges which may make it difficult to easily apply within education. Koehler and Mishra (2005) applied the work of Schön (1987) to technology integration in education when they argued that using design involves certain complexities. These scholars found design to be a holistic skill that is dependent on a recognition of design aspects, is a creative process, can be initially confusing or ambiguous, and is suffused with gaps between concept and final design. They further argued that the best way to overcome these challenges was to allow learners to proceed through the design process. Bower et al. (2017) additionally suggested that becoming a reflective practitioner, as defined by Schön (1987), also supports a Design Thinking approach: "In order to learn to design, we need to reflect while we design, so as to take advantage of the intrinsic learning and optimization opportunities embedded within our moment-by-moment design practices" (p. 128).

This need to foster reflection additionally supports an argument proffered by Carlgren (1999) in which she stated: "If this design work is seen as part of teachers' work, and as practice, then student teachers must have practical experience of planning as designing. In order to develop professionalism as designers of school practice, they need experience of the practice of reflective curriculum planning" (p. 54). Though Carlgren focused on pre-service student teachers, much the same can be said of in-service teachers. For a DTIP approach to be effective, teachers must first have a belief that they are professional designers solving instructional problems and then have opportunities to practice in that manner. Pajares (1992) argued, "Beliefs are instrumental in defining tasks and selecting the cognitive tools with which to interpret, plan, and make decisions regarding such tasks; hence, they play a critical role in defining behavior and organizing knowledge and information" (p. 325). Therefore, if teacher participants have negative perceptions of the DTIP approach to the development of instructional lessons, it is unlikely that the approach will be sustainable.

Study Context

This study was conducted with 16 teacher participants during a summer Research Experience for Teachers program through an Engineering Research Center funded through the National Science Foundation. As part of the study design, I worked with the program directors to embed a Design Thinking Instructional Problems model and professional development sessions as an approach to developing their instructional lessons throughout the summer program. In this section, I provide context through literature on professional development theory, Engineering Research Centers, the Research Experience for Teachers program, the study-specific RET programs, and the DTIP pilot study.

Professional Development Theory

Education reform in the last few decades has pushed the education field toward a more scientific standardized model (Laurillard, 2012). In an attempt to provide accountability for school districts and teachers, these standards have also become a political tool for local and state power, and have been used to determine assessment, evaluation, and teacher pay for performance (Labaree, 2004). These results provide a process for teacher proofing or removing teachers as a variable in student achievement.

Yet, teaching is one of the only professions in which the professionals (teachers) are expected to design learning environments for a diverse, ever-changing coerced population within ever-changing local and state constraints for a stakeholder base who believe—based on their own 12 years of being a student—that a teacher's job is straightforward and easy, while being trained through a teacher education program whose main focus is a large teacher workforce (Labaree, 2004). Yet, there are still those who are unaware of the inherently wicked nature of education. Therefore, the development of innovative learning can be considered a wicked instructional problem; thus, teachers must begin to see themselves as designers in order to best prepare their students for a 21st century global society focused on communication, collaboration, critical thinking, and creativity (Partnership for 21st Century Learning, 2015). This paradigm shift will need to occur through professional development.

Research has shown that the continued learning of in-service practicing teachers is critical for educational reform (Desimone, 2009). A national probability survey of math teachers conducted by Garet, Porter, Desimone, Birman, and Yoon (2001) showed that *sustained* professional development that focuses on *content* and allows for *active engagement* while being *coherent* provided those teachers with the highest likelihood for long-term impact. Desimone (2009) conducted a critical review of empirical literature in which she discovered the same four recurring elements as Garet et al., plus an additional element she described as *collective participation*.

Desimone (2009) found a surfeit of research demonstrating that professional development should most strongly focus on linking specific *content* to the best methods for teaching that content. Teachers should be *actively engaged* in the discussion, reflection, and interaction with the content. The professional development must demonstrate *coherence* with not only teachers' knowledge and beliefs but with local and state policy, objectives, and standards. Also, the professional development must be of *sustained* duration: "Research has not indicated an exact 'tipping point' for duration but shows support for activities that are spread over a semester (or intense summer institutes with follow-up during the semester) and include 20 hours or more of contact time" (Desimone, 2009, p. 184). Finally, professional development should allow for discussion and interaction between the same schools, grades, departments, or subjects through *collective participation*. She further argues that research in professional development should utilize these elements in order to create a clear path for comparison of impact studies. This type of professional development is embedded in the National Science Foundation's Engineering Research Center program.

This research suggests that DTIP professional development sessions that are used to foster the creative development of instructional lessons should consist of the following elements: contain relevant content, allow teachers to be actively engaged, resonate with their teaching expectations, build sustained connections, and foster collaboration. The sessions will also need to be compatible with the Engineering Research Center goals and expectations through which the Research Experience for Teachers programs are provided.

Engineering Research Centers

In 1984, the National Science Foundation (NSF) began funding an Engineering Research Centers (ERC) program. These ERCs provide interdisciplinary partnerships between the United States government, universities, and industry to innovate and provide transformative experiences for undergraduate students in the field of engineering. Researchers at universities across the United States partner with NSF and local industry to "provide the intellectual foundation for industry to collaborate with faculty and students on resolving generic, long-range challenges, producing the knowledge base needed for steady advances in technology and their speedy transition to the marketplace" (ERCs Partnerships, 2017, p. 1). NSF has funded a total of 64 ERCs and three Earthquake ERCs since 1985 (ERC Program, n.d.). Part of NSF's ERC mission is to "advance transformational engineered systems and produce graduates who will be creative innovators in the global economy" (NSF, n.d., p. 1).

As part of their strategic plans, NSF requires ERCs to develop and implement education programs that promote creative and innovative experiences for K-14 teachers, undergraduate students, and high school students. Each center is expected to develop summer programs for these groups, to include a Research Experience for Teachers (RET), a Research Experience for Undergraduates (REU), and a Young Scholars (YS) program for pre-college students, usually ages 16-18. The strategic mission of NSF also includes a goal to increase the presence of under-served populations, and this too is part of the ERC mandate.

An ERC provides a strong context to study Design Thinking. ERCs focus on innovative approaches to STEM research and education, partnerships with multiple stakeholders, and strengthening diversity in the scientific and engineering fields. Because of Design Thinking assumptions, which involve diverse perspectives and a fluctuating iterative approach toward innovative and creative problem-solving, the Design Thinking approach can well represent these ERC goals. Additionally, the RET program would allow the specific study of K-14 teachers charged with the design of new and innovative instructional lessons.

RET Summer Programs

An RET summer program, developed for an ERC, is typically five to eight weeks long. Teachers apply to be participants and are paid a stipend for their time. They come to a university campus five days a week during the program. Part of their time is devoted to learning about the particular engineering and science content for that center. They might participate in workshops, discussions, or webinars. Also, teachers typically conduct research projects and are mentored by graduate students and research faculty. RET program administrators expect teacher participants to (1) develop a grade-level appropriate instructional lesson based on the engineering research being conducted within that ERC, (2) develop a research poster, and (3) implement their instructional unit in their classroom sometime in the following academic year.

I conducted this study by working with two separate ERCs located at a large southwestern university in the United States. One ERC conducted biogeotechnical research (soil) and one conducted solar technologies research (solar). Both centers had developed separate summer RET programs for K-14 STEM teachers that ran concurrently. The collaboration between the two centers made it possible for me to work with their educational directors and teams to integrate a DTIP approach for solving instructional problems into both RET programs. The two centers were similar in their NSF-guided goals, but did have a few differences.

RETsolar (May 30 – July 3). The goal of the solar RET was to rethink, rebuild, and re-engineer science education by providing K-14 teachers the opportunity to work with research faculty at a large university's solar power laboratories. Teachers conducted research with the nation's top photovoltaic scientists with open access to the lab equipped with industrial grade fabrication equipment. The solar RET provided seven selected applicants with a $5,200 stipend. Applicants were expected to complete an RET application and submit a curriculum vitae. The first two weeks of their program immersed teachers in the science and research of solar power. The last three weeks the teachers utilized their mornings to develop their instructional unit while their afternoons were spent working with engineering education researchers to connect the lab to the classroom. At least one day a week, teachers worked outside the lab making external connections to industry partners. Also, the RET Education Director asked their teacher participants to fill out a provided instructional lesson plan template as evidence of completion of their instructional plan.

RETsoil (June 7 – July 7). The goal of the soil RET was to develop sustainable biologically-controlled and -inspired solutions in the areas of hazard mitigation, environmental protection and restoration, infrastructure construction, and resource development. The RET program provided nine selected applicants with a $5,000 stipend for the summer program, and an additional $1,000 stipend for implementing their instructional unit in their classrooms in the Fall. Applicants were expected to complete an online application form and email a resume/CV with a professional reference. Final participants were selected by a committee made up of education, diversity, and research faculty and staff.

The first three days of the RETsoil summer program involved an orientation. For the rest of the program, the mornings involved the teacher participants conducting research in labs under the supervision of graduate student and faculty researchers, and the afternoons were set aside for learning experiences and the development of their instructional lesson. The RET's Educational Director, Education Coordinator, and staff also asked teacher participants to fill out a provided instructional lesson plan template, similar to the one used by RETsolar, for evidence of completion of their instructional plan. They asked that a draft of the template be submitted the last week of the program.

Design Thinking Instructional Problems Pilot Study

I conducted a pilot study of 14 K-14 STEM teachers who participated in a DTIP program embedded in both the RETsolar and RETsoil 2016 summer programs (Elwood, Savenye, Larson, Jordan, & Zapata, 2017). The purpose of that study was to explore how K-14 in-service teachers implemented a DTIP approach to create instruction within a STEM summer research experience context.

I asked all teacher participants of RETsoil and RETsolar to respond to a DTIP pre-survey. Afterwards, I conducted a three-hour workshop providing an overview of Design Thinking (Elwood, Savenye, Jordan, Larson, & Zapata, 2016). For RETsoil this workshop was part of their orientation week and included all summer participants: teachers, undergraduates, and young scholar students. The design problem was to work in small groups to develop a new lab space for their school. The following week I met with just the RETsoil teacher participants and discussed DTIP as an approach to creating instruction. I then met with them formally once a week to mentor them in their instructional lesson development, and I conducted a group interview of all of the RETsoil participants.

For RETsolar, the teacher participants spent the first two weeks working with solar researchers. During the third week of the program, I conducted a Design Thinking workshop just for the RETsolar teacher participants. At that time, I more directly facilitated the development of their instructional lesson plan utilizing a DTIP approach. I was not able to meet with them as often to mentor their progress. Though I did conduct group interviews with both RET programs, I did not conduct individual interviews with any of the RET participants from either group. However, I was able to follow-up with all participants of both groups through the DTIP post-program survey.

I analyzed frequencies, descriptive statistics, and correlations from the DTIP survey (pre and post). The pre-program survey included a demographic section regarding gender, race, age, years teaching, STEM subject, and highest educational degree. The majority of items on both the pre- and post-program survey were Likert-type items on a scale of 1 to 5, with 1 being *not at all* and 5 being *a great deal*. Six items on the Design Disposition sub-scale were adapted from a scale developed by Koh, Chai, Hong, and Tsai (2014). They included questions like *I am comfortable deviating from established routines and practices during course instruction* and *I am comfortable with conflicting ideas*. The last item was an open-ended question concerning lesson design.

The DTIP post-program survey asked respondents to provide a pseudonym and included the same Design Disposition items as on the pre-program survey instrument. The post-program survey also included three items regarding teachers' perception of the impact of the DTIP approach used during the summer RET. The items included *To what extent do you believe Design Thinking helped guide your summer project development* and *To what extent do you intend to use Design Thinking practices in the development of* *future instruction*. Three open-ended items concerning teacher participants' possible future application of Design Thinking, and the strengths and weaknesses of Design Thinking as an approach for designing instruction were also included.

Open-ended items, interview transcriptions, and classroom observation field notes were analyzed through open coding (Creswell, 2013) combined with the constant comparative method (Charmaz, 1995).

On the post-program survey, participants' responses resulted in a mean score of 3.5, on a scale of 1 to 5, for the item *To what extent do you believe Design Thinking helped guide your summer project*, and a slightly higher mean score of 3.85 for *To what extent do you intend to use Design Thinking practices*. However, their responses to the item: *To what extent do you think a Design Thinking model could help undergrad teachers be more prepared for teaching* resulted in a mean score of 4.07. Furthermore, on average, data from eight of fourteen teacher participants' design dispositions before and after their summer design thinking training and experience did not seem to change.

It is possible that the participants in the pilot study who did not experience any change in their design dispositions may have already viewed themselves as highly design-oriented. If this was true, the Design Disposition sub-scale may not be able to discern fine-grain variability when utilized with these teacher participants. However, individual change in design dispositions may provide valuable data as to possible characteristics that may or may not influence how teacher participants perceive a DTIP approach to developing instructional lessons. Also, certain participants may not have viewed their instructional problem as a wicked one, possibly making the DTIP approach less valuable for them. This suggests that items attempting to measure the extent to which teacher participants see their instructional problem as "wicked" should be added to the DTIP survey.

Also, the group interviews demonstrated a focus on local and state standards as a beginning point for designing instruction, and a perception by the teacher participants that novice teacher candidates seem unprepared for real world teaching. The data did not provide a clear view of how individual teachers perceived Design Thinking. This suggests that individual interviews could provide more valuable data. Also, I was not able to observe the participants at a deep enough level to provide insight to their design approach. Spending more time with participants, gathering field notes, and conducting follow-up interviews and member checks might also provide a stronger sense of how they perceive Design Thinking.

The instruments used during the pilot were not varied or fine-grain enough to capture how the teacher participants perceived Design Thinking. However, through one-on-one feedback from participants, feedback from the RET educational directors, and feedback through the ERC survey, the participants indicated that they found Design Thinking to be engaging.

Purpose of the Study

I taught public high school for twelve years and was the department chair for two different departments: English and Career and Technical Education (CTE). I was often assigned to mentor novice teachers, provide support for experienced teachers in my department, and plan and conduct professional development. Having earned an M.Ed. in Educational Technology, I was also often asked to develop and provide training for curriculum for new district-wide courses.

Many of the teachers with whom I worked demonstrated an interest in developing problem-solving opportunities for their students that might heighten critical thinking, application, and motivation. It therefore became my professional goal to investigate practical strategies that could support teachers and give them confidence and a willingness to grow in the profession, while still pushing themselves toward the creation of high-level learning opportunities for their students. Based on my theoretical research on Design Thinking, and my experience providing Design Thinking workshops for various types of educators, I believe this approach has the potential to support teachers in achieving this goal. However, I also know that gaining insight into the perceived strengths and weaknesses of the approach will provide a better foundation within educational contexts for future research and provide better support for teachers.

The pilot study findings suggest that a new study exploring how a DTIP approach to developing instructional lessons is perceived by K-14 STEM teachers could provide valuable insight (Elwood et al., 2017). A DTIP approach could provide teachers with a means for developing higher-level inquiry and innovation for their students' learning experiences while continuing to permeate that instruction with current best practices in teaching. Such an approach could also help teachers feel more prepared for 21st century expectations for their classrooms. With the increased emphasis on engineering and design practices in science education and teacher professional development, collecting data on the nature of Design Thinking as an educational framework is the necessary first step.

To further demonstrate the potential value of a DTIP approach, NSF published an informal "Dear Colleague" letter that encouraged researchers to submit "proposals to conduct exploratory work in its early stages on untested, but potentially transformative research ideas or approaches that advance the frontier of knowledge with respect to STEM learning and design thinking" (NSF, 2015, p. 2).

There is still so little empirical data concerning the use of Design Thinking as an approach to instructional problems that each new finding better provides insight into its affordances.

Research Questions

Because research has shown that beliefs affect behavior and that those beliefs "tend to self-perpetuate, persevering even against contradictions caused by reason, time, schooling, or experience" (Pajares, 1992, p. 324), I was interested in researching how teacher participants might perceive a DTIP approach to developing instructional lessons. If the DITP approach was found to resonate with teacher participants, the approach may be sustainable. I define *resonate* in this study as the perception that all or some aspect of the DTIP approach positively aligns with teacher participants' current beliefs regarding teaching and learning. Therefore, I explored the following research questions:

1. To what extent did the teacher participants view themselves as designers solving complex instructional problems?
2. How and to what extent did the DTIP professional development sessions resonate with the teacher participants?
3. How and to what extent did the DTIP model resonate with the teacher participants?
4. What are the characteristics of, and the teacher participants' perspectives on, the lessons developed in conjunction with the DTIP approach within the RET summer program?

Summary

In this study, I aimed to explore how K-14 STEM teacher participants perceived a DTIP approach to developing RET instructional lessons. This chapter summarized the literature surrounding Design Thinking practices and the DTIP approach. It provided the study context, the study purpose, and research questions. The following chapter describes the DTIP study methods.

CHAPTER 2

METHOD

This chapter outlines the researcher role and the mixed-methods study design and rationale for exploring how K-14 STEM teacher participants perceived a DTIP approach to developing instructional lessons. This was a three-phase study of 16 teacher participants during two separate but concurrent summer RET programs located at a large southwestern university in the United States. Descriptions of participants, study phases, and data collection and analysis procedures are provided.

Study Design

I explored the teacher participants' perceptions towards a DTIP approach to developing instructional lessons during two separate, but concurrently-run, RET summer programs held at a large southwestern university in the United States. I worked as a graduate research assistant for both RET programs to help facilitate and support teacher participants while I concurrently collected data for this study. My worldview is one of pragmatism in which I am most often concerned with using data that will best support practical answers to my research questions (Creswell, 2013). I therefore used a convergent parallel mixed-methods design (Creswell, 2014), which included a survey instrument and a multiple case study to provide a triangulation of data (Creswell, 2013). Creswell defines this convergent parallel method as a form of mixed-methods in which "the researcher converges or merges quantitative and qualitative data in order to provide a comprehensive analysis of the research problem" (2014, p. 15). For this type of research design, the data was collected concurrently and then integrated as part of the overall interpretation and discussion. I therefore used the survey instrument to provide data on the *to what extent* aspect of the research questions, while the multiple case study data provided insight into the *how.*

A case study can provide an in-depth understanding of the case through a variety of data collection methods (Creswell, 2013) in order to better "understand complex social phenomena" (Yin, 1989, p.14). Yin also suggests that a case study method is best reserved for studies that (1) utilize how or why research questions, (2) do not require control over participant behavior, and (3) focus on contemporary events within a real-life context. This suggests that survey data integrated with case study data could provide a layered combination of data sources that would offer valuable insights into the complex nature of how the DTIP approach was perceived by case-teachers.

I acted as the key instrument for data collection in this study (Creswell, 2014). As such, I collected multiple sources of data to triangulate (Creswell, 2013) the different aspects and perspectives involved in understanding how a DTIP approach was perceived by teacher participants. Though I had preliminary research and interview questions in mind when the study began, I allowed the data to guide my collection process as the study progressed (Creswell, 2013).

This study involved data collection over three phases during two concurrent RET programs delivered by two ERCs located at a large southwestern university during the summer and fall of 2017. Sixteen RET teachers participated in Phases I and II embedded with DTIP professional development sessions. Then ten of those teachers were selected as case-teachers for Phase III involving classroom observation.

I conducted frequency analysis and developed descriptive statistics on Likert-type survey data (Creswell & Clark, 2011) and followed the same process used during the pilot study (Elwood et al., 2017). I utilized direct interpretation (Creswell, 2013) with the background interview transcripts, thematic analysis (Creswell, 2013) for the DTIP open-ended survey item responses and the post-implementation interview transcripts, and a more in-depth open coding combined with constant comparative method (Charmaz, 1995; Creswell, 2013; Tracy, 2013) for the implementation observation field notes. For the ten participants selected as cases, I first conducted a cross-case analysis to discern possible patterns and themes by research question across cases (Creswell, 2013; Yin, 1989). Then, because I am most interested in how the DTIP approach was perceived by individual case-teachers, I conducted a within-case analysis of individual case-teachers to provide thick description (Geertz, 1973; Tracy, 2013).

Researcher Role

I held a dual role as I collected data for this study. I was a graduate research assistant for the RET programs: half-time with RETsoil and quarter-time with RETsolar. This meant, I assisted with the miscellaneous needs of the program and the teacher participants as required by the administrators, while I simultaneously conducted my study. Most of the time, these two roles did not conflict. In addition, because I was already a consistent part of the RET team, teacher participants seemed to feel comfortable working with me, which provided easier access.

During the pilot study, I also experienced these dual roles (Elwood et al., 2017). I found that I could easily meet with the RET administrators as an assistant who created RET-related hand-outs and forms, and helped to brainstorm and facilitate learning activities. Later, I easily met in small groups or one-on-one with teacher participants. The teacher participants seemed to respond well to me as both an RET assistant and a fellow teacher. The education leaders of both RETs were supportive and eager to have me conduct the Design Thinking workshops and sessions, which suggests that they saw the value of the Design Thinking experience for their participants.

Teacher Participants

Flyers summarizing the RET programs were disseminated to local K-14 schools via email, hard copies at local STEM events, and to ERC partner schools. Applicants submitted a copy of their resume, a letter of reference, and a basic application form. Center administrators and lab directors selected the candidates. Those selected received a stipend from the RET program funded through NSF for participating in the program, and received another smaller stipend for implementing their instruction in their classrooms. Demographic data for study participants are shown in Table 2.1.

Sixteen in-service STEM K-14 teachers from local schools and community colleges were accepted to participate in the two five-week summer RET programs. Nine teachers participated in the biogeotechnical RET (RETsoil) and seven with the solar technologies RET (RETsolar). Often the RET program administers of both programs selected teacher participants from schools with large groups of students from typically under-represented populations in the STEM fields. Therefore, while the teachers themselves were approximately 70% white, their student populations were primarily Hispanic, with some pockets of students who were Native American or African American. Teacher participant gender was equally split, though for the case-teachers, there were slightly more men than women. Lastly, though all adult age ranges were represented, approximately half of the teacher participants were aged 19-29.

Table 2.1

Characteristic Frequencies of Teacher Participants and Case-Teachers

	Teacher Participants (n=16)		Case-Teachers (n=10)	
Characteristics	n	%	n	%
Engineering Research Center				
RETsoil	9	56	9	90
RETsolar	7	44	1	10
Sex				
Male	8	50	6	60
Female	8	50	4	40
Race/Ethnicity				
American Indian/Alaska Native	1	6	0	0
Black/African American	2	13	1	10
Hispanic/Latinx	1	6	1	10
White	11	69	7	70
Non-Response	1	6	1	10
Age				
19-29	7	44	5	50
30-39	2	13	1	10
40-49	3	19	2	20
50-59	4	25	2	20

Note. Two Research Experience for Teachers (RET) groups participated in this study. The RETsolar group focused on solar technologies research and RETsoil focused on biogeotechnical research. Ten case-teachers were selected from the original 16 teacher participants for further in-depth observation.

Study Procedure

As shown in Figure 2.1, data were collected sequentially over three phases. I collected the pre-program DTIP survey and background interviews, and conducted an overview workshop on Design Thinking during Phase I. During Phase II, I facilitated weekly DTIP professional development sessions with the same 16 teacher participants. At the end of the RET program, I collected responses to the post-program DTIP survey and the DTIP survey open-ended item responses. During Phase III, I selected from the original 16 teacher participants 10 case-teachers for whom I conducted classroom observations and post-implementation interviews. The methods for this study are presented in a similar chronological order as these three study phases.

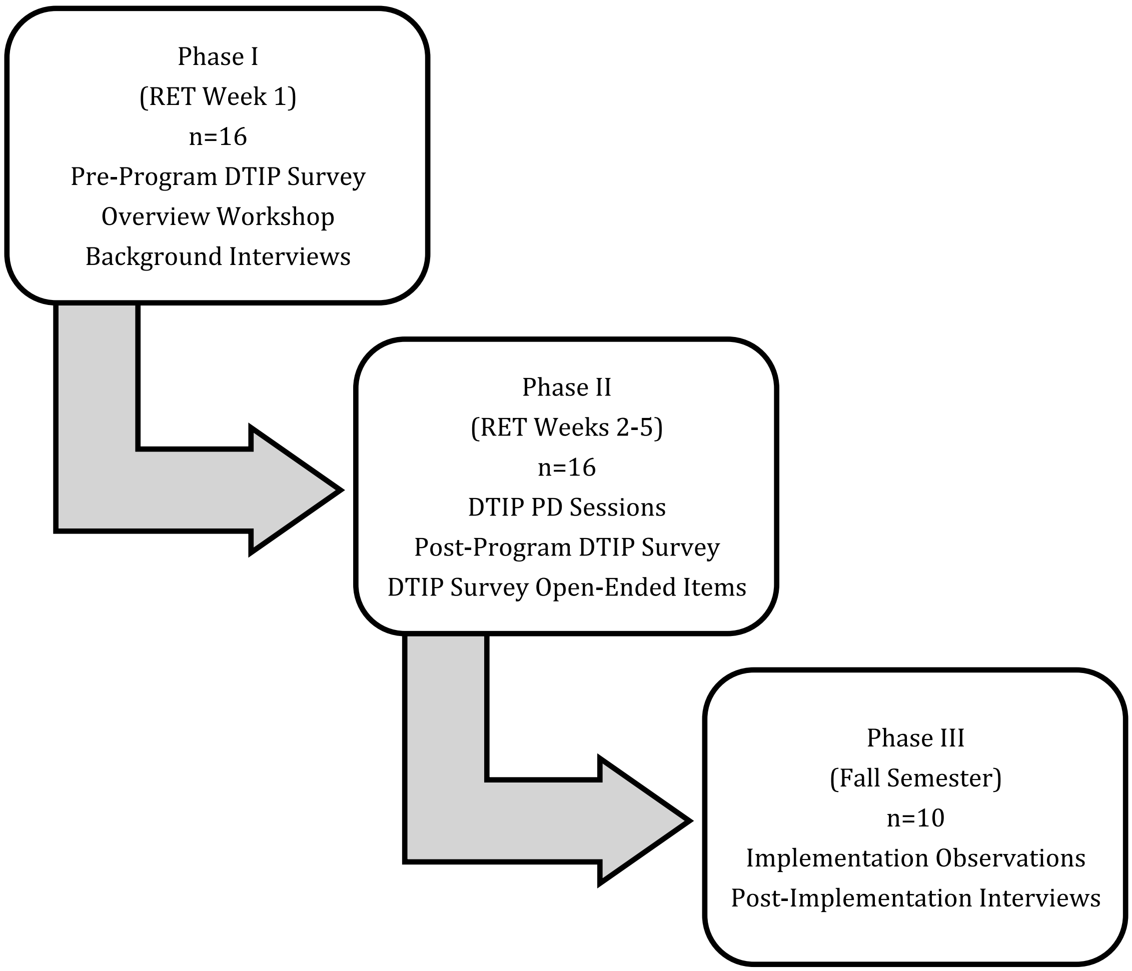

Figure 2.1. Design Thinking Instructional Problems study phases.

The education directors of both the RETsolar and RETsoil programs requested that I conduct a Design Thinking overview workshop as part of the orientation week for their summer participants. They also agreed to provide access to their RET teacher participants throughout the summer programs, as the schedule allowed, to work with and observe teacher participants. The RETsolar program began before the RETsoil program, and the programs were housed in separate buildings on the university campus. Therefore, data for the participants were collected on different dates at separate locations. However, as shown in Table 2.2, large portions of the RET programs did overlap, which enabled the procedure for data collection between the two RET programs to be maintained as much as possible within the situated contexts.

Table 2.2

Design Thinking Instructional Problems Study Timeline

Study Event	RETsolar	RETsoil
Phase I (RET Week 1)	May 30 – June 2, 2017	June 7 – 9, 2017
Phase II (RET Weeks 2-5)	June 5 – July 3, 2017	June 12 – July 7, 2017
Survey Data Analysis	August 2017	August 2017
Phase III (Fall Semester)	September 2017	September – October 2017
Interview and Observation Data Analysis	October 2017 – January 2018	October 2017 – January 2018

Note. Two Research Experience for Teachers (RET) groups participated in this study. The RETsolar group focused on solar technologies research and the RETsoil group focused on biogeotechnical research.

Phase I: Orientation Week (RET Week 1)

On the first day of their respective RET programs (RETsolar/RETsoil), teacher participants were asked to fill out RET paperwork and participate in a pre-program survey developed by the RET education team. The RET education team then introduced me as an affiliated team member conducting additional research on the teacher participants' approach to developing instructional lessons. As each teacher participant completed his or her RET paperwork and pre-program surveys, I approached them individually. I showed them the letter of consent, explained that I had IRB approval through the university (see Appendix A), and outlined the type of data I intended to collect.

I reminded them that whether or not they consented to participate in the study would have no effect on their participation in the summer RET program or their employment as teachers. I also clarified that they would still be participating in all of the DTIP professional development sessions I was holding, since those sessions were embedded as part of the RET program. If they chose not to consent, I simply would not be able to use their data in my study. All 16 teacher participants signed the letter of consent. Teacher participants were then given a paper-pencil copy of the pre-program DTIP Survey, which took approximately five minutes for the majority of participants to complete.

Immediately after collecting the pre-program DTIP survey, I presented a three-hour Design Thinking Overview workshop for each RET program. These occurred on separate dates, but during the first week of their respective orientations. As in the pilot study (Elwood et al., 2017), the overview workshop included RET teacher participants, as well as REU undergraduate and YS high school students. The workshop, therefore, needed to be general enough to be relevant to all of these groups; yet provide enough background for meaningful foundation for teacher participants.

Background interviews were conducted with all 16 teacher participants of both RET programs. I worked with the education team of both programs to find a convenient interview date after I gave the Design Thinking Overview workshop, but before we were heavily involved in the program. For each RET program, I was able to meet with participants during one of their regularly scheduled education work times to pull them individually into a small conference room to conduct the interview. Interviews lasted 10-20 minutes, were audio recorded, and were later transcribed.

Pre-Program DTIP Survey responses. I first collected data through a survey instrument to better understand the extent to which teacher participants might view themselves as designers solving complex instructional problems. I adapted the pre-program DTIP survey for this study (see Appendix B) from the original used during the pilot study (Elwood et al., 2017). The pre-program DTIP survey included a total of 17-items with demographic, Design Disposition, and Wicked Instructional Problems sub-scales. The demographic sub-scale included eight items on gender, race, age, years teaching, school level, STEM subject, years teaching STEM, and highest degree of education. The Design Disposition and Wicked Instructional Problems sub-scales included Likert-type items on a scale of 1 to 5 with 1 being *not at all* and 5 being *a great deal*. As shown in Table 2.3, the Design Disposition sub-scale included four items from a scale developed by Koh et al. (2014), and I included an additional item regarding technology which was later removed during analysis.

Findings from the Design Thinking RET pilot study (Elwood et al., 2017) suggested that participants were reluctant to use Design Thinking practices if they felt their instructional problem did not hold wicked or complex problem elements. I, therefore, developed a four-item Wicked Instructional Problems sub-scale based on *a priori* research as shown in Table 2.4, in which Head (2008) suggested that wicked problems are those that have high levels of complexity, uncertainty, and value divergence.

Table 2.3

DTIP Survey Design Disposition Sub-Scale Items

1. I am comfortable exploring conflicting ideas.
2. I am comfortable deviating from established practices.
3. I am comfortable with occasional failures from trying out new approaches.
4. I am comfortable seeking ways to turn constraints into opportunities.
5. I am comfortable incorporating innovative technologies into my practices.

Note. DTIP = Design Thinking Instructional Problems. Items DD1-DD4 are from Koh et al. (2014). Item DD5 was developed for this study, but was removed during analysis. The same items were used for both the pre- and post-program DTIP survey.

Table 2.4

DTIP Survey Wicked Instructional Problems Sub-Scale Items

1. I believe that the process of creating a new instructional unit is similar to the process of solving a complex problem.
2. I believe that the process of creating a new instructional unit involves interconnected variables that influence each other in unpredictable ways.
3. I believe that the process of creating a new instructional unit involves uncertain outcomes.
4. I believe that the process of creating a new instructional unit involves a diverse group of stakeholders who have differing perspectives and values regarding the instruction.

Note. DTIP = Design Thinking Instructional Problems. The WIP sub-scale was developed specifically for the DTIP study based on *a priori* research (Head, 2008). The same items were used for both the pre- and post-program DTIP survey.

Design Thinking Overview workshop. I conducted the same three-hour workshop for both RET programs. Because the education directors of each program requested that it be conducted for all of their summer program participants, RET teachers, REU undergraduates, and YS high school students, both workshops involved approximately 20 participants. I first used a presentation format to define Design

Thinking as a creative approach to solving problems. This included a discussion of four problem types: simple, complicated, complex, and wicked (Head, 2008). I then suggested to the audience that Design Thinking is an approach that can be used to solve wicked instructional problems, or as a way to develop creativity or innovation in complicated or complex instructional problems.

I showed them the IDEO and Stanford models as traditionally-used models, and then informed them that we would be using a different model—the Design Thinking Instructional Problems model (Elwood & Jordan, 2016), as shown in Figure 2.2.

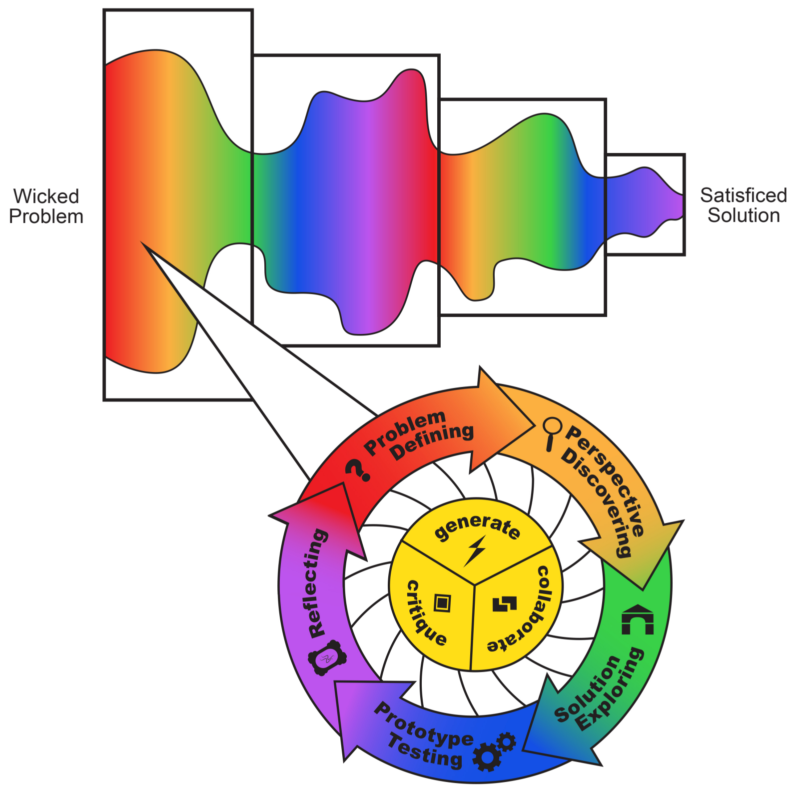

Figure 2.2. Design Thinking Instructional Problems (DTIP) model (Elwood & Jordan, 2016), developed specifically for the DTIP study.

The DTIP model was developed to more fully incorporate the key aspects of both the fluctuating problem-framing approach and the stages used to provide divergence and convergence for reframing towards a satisficed solution. However, I reminded participants that though I intended to use this particular model, several process models for Design Thinking already exist. I encouraged them to view any Design Thinking model as only a starting point, and suggested that they adapt the model to their own needs.

For each of the RET program workshops, I broke the workshop group into smaller teams by program (RET, REU, and YS). During the workshop the teams were provided with a document to develop a team charter that included space for a team name, roles, and norms (see Appendix C). They were then tasked with redesigning a science lab for their school:

> Your school has decided to redesign their laboratories to better focus on inquiry learning as defined through the Next Generation Science Standards dimensions of learning and the 21st Century "super skills" of communication, collaboration, critical thinking, and creativity. As a team, you are tasked with creating a laboratory space that would be conducive to authentic real-world learning that also incorporates the above standards. The lab must work for biology, chemistry, physics, and engineering courses.

I then facilitated the Design Thinking approach as the teams worked toward solving the task by asking them to define the problem in their own words. They brainstormed a list of possible stakeholders who might offer expertise in the problem, and developed possible questions for them. Each team then interviewed another team by providing their definition of the problem and asking their questions. Teachers interviewed students, students interviewed undergraduates, undergraduates interviewed teachers, and then they rotated. Teams added new information to their easel notepad and reframed their problems. We then did a brainstorming activity to push participants to use their imaginations and diverge from any possible solutions they may have initially gravitated towards. Teams were then given blank paper to develop a draft sketch of their lab designs.

Teams then participated in a critical feedback session. Each team sent two people to another team to hear their lab design ideas, and provide feedback on sticky notes, while the rest of the team remained behind to present their design and ask questions regarding areas of concern. Then, teams came back together to discuss the feedback and other team ideas among themselves. They used the information gleaned from their visits to reframe their problem and revise their design. As a group, we discussed how this approach could go through several iterations as a team moves closer and closer to a solution which they feel will work, with some stages of the approach being utilized more often than others, depending on the needs of the team. I then shared with the group that this approach could be used to solve problems in research, but that I would be working specifically with the teacher participants to use it as a way to design instructional lessons.

Background interview transcripts. I conducted individual semi-structured interviews with all 16 teacher participants to gather background information about their teaching dispositions and contexts, as shown in Table 2.5. During the pilot study (Elwood et al., 2017), a few participants suggested that teachers may not feel that they have the authority to develop or change instructional lessons. I therefore included background interview question six concerning their perceived authority level. Also, the first teacher participant I interviewed heavily discussed a need for collaboration. Since collaboration is an assumed aspect of the Design Thinking approach, I felt that a question concerning teacher collaboration was also needed, which resulted in adding question three to subsequent interviews.

Table 2.5

Semi-Structured Background Interview Questions

1. Please tell me what got you into teaching?
2. Describe what it is like to teach at your specific school.
3. Do you feel like you are provided with opportunities to collaborate with other teachers?
4. What made you decide to participate in this RET program?
5. When you create a lesson for your students, what does your typical process look like?
6. Do you feel you have the authority and/or are given support at your school to implement instruction you have created or adapted?
7. Is there anything I forgot to ask about your teaching background that you would like to share, or any questions that you have for me?

Note. RET = Research Experience for Teachers.

Phase II: Research and Instructional Lesson Development (RET Weeks 2-5)

I met with RETsolar teacher participants on Monday mornings in a large lounge area at a solar research facility 20 minutes from the university campus, usually spending most of that day with them until they went into the labs. I met with RETsoil teacher participants on Friday afternoons in the outreach room located in their center's offices at the university campus. I also participated with both groups of RET program participants as they attended research presentations and webinars, and often participated in other education presentations and activities throughout the summer. Because I was also a half-time research assistant with the center conducting the RETsoil program, which was housed on the university campus, I had much greater access to those teacher participants.

I often interacted with them an additional one to two times a week, for a total of two to three times a week. The RETsolar participants were often at the off-campus solar facility, which required a security card for access, making it much more difficult to schedule time with them. I was limited to one time per week with their group with the occasional additional activity.

DTIP Professional Development Sessions. I facilitated weekly DTIP professional development sessions with teacher participants to support the development of their RET instructional lesson. Each week we focused on an aspect of Design Thinking. For example, during the first DTIP session, I reminded teacher participants of the four types of problems (Head, 2008), and I asked them to reflect on the variety of things they were expected to think about in order to develop a lesson that would meet the needs of all their students. We discussed why developing a learning experience could be considered a type of wicked instructional problem. The activity that we utilized during that session was one that would help provide critical thinking concerning the first stage of the DTIP approach. During that time, as part of the summer program, the education director and coordinator of each RET provided time for teacher participants to collaborate with each other; seek feedback from their research mentors, undergraduates, and young scholar students; and set aside time to help answer any questions or concerns the teacher participants may have.

I was concerned with the possibility that I was creating a confounding factor by working so closely with the teacher participants as they developed their instruction. I therefore tried to make my role that of a nonparticipant-observer throughout the study (Creswell, 2013). I facilitated teacher participants' critical thinking about their instructional lesson development through the DTIP sessions. When I observed the teacher participants experiencing frustrations or challenges, I worked with the RET education directors to help provide avenues for the teacher participants to more explicitly deal with those issues. I consistently reminded teacher participants that I was interested in their voice and not the specific strategies with which they chose to use. I reminded them that this was about what would work best in their own classrooms, and that while they did need to meet the requirements of the RET program, I was there solely as a facilitator and sounding board. If directly asked to provide a particular curricular direction, I tried to clarify the challenge the teacher participant was experiencing, ask guiding questions, or help them connect with another RET participant who might provide insight. I tried not to influence the actual content, activities, or organization of their instructional lesson beyond facilitating the DTIP approach.

The DTIP professional development sessions corresponded with the five stages of the DTIP model: problem defining, perspective discovering, solution exploring, prototype testing, and reflecting. The first DTIP professional development session, held during the second week of the RET program, covered both problem defining and perspective discovering, since those are often interwoven. Each subsequent RET program week was dedicated to one new stage; however, we continued to reflect on how that new information added to or changed the initial problem frame.

DTIP session on problem defining (week 2). The DTIP Session on problem defining provided support for developing an initial frame for understanding teacher participants' instructional problem. Focus group interviews from the pilot study (Elwood et al., 2017) suggested that teacher participants tended to build their instructional lessons around their state or local standards, often without being situated in a larger real-world context. In addition, guiding teacher participants toward a larger context may help them view the instructional problem as more complex than originally viewed, thereby allowing them to be more open to other possible instructional solution paths as they develop their lessons.

I led teacher participants through a *Five Whys Root-Cause Analysis* (D. Henriksen, personal communication, March 13, 2017) as a method for more reflectively digging into the instructional problem (see Appendix D). In this strategy, participants wrote down their initial instructional problem. Then they asked themselves why they believe this problem occurs. They wrote down an answer and then asked why again. They continued to ask why and determine a reason a total of five times. The purpose of the strategy is to move the designer towards a larger, more generally situated problem.

I first conducted this activity with RETsolar. Again, I was trying to facilitate their problem framing without prescribing a particular approach. Therefore, I did have several teacher participants who asked me to better define or give an example of what I meant by the initial instructional problem. I reminded them that their task as part of this program is to develop a grade-appropriate instructional lesson based on the research they were conducting here. I asked them to think about what it is they wanted to teach to their students, and put that into a problem statement in whatever way made sense to them to begin developing a lesson. Similar to what occurred in the pilot study (Elwood et al., 2017), the majority of them immediately thought of a state standard and used that as their initial instructional problem, but a few started with large over-arching concepts. Those who began with the state standard used the Five Whys activity to develop a larger frame in which to situate their instructional problem. Those who began with an over-arching concept already had a larger frame, and therefore became frustrated with the activity. Therefore, when I facilitated the same activity with RETsoil, I specifically asked teacher participants to begin with a school or state standard and work from there.

Throughout the rest of the Design Thinking sessions, I often asked teacher participants to reflect on the larger situated instructional problem they developed that first session. I asked them to clarify, change, or add to it as they gained new information or as they felt their instructional problem had changed. By this point in the process though, the majority of them had a working plan for the type of instruction they were going to teach. It is possible that the initial plan created is the most effective way of solving the problem, but it is also possible that they went with a plan with which they were already traditionally comfortable. This could possibly lead to over generalizing certain learning practices to all objectives.

DTIP session on perspective discovering (week 2). Some Design Thinking models begin with the perspective discovering stage by choosing to focus on building empathy between stakeholders. However, Design Thinking stages are not necessarily so discrete. A designer may need to first talk to the stakeholders to understand the problem, but the designer also may not know who to talk to until the problem is defined. These stages are interwoven and depend heavily on the subject matter, designer, and the stakeholders involved. What might make instructional problems particularly wicked is that teachers may believe they already understand the needs of their students, or they may attempt to apply the same needs to all students. While many learning strategies may work from class to class, teachers might be surprised to discover that the problem with the instruction is not what they thought it was.

Earlier in the second week, I asked teacher participants to interview a student who was of a similar age to those typically in their classes using an *Interviewing for Perspective* strategy adapted from Stanford University's d.School (2016), see Appendix D. Because this study took place over the summer, many of the teacher participants chose to interview the young scholar student working in their assigned research lab. For the interview, teacher participants asked open-ended questions concerning the instructional problem. Then teacher participants developed a *Problem Statement*, to include a description of the problem, audience, context, root cause, and teacher point of view (D. Henriksen, personal communication, March 13, 2017).

DTIP session on solution exploring (week 3). Once teacher participants determined which standard and objectives they intended to use for their instructional problem, had a chance to think of a larger context that connects to those objectives, and thought about the audience for their instruction, they began to develop solutions for their instructional problem. Some of them began creating outlines to determine where in their curriculum the RET instructional lesson could be integrated. Others began adapting a lesson or learning strategy that they had seen work well in the past. By this point, the majority of them had a working plan as to the type of instruction they were going to teach. An aspect of the Design Thinking approach is to consider several solution paths before narrowing down to just one (Cross, 2011). It is possible that the initial plan created is the most effective way of solving the problem; however, it is also possible that this initial plan is simply the one with which the designer is most traditionally comfortable.

Participating in a *Wrong Theory Design Protocol* (Svihla & Reeve, 2016) suggested a potential to provide a new angle for consideration (see Appendix D). In this activity, teacher participants described their instructional problem, context, audience, and constraints. Then they were asked to violate those elements by describing the worst possible way to instruct for that problem, in that context, to that audience, and with those constraints. Teacher participants then shared their Wrong Theories. The purpose of the activity was to help demonstrate the underlying aspects of learning that certain teacher participants perceived as the most important, such as active learning, collaboration, or connection to real-world contexts. Teacher participants were then asked to think about practices or learning strategies that would best support and promote that type of learning.

Then teacher participants utilized a brainstorming strategy, in which teachers openly and without constraints considered the imagined possibilities. Teacher participants were then grouped by school level (elementary, middle, high school, college). The groups shared with each other their current understanding of the instructional problem and its context, and described their stakeholders. Then they wrote down the learning content, activities, practices, and strategies that they thought could work for their context. For this activity, participants were instructed to develop as many ideas as possible, use someone else's ideas to build their own, speak one at a time, and not block anyone else's idea. Later, we referred to these ideas to help reframe the instructional problem and begin developing actual instruction.

DTIP session on prototype testing (week 4). Teachers may lack the time to follow through on testing their materials before implementation. Instead, the implementation may become the test, and the revision may not occur until the following year when the lesson must be given again. Many teachers may not even seek out collaboration or feedback from their colleagues, let alone a student. However, designers may not become fully aware of certain aspects of the problem until manifested through testing (Cross, 2011). At the beginning of the RET program, teacher participants were given composition notebooks to utilize for their lab data, brainstorming, and initial lesson drafting. I asked teacher participants to sketch (Cross, 2011) a draft of their instructional planning ideas to begin building the foundation for their instruction. Teacher participants were asked to utilize sketching and keep a journal for their reflective thoughts as part of the Design Thinking approach, but these items were not included as part of the analysis process.

Each RET program required that lesson plans be submitted utilizing an RET-developed lesson template, which required a listing of connected state and Next Generation Science Standards, and other typical lesson topics such as activities, procedures, and assessments. However, it was completely up to the teacher participants to determine what aspect of their research experience would be utilized in their lesson plan and in what ways they would design the learning to ensure that aspect met the needs of their particular students. Teacher participants were asked to develop a short presentation around some aspect of their instruction for a sharing session with the REU and YS students. This same strategy was utilized for RETsoil during the pilot study (Elwood et al., 2017) and was successful, as indicated by anecdotal feedback from the education staff and from all three types of participants. In turn, the REU and YS students provided a summary of their plan for their research poster. Each group then provided the other with critical feedback. I also worked with the education directors and coordinators of each RET to coordinate a combined luncheon, after which teacher participants from RETsolar and RETsoil were partnered by grade level. They each presented a working draft of their instructional lesson and provided each other another level of critical feedback.

DTIP session on reflecting (week 5). Throughout both RET programs, teacher participants were asked to regularly reflect as a type of journalling (D. Henriksen, personal communication, March 13, 2017). After each DTIP session, teacher participants were asked to reframe their problem context and consider any new questions or concerns as they progressed (see Appendix D). The RETsolar program had already integrated a reflection process with their participants, so I worked with them to include the Design Thinking reflection questions as part of that process. In the RETsoil program, I wrote the same reflection questions on a white board and participants answered them in their composition notebooks.

During this last week of the summer program, RET teacher participants submitted their preliminary instructional lesson plans to the RET education team. These lesson plans were used to provide some support for a summary description of the RET instructional lessons, but were not part of the primary analysis process. Over the last few days of each RET program, teacher participants concluded with presentation showcases and several types of RET specific program measures. As they finished the RET measures, I asked them to respond to the DTIP measures developed for this study as well.

Post-Program DTIP Survey responses. The post-program DTIP survey included 22 items (see Appendix B). The first two sub-scales on Design Disposition and Wicked Instructional Problems included the same nine items from the pre-program DTIP survey. In addition, as shown in Table 2.6, the post-program DTIP survey included a DTIP professional development sessions sub-scale with nine Likert-type items on a scale of 1 to 5 with 1 being *not at all* and 5 being *a great deal*. The survey also included four open-ended items to measure teacher participant perception of the DTIP professional development sessions and the DTIP model.

Table 2.6
DTIP Survey Professional Development Sessions Sub-Scale Items

1. I believe the "5 Whys" activity influenced how I created my instructional lesson.
2. I believe interviewing a young student similar in age to my students influenced how I created my instructional lesson.
3. I believe the "Wrong Theory" activity influenced how I created my instructional lesson.
4. I believe the sketching activity influenced how I created my instructional lesson.
5. I believe formally sharing my instructional lesson with other teachers influenced how I created my instructional lesson.
6. I believe having access to colleagues influenced how I created my instructional lesson.
7. I believe that participating in reflection influenced how I created my instructional lesson.
8. I believe that my instructional lesson plan has changed from when I first started thinking about it.
9. I believe I had adequate time to focus on the creation of my instructional lesson plan.

Note. DTIP = Design Thinking Instructional Problems. This sub-scale was only used on the post-program DTIP survey.

The RETsolar education team had their teacher participants gathered in a small conference room where they were finishing their instructional lesson plans. I asked if I could have them pause for a moment to take the post-program DTIP survey, at which point I passed out the paper-pencil survey. During the first few minutes, several of the participants read the items aloud or made comments as they responded, to which I laughed and jokingly reminded them that this was an individual survey. Also, throughout the process, another member of the RET education team would pull a teacher participant out to conduct their own RET post-program surveys and interviews.

RETsoil conducted their post-program surveys in a computer lab. Then, as teacher participants finished, they walked over to another room where I presented them with a paper-pencil copy of the post-program DTIP survey. The majority of teacher participants finished after approximately 10 minutes. As they finished, I collected their surveys and they talked quietly while others finished.

Post-Program DTIP Survey open-ended item responses. Besides the nine-item DTIP professional development sessions sub-scale, the post-program DTIP survey also included four Professional Development Sessions open-ended (PDSOE) items and one follow-up item as shown in Table 2.7. The RETsolar summer program began a week before the RETsoil summer program, which created a gap between conducting and collecting measures for each RET program. This gap between RET programs provided me with an opportunity to spot-check the RETsolar program survey results for any areas that may have required additional follow-up or clarification. I noticed that several teacher participant responses to item PDSOE4a *In what ways if any, did the rainbow-colored Design Thinking model help you understand the Design Thinking process* were overly vague or respondents mentioned a lack of memory regarding the "rainbow colored" model. I therefore realized that I would probably elicit more meaningful responses if the item was more specifically worded and if teacher participants were given a picture of the model to view while responding.

Table 2.7

DTIP Survey Professional Development Sessions Open-Ended Items

1.	What experiences from the RET summer program do you believe influenced the creation of your instructional lesson plan? List and explain.
2.	What aspects of the Design Thinking approach did you find to be the most valuable as you created your instructional lesson plan during the RET summer program? Why were they valuable?
3.	What aspects of the Design Thinking approach did you find to be the most challenging as you created your instructional lesson plan during the RET summer program? Why were they challenging?
4a.	In what ways if any, did the rainbow-colored Design Thinking model help you understand the Design Thinking process?
4b.	Do you feel that participating in an RET program that used this model [see visual] as a guide for creating your instructional lesson provided added value? Why or why not?

Note. DTIP = Design Thinking Instructional Problems; RET = Research Experience for Teachers. Item PDSOE4a was vague and did not elicit rich responses. Item PDSOE4b was developed as a follow-up item and included the DTIP model graphic in color. These items were only used on the post-program DTIP survey.

After completing the original post-program DTIP survey, the RETsolar teacher participants were pulled into another conference room with a different ERC education team member to complete their RET post-program surveys. I left the building at that point to quickly develop a follow-up survey item (see Appendix B). The top half of the page for this follow-up survey item included the DTIP model graphic in color, as a response aide (Weisberg, 2005), and a short summarization of the DTIP professional development sessions. Teacher participants were then prompted with the following open-ended item (PDSOE4b): *Do you feel that participating in an RET program that used this model as a guide for creating your instructional lesson provided added value? Why or why not?* The rest of the page was left blank to foster rich response, and on average, those responses were longer and more detailed than the responses from the original survey item (PDSOE4a).

Once I had completed the follow-up survey item, I printed several copies and returned to the ERC building where RETsolar teacher participants were concluding their RET post-program surveys and interviews. I approached the RETsolar education team member and asked if I could have the teacher participants answer one last survey item as they finished their RET post-program surveys and was given approval to proceed. As each teacher participant finished their RET post-program surveys, I handed them the post-program DTIP survey follow-up survey item (PDSOE4b). Two of the participants were still in RET post-program interviews elsewhere. When they finished, I brought them over to the conference room to complete the follow-up survey item along with everyone else.

The RETsoil teacher participants responded to the post-program DTIP survey professional development sessions open-ended items directly after responding to the post-program DTIP survey. They responded to the open-ended items, including the follow-up survey item, while in a large quiet room with adequate time in which to process the task. However, a lunch buffet was brought into the room at about the same time that several teacher participants were finishing up. Those teacher participants got their lunches and continued to work on the open-ended survey items while they ate and talked with others.

During the last week of both RET summer programs, teacher participants submitted draft versions of their RET instructional lesson plans. Also, they were reminded by the RET education teams that they would love to be invited to observe their instructional lesson implementation. Additionally, RETsoil teacher participants were told by the RET education team that they needed to submit a final instructional lesson plan and implementation report by October 2nd in order to receive an additional stipend from the RET. RETsolar had slightly different requirements for their RET teacher participants, and did not require a specific implementation deadline. The majority of the RETsolar teacher participants felt their lessons would best fit with content being taught in the Spring semester. Therefore, only one RETsolar teacher participant implemented his RET lesson during this study.

Phase III: Instructional Lesson Implementation (Fall Semester)

I kept in contact via email with the teacher participants as they determined an appropriate time to implement their RET instructional lesson. When they had a date in mind, they would contact the RET education team, and that information was then forwarded to me. The 10 teacher participants who were selected as individual cases for Phase III observation were selected because they described an intention to implement their RET instructional lesson during the Fall semester. The other participants did not implement until later in the year. In addition, because the RETsoil education team required teacher participants to implement their lessons by October, nine of the 10 case-teachers were RETsoil program participants. Also, since I worked more often with the RETsoil teacher participants, I had stronger rapport and easier access to them.

Implementation observation field notes. During the last week of the summer RET program, I provided all 16 teacher participants with a consent letter requesting permission to observe their instructional lesson implementation and take field notes to use for data in my study. All 16 consented. From the original 16 RET teacher participants, 10 fully implemented their RET instructional lesson during the Fall semester, enabling my observation of those 10 teacher participants as cases.

As shown in Table 2.8, I conducted 28 hours of classroom observation across the 10 case-teachers, all of whom were assigned pseudonyms to preserve relative anonymity. Seven of 10 case-teachers were observed for three to four hours each. Three case-teachers were only observed for one to one-and-a-half hours, either because that was the length of their lesson, or because other school activities made further access difficult. For the majority of the participants, the observation involved one lesson on one day. However, for three of those 10 case-teachers, I was able to return to observe a second lesson on a different day. This follow-up lesson always connected with the previous one as part of a larger unit. Seven out of the 10 case-teachers developed a larger overall unit that encompassed several smaller lessons based on their RET experience, even though they were only required to develop one lesson.

I attended these observations with one to two ERC education team members. The case-teachers would usually introduce us as researchers from the university. The education team members often brought supplies for the teacher participant to use as part of the lesson, assisted in the setting up of aspects of the RET lesson, or helped guide small group discussions. I took a more traditional nonparticipant-observational role (Creswell, 2013). Occasionally, a case-teacher would explicitly ask me to walk around

Table 2.8
Summary of RET Instructional Lesson Observation by Case-Teacher

Case-Teacher	No. of Lessons Observed	No. of Blocks Observed	Total Hours Observed	Overall Unit Length	Unit/Lesson Summary
Colin (P1)	2	1 of 1	3	4 weeks	Determine location for and build a prototype concrete dam.
Evan (P2)	1	4 of 4	4	3 days	Propose a nature-inspired product (shark tank).
Claire (P3)	2	2 of 2	4	4 weeks	Conduct a sieve analysis and design a soil solution.
Angelica (P4)	2	2 of 4	4	3 weeks	Conduct an experiment using microbes.
Thad (P5)	1	1 of 1	1.5	2 days	Determine calculations for remediation research.
Sam (P6)	1	1 of 1	1.5	1 day	Conduct a soil classification and sieve analysis.
Ben (P7)	1	3 of 4	3	2 weeks	Conduct a liquefaction remediation experiment.
Zane (P8)	1	1 of 4	1	2 weeks	Conduct a dust mitigation experiment.
Leslie (P9)	1	3 of 4	3	2 weeks	Observe liquefaction effects on building models (shake table).
Lou (P10)	1	2 of 3	3	3 weeks	Design and test an infinite spinner using a solar cell.

Note. RET = Research Experience for Teachers. Several case-teachers taught the same lesson across several class periods, which they usually called *blocks*. Most case-teachers were only able to give one to one and a half hours per day to the RET instructional lesson. Either they only had that class for that amount of time, or they had other subject areas they had to cover that same day. Therefore, four weeks approximates twenty hours towards the learning of that particular topic (one hour per day, five days a week for four weeks), while three days approximates three hours of learning.

and question students as to their plans and understanding of the content. When this occurred, I asked open-ended questions and refrained from any attempt to guide student learning beyond listening to their explanations.

I took detailed handwritten field notes in a notebook while observing. I primarily focused on how the case-teacher implemented the lesson, but I also observed overall student engagement and comments. When the case-teacher was conducting direct instruction, I remained in a corner of the classroom so I could observe without being a distraction, and when students were doing independent work, I walked around to better observe how the students were interacting with the instructional lesson.

While I attempted to note anything that occurred that might relate to the lesson being implemented, I was especially observant of events that might seem to suggest the use of Design Thinking practices. As I completed each field observation, I used Dragon Dictate, a voice-to-text digital application, to transcribe my handwritten notes, then I copy/pasted the text into a Word document for analysis.

Post-implementation interview transcripts. Before conducting the post-implementation interview, I ensured that the case-teacher had completed the implementation of the RET instructional lesson, had already conducted assessment on the implementation, and had had at least a few days of reflection. Then I was able to schedule a convenient time and location at which to conduct the interview. Approximately half of the RETsoil case-teachers attended the ERC's annual NSF site visit and consented to being interviewed between activities during that event. The remaining case-teachers were interviewed either through face-to-face follow-up visits at their schools or via telephone conversations.

As shown in Table 2.9, the semi-structured post-implementation interview included five semi-structured questions. If case-teachers provided overly general responses, I asked them to describe what the event looked like in their classrooms or provide specific examples. Before asking post-implementation interview question 4 *What was your process for creating your RET instructional lesson compared to the DTIP model?*, I included a landmarking memory cue (Weisberg, 2005), in which case-teachers were asked to think specifically about the first day of the RET program until now. Then they were asked to think about the approach they used during that period to develop their instructional lesson. I then provided a response aide for this question (Weisberg, 2005).

Table 2.9

Semi-Structured Post-Implementation Interview Questions

1.	How do you think the implementation went?
2.	Did you revise anything? Why?
3.	What kind of student learning outcomes resulted?
4.	What was your process for creating your RET instructional lesson compared to the DTIP model?
5.	Was there anything I forgot to ask concerning your RET experience or Design Thinking? Anything you think I should know about?

Note. RET = Research Experience for Teachers; DTIP = Design Thinking Instructional Problems.

If the interview took place in person, they were given a large hard-copy color print-out of the DTIP model. If the interview was a telephone interview, they were emailed a PDF of the DTIP model the day before the interview. That email instructed them that they would be asked about their specific instructional lesson planning approach, and that I wanted them to visualize that firmly in their minds before looking at the graphic of the DTIP model.

Once case-teachers had the graphic for the DTIP model in front of them, I asked them to describe the specific approach they used in comparison to the model. If they generalized, I would push them for deeper description by asking them how their approach was similar or different. I sometimes also asked them how they would change or add to the model so it might better correspond to their own approach. The interviews ranged from 10-20 minutes, were audio recorded, and later transcribed.

Study Data Analysis

I collected data across three study phases. These data sources included the pre-program DTIP survey sub-scale responses, background interview transcripts, post-program DTIP survey sub-scale and open-ended responses, implementation observation field notes, and post-implementation interview transcripts. To analyze these sources, I used four analysis methods: descriptive statistics, direct interpretation, thematic analysis, and in-depth open coding combined with the constant comparative method.

The hard copies of the first data sources I collected were kept in the order they were received and a participant number was assigned to each—one through sixteen. A master list was created listing the participant's actual name and contact information, participant number, and pseudonym (Creswell, 2013). This list was then separated from the data. I went through each hard copy and digital source de-identifying the data. Though participant numbers are separated by RET program, they are otherwise random.

Quantitative Data Analysis

Nominal data and ordinal Likert-type data from the pre- and post-program DTIP survey responses were manually typed into a Microsoft Excel file, organized, and cleaned. Missing data were coded as -999. Descriptive statistics, including frequencies, means, and standard deviations were generated by uploading the data from the Excel files into IBM's SPSS software version 23 for Macintosh platforms. Reliability tests using Cronbach's alpha were also conducted on survey sub-scales to determine the internal consistency of constructs (Cronbach, 1951).

Qualitative Data Analysis

Qualitative data came from the following data source types: background interview transcripts, open-ended item responses from the post-program DTIP survey, implementation observation field notes, and post-implementation interview transcripts. I used direct interpretation on the background interview transcripts, thematic analysis on the open-ended item responses and post-implementation interview transcripts, and open coding combined with the constant comparative method on the implementation observation field notes.

Background interview transcripts. Though I conducted background interviews with all 16 teacher participants, I only analyzed the transcripts of the 10 case-teachers. I followed a direct interpretation approach to gather specific data to best support a description of their contexts (Creswell, 2013). First, I read through the 10 case-teacher transcripts. Then I used the summary table to simplify the descriptions they provided in their interviews. For example, I listed whether or not they perceived their school to have a process for supporting collaboration. This data was merged with data collected through other sources to build case-teacher vignettes, see Appendix G (Creswell, 2013).

Post-Program DTIP Survey open-ended item responses. The post-program DTIP survey included four open-ended items. PDSOE4a *In what ways if any, did the rainbow-colored Design Thinking model help you understand the Design Thinking* *process* was overly vague and many teacher participants simply did not understand to what "the rainbow colored" model referred, which elicited very little usable data. Therefore, item PDSOE4a was removed from analysis and replaced with the follow-up survey item PDSOE4b *Do you feel that participating in an RET program that used this model as a guide for creating your instructional lesson provided added value? Why or why not?* All of the transcribed responses were relatively short, usually one to five sentences in length. First I read through all of the transcribed responses. Then I went back through, highlighting key phrases, while organizing similar phrases into thematic categories (Creswell, 2013). After completing one iteration of highlighting, I went through all of the short-responses at least two more times to determine the extent to which my interpretation and organization of later phrases had changed how I viewed any of the earlier categorizations.

Implementation observation field notes. I analyzed the implementation observation field notes using open coding (Creswell, 2013; Tracy, 2013) combined with the constant comparative method (Charmaz, 1995). The first stage of this process has been described similarly by various scholars as open coding (Creswell, 2013), initial-coding (Charmaz, 1995), and as primary-cycle coding (Tracy, 2013). It is a process in which the researcher uses iterative interpretation to "open up meaning in the data" (Tracy, 2013, p. 189). I began by reading the typed field notes line-by-line, searching for key words or phrases of interest (Creswell, 2013). As I did so, I initially highlighted all words and phrases of interest in yellow.

By the time I had read the field notes for the third case-teacher, I began to see a few patterns in the phrases I was highlighting. At that point, I opened a new Excel file and began listing one to two word phrases to develop first-level codes that seemed to best summarize the pattern (Tracy, 2013). Sometimes I developed *in vivo* codes by using the actual language of the teacher participant instead (Charmaz, 1995; Creswell, 2013; Tracy, 2013). In the Excel file, I highlighted these first-level codes with their own highlight color. I then read the subsequent case-teacher field notes and highlighted them with these new colors while also continuing to look for any phrases of interest that did not seem to fit into those initial codes and that might signify an additional first-level code. If I found a phrase that suggested a new code, I would add it to the Excel code book, highlight it with a new color, and return to earlier field notes to search for additional examples. By the fourth read through of all case-teacher field notes, all of the phrases of interest had been highlighted.

This process led to what Tracy (2013) describes as secondary-cycle coding. I returned to the very first set of field notes and looked at the highlighted phrases to begin to interpret those codes as larger categories of meaning. I also further developed the Excel file into a working code book (Tracy, 2013; see Appendix E). For each first-level code, I developed a preliminary operational definition. For example, the code *Design Thinking Practices* was loosely defined as any activity or strategy utilizing a Design Thinking assumption or stage in order to solve a problem. I then went through all of the field notes again, applying the preliminary definition to each phrase highlighted as a Design Thinking Practice. As I worked, I either added detail to the definitions to better separate one code from another or merged codes that demonstrated too many similarities. At this point, I was able to develop initial hierarchical codes as umbrella categories to provide more conceptual sense (Tracy, 2013).

Once I was satisfied with the working codebook, I uploaded the field notes into the qualitative analysis software program Nvivo for Mac version 11.4.3. I added all of the codes previously developed during primary- and secondary-cycle coding as nodes, and organized each individual code within those nodes. Then I went through each transcript again and assigned highlighted phrases to each coded node as well as coding them to each case-teacher. I then developed a more precise NVivo codebook which I checked against all previously coded references within the NVivo program (see Appendix E). This allowed me to view frequencies for codes aggregated across case-teachers, as well as for each individual.

I again compared the highlighted phrases still visible in the uploaded PDFs to the definitions I had already developed in the code book. In most cases the codes required some fracturing (Tracy, 2013) into sub-codes that I then further defined. The original code for Design Thinking Practices resulted in several sub-codes such as *DTP1 Problem Identifying* or *DTP2 Perspective Discovering*.

Once codes were assigned more clearly defined parameters, I returned again to the initial uploaded field notes. I compared each highlighted phrase to the new sub-code definition, and if it corresponded well, I coded it in Nvivo as a child node. Whenever it was unclear which code might best apply, I changed the definition to better clarify the code, and then returned to any earlier codes to determine whether or not they still fit the definition or needed to be recoded. I read through all of the field notes one more time, checking coded phrases against the definitions listed in the code book. At that point, I was confident the analysis was saturated (Creswell, 2013).

Post-implementation interview transcripts. The 10 transcripts from case-teacher post-implementation interviews were analyzed using a similar approach as the DTIP survey open-ended item responses, except that I used qualitative software instead of manual analysis. I first read through all of the transcripts. Then I uploaded the transcripts to the same Nvivo file as the observation field notes. I coded interesting phrases or concepts as nodes within the software program until I began to see thematic patterns (Creswell, 2013). I used the constant comparative method (Charmaz, 1995) to continue adding new codes or fragmenting them. After reading through the transcripts three times without any of the themes changing, I felt confident the analysis was saturated (Creswell, 2013).

Study Validation Strategies

The pre- and post-program DTIP surveys were reviewed by my dissertation committee chair and an outside professional with a background in technical writing and graphic design. The surveys were also tested during a pilot study conducted with a similar group of teacher participants the year before (Elwood et al., 2017).

For the qualitative data, my main intention was to embody a strong sense of trustworthiness (Creswell, 2013) and sincerity (Tracy, 2013). Towards this end, I have incorporated several qualitative validation strategies suggested by Creswell (2013). I worked consistently for a prolonged amount of time with teacher participants throughout a five week summer RET program and then further interacted with 10 of those participants as case-teachers during the following semester. I triangulated patterns through a variety of data sources. I developed formal researcher memos after field observations and informal memos as I analyzed data. I met regularly with my dissertation committee chair and my research advisor in debriefing sessions to discuss my progress. They provided a sounding board for my thoughts and concerns as I developed my interpretations. I have been reflexive in the description of my own possible biases and will be explicit in describing the data as interpreted through my lens. I provided a rich, thick description of case-teacher contexts, and I sent copies of those descriptions to them for feedback and member checking.

Summary

This study explored the perceptions of teacher participants towards the DTIP approach as they developed RET instructional lessons. Data were collected across three phases during the summer and fall of 2017. Pre- and post-program DTIP demographic and Likert-type survey responses, background interview transcripts, and post-program DTIP survey open-ended responses were collected from 16 teacher participants during Phases I and II. From those 16 teacher participants, 10 case-teachers were selected for further study during Phase III. This phase involved the collection of implementation observation field notes and post-implementation interview transcripts. The data from these sources were analyzed using descriptive statistics, direct interpretation, thematic analysis, and open coding combined with the constant comparative method. The next chapter provides a detailed description of the study results.

CHAPTER 3

RESULTS

Yin (1989) recommends arranging qualitative case study data in a variety of arrays, matrices, and tables to better understand holistic patterns across and within multiple cases. Though helpful for sense-making, this process may also lead to an overabundance of data that may provide additional context, but not additional insight on the specific questions being researched. Creswell (2013) asserts that a specific case study format does not exist, but suggests that the overall intent of the study be its primary focus. Therefore, I will be focusing upon the study results that demonstrated how the teacher participants perceived the DTIP approach for developing instructional lessons across the four DTIP study research questions. I will include any additional contextual results within the appendices (see Appendices F and G).

Organizing this chapter by research question presented a somewhat complex organization since I dealt with the issue of response burden (Blair, Czaja, & Blair, 2014) by incorporating items supporting different research questions into each data source. For example, the post-implementation interview included questions on case-teachers' perception of the DTIP model (RQ3) and their perception of the instructional lesson implementation (RQ4). Though this provided a streamlined experience for the teacher participants, it also complicated the way in which the results are reported. To better clarify this presentation of results, I included a summary table of the study. Table 3.1 provides each research question, related data source, the phase in which each research question was addressed, and the analysis method used for the data source.

Table 3.1

Summary of DTIP Study Characteristics by Research Question

Research Questions	Data Source	Study Phase	Analysis Method
RQ1: Designer Solving Problems	Pre- and Post-Program DTIP Survey Responses	Phase I and II	Descriptive Statistics
RQ2: DTIP PD Sessions	Post-Program DTIP Survey Responses	Phase II	Descriptive Statistics
	Post-Program DTIP Survey Open-Ended Item Responses	Phase II	Thematic Analysis
RQ3: DTIP Model	Post-Program DTIP Survey Open-Ended Item Responses	Phase II	Thematic Analysis
	Post-Implementation Interview Transcripts	Phase III	Thematic Analysis
RQ4: RET Instructional Lessons	Implementation Observation Field Notes	Phase III	Open Coding Constant Comparative Method
	Post-Implementation Interview Transcripts	Phase III	Thematic Analysis

Note. DTIP = Design Thinking Instructional Problems; PD = professional development; RET = Research Experience for Teachers.

RQ1: To what extent did teacher participants view themselves as designers solving complex instructional problems?

Results supporting research question one are broken into two parts to include the results on the Design Disposition (DD) sub-scale and the results on the Wicked Instructional Problems (WIP) sub-scale. Because this is a multiple case study of a small group of teacher participants, the sub-scale results are provided across the whole group of participants and then for each individual teacher participant within the group.

Pre- and Post-Program DTIP Survey Sub-Scales across Teacher Participants

The pre- and post-program DTIP surveys included a Design Disposition sub-scale developed by Koh et al. (2014) and a Wicked Instructional Problems sub-scale specifically developed for this study. Yin (1989) suggests that one method for determining patterns in a multiple case study is to view the data aggregately across cases and then individually within cases. Since I am most interested in how individual case-teachers perceived the DTIP approach, I briefly describe results across teacher participants for each sub-scale, and then I describe results within individual teacher participants for each sub-scale.

Design Disposition sub-scale across teacher participants. A pre- and post-program DTIP survey was given to all RET teacher participants (n=16). The DTIP survey included a Design Disposition (DD) sub-scale that was developed by Koh et al. (2014) and was also utilized during the pilot study (Elwood et al., 2017). On the DTIP survey instrument, I had added item DD5 *I am comfortable incorporating innovative technologies into my practices* to the sub-scale, which did not demonstrate internal consistency and was removed from analysis. A reliability analysis was then carried out on the original four-item DD scale. On this sub-scale, Cronbach's alpha demonstrated a high internal reliability, $\alpha = 0.87$ (Streiner, 2003). All items would result in a decrease in the alpha if any were removed. This internal reliability was somewhat lower than that achieved by Koh et al. (2014), whose study of 201 Singapore teachers resulted in a coefficient alpha of 0.91. However, this study of 16 teacher participants was much smaller and more homogenous than that conducted by Koh et al., which Streiner (2003) suggests may affect the reliability level.

Results were determined from the responses to Likert-type data from the pre- and post-program DTIP survey. On average, as shown in Table 3.2, the RET teacher participants (n=16) as a group experienced a slight increase in their perceived design dispositions ($\Delta M=0.28$).

Before the program, the teacher participants saw themselves as *somewhat* to *very much* having design dispositions (Pre-Program M=3.96) which slightly increased to *very much* to *a great deal* (Post-Program M=4.24). The case-teacher group demonstrated a slightly stronger increase than the teacher participant group, with a pre-program mean score of 3.93 and a post-program mean score of 4.30. Specifically, data from the teacher participant group showed a decrease in the pre/post mean score ($\Delta M=-0.07$) for DD1 *I am comfortable exploring conflicting ideas*, whereas the case-teacher group showed no change in the pre/post mean score ($\Delta M=0.00$).

Wicked Instructional Problems sub-scale across teacher participants. Results of the pilot study suggested that some teacher participants might have found the DTIP approach less valuable if they did not perceive their instruction to be a wicked or complex problem (Elwood et al., 2017). Therefore, the DTIP survey instrument was revised for the present study to include a sub-scale on Wicked Instructional Problems (WIP) developed using *a priori* literature (Head, 2008).

A reliability analysis was carried out on the four-item WIP sub-scale. On this sub-scale, Cronbach's alpha demonstrated a reliability of $\alpha = 0.64$. All items except one would result in a decrease in the alpha. The removal of WIP4 *I believe that the process*

Table 3.2

Pre- and Post-Mean Scores on the Design Disposition Sub-Scale

Items	Pre		Post		
	M	SD	M	SD	ΔM
All Teacher Participants (n=16)					
1. I am comfortable exploring conflicting ideas.	4.13	.500	4.06	.772	-0.07
2. I am comfortable deviating from established practices.	3.94	.680	4.25	.775	0.31
3. I am comfortable with occasional failures from trying out new approaches.	3.94	.772	4.50	.816	0.56
4. I am comfortable seeking ways to turn constraints into opportunities.	3.81	.834	4.13	1.025	0.32
Sub-scale Mean	3.96		4.24		0.28
Case-Teachers (n=10)					
1. I am comfortable exploring conflicting ideas.	4.10	.568	4.10	.876	0.00
2. I am comfortable deviating from established practices.	4.00	.471	4.50	.707	0.50
3. I am comfortable with occasional failures from trying out new approaches.	3.90	.738	4.40	.966	0.50
4. I am comfortable seeking ways to turn constraints into opportunities.	3.70	.823	4.20	1.135	0.50
Sub-scale Mean	3.93		4.30		0.37

Note. DTIP = Design Thinking Instructional Problems. Likert-scale items were adapted from Koh et al. (2014) and used a scale of 1 to 5, with 1 being *not at all* and 5 being *a great deal*.

of creating a new instructional unit involves a diverse group of stakeholders who have differing perspectives and values regarding the instruction would increase the alpha, α = 0.70. Streiner (2003) states: "In the first version of his book, Nunnally (1967) recommended .50 to .60 for the early stages of research, .80 for basic research tools, and .90 as the 'minimally tolerable estimate' for clinical purposes, with an ideal of .95. He increased the starting level to .70 in later versions of his book" (p. 103). However, Streiner notes though that reliability levels over .90 often indicate redundancy, due to an overabundance of items. Therefore, while the internal reliability for the WIP sub-scale is not quite at an acceptable level, I decided to retain all four items because this study represented the early stages of this research, and because the sample represented a small and homogenous group (Streiner, 2003).

Results were determined from the responses to Likert-type data from the pre- and post-program DTIP survey. On average, as shown in Table 3.3, the RET teacher participants (n=16) as a group experienced a slight increase in their responses on the WIP sub-scale (ΔM=0.26). Before the program, they saw themselves as *very much* believing in Wicked Instructional Problems (Pre-Program M=4.08), which slightly increased to *very much* to *a great deal* by the end of the program (Post-Program M=4.34).

The case-teachers (n=10) also saw themselves as *very mu*ch believing in Wicked Instructional Problems, but at a slightly lower initial belief level than that of all the RET teacher participants (Pre-Program M=4.03). They also had an extremely similar concluding belief level (Post-Program M=4.35). This resulted in a slightly stronger pre/post mean score increase in case-teachers' belief in Wicked Instructional Problems (ΔM=0.32) than that of all the RET teacher participants. The case-teachers group showed

Table 3.3
Pre- and Post-Mean Scores on the Wicked Instructional Problems Sub-Scale

Items	Pre M	Pre SD	Post M	Post SD	ΔM
All Teacher Participants (n=16)					
1. I believe that the process of creating a new instructional unit is similar to the process of solving a complex problem.	3.94	.574	4.38	.619	0.44
2. I believe that the process of creating a new instructional unit involves interconnected variables that influence each other in unpredictable ways.	4.13	.619	4.25	.775	0.12
3. I believe that the process of creating a new instructional unit involves uncertain outcomes.	3.94	.929	4.37	.619	0.43
4. I believe that the process of creating a new instructional unit involves a diverse group of stakeholders who have differing perspectives and values regarding the instruction.	4.31	.873	4.37	.719	0.06
Sub-scale Mean	4.08		4.34		0.26
Case-Teachers (n=10)					
1. I believe that the process of creating a new instructional unit is similar to the process of solving a complex problem.	4.00	.667	4.60	.516	0.60
2. I believe that the process of creating a new instructional unit involves interconnected variables that influence each other in unpredictable ways.	4.30	.675	4.10	.876	-0.20
3. I believe that the process of creating a new instructional unit involves uncertain outcomes.	3.70	1.059	4.30	.675	0.60
4. I believe that the process of creating a new instructional unit involves a diverse group of stakeholders who have differing perspectives and values regarding the instruction.	4.10	.994	4.40	.699	0.30
Sub-scale Mean	4.03		4.35		0.32

Note. DTIP = Design Thinking Instructional Problems. Likert-type items were developed using *a priori* literature from Head (2008) and used a scale of 1 to 5, with 1 being *not at all* and 5 being *a great deal*.

a pre/post mean score decrease in WIP2 *I believe that the process of creating a new instructional unit involves interconnected variables that influence each other in unpredictable ways* (ΔM= -0.20), but showed even stronger pre/post mean score increases in WIP1 *I believe that the process of creating a new instructional unit is similar to the process of solving a complex problem* and WIP3 *I believe that the process of creating a new instructional unit involves uncertain outcomes* (ΔM=0.60).

Pre- and Post-Program DTIP Survey Sub-Scales within Case-Teachers

In this section, I present the results on the Design Disposition sub-scale and the Wicked Instructional Problems sub-scale by case-teacher to better explore how they individually perceived these constructs. I considered these data to be another source for triangulating the individual perceptions of these participants.

I first describe the results on the Design Disposition sub-scale and then on the Wicked Instructional Problems sub-scale. The description is broken down by the 10 teacher participants who were selected for further study as cases from amongst the original 16 RET teacher participants. All case-teacher names listed are pseudonyms and are organized by participant number, which were randomly assigned, but are consistently used throughout the study.

Design Disposition sub-scale within case-teachers. Six out of 10 of the case-teachers demonstrated a positive mean change in their responses on the Design Dispositions sub-scale, as shown in Table 3.4. Two case-teachers demonstrated no change, and one case-teacher demonstrated a negative change. Ben, Zane, and Leslie had the highest perceived post-mean responses on the DD sub-scale (M=5.00), with Sam

Table 3.4

Pre- and Post-Mean Scores on the Design Disposition Sub-Scale by Case-Teacher

Case-Teacher Participant	Pre		Post		
	M	SD	M	SD	ΔM
Colin (P1)	4.00	.000	4.50	.577	0.50
Evan (P2)	3.50	.577	3.75	.957	0.25
Claire (P3)	4.00	.000	4.00	.816	0.00
Angelica (P4)	2.75	.500	4.00	.816	1.25
Thad (P5)	4.00	.000	4.75	.500	0.75
Sam (P6)	3.50	.577	2.50	.577	-1.00
Ben (P7)	4.50	.577	5.00	.000	0.50
Zane (P8)	4.00	.000	5.00	.000	1.00
Leslie (P9)	5.00	.000	5.00	.000	0.00
Lou (P10)	4.00	.000	4.50	.577	0.50

Note. DTIP = Design Thinking Instructional Problems. Likert-scale items were adapted from Koh et al. (2014) and used a scale of 1 to 5, with 1 being *not at all* and 5 being *a great deal*.

(M=2.50) and Evan (M=3.75) having the lowest. Angelica had the greatest positive mean change (ΔM=1.25), while Sam had the greatest negative mean change (ΔM= -1.00).

Wicked Instructional Problems sub-scale within case-teachers. The Wicked Instructional Problems sub-scale resulted in five case-teachers with positive mean change, two with no change, and three with negative change, as shown in Table 3.5. Sam, Ben, and Lou demonstrated the highest post Wicked Instructional Problem mean (M=5.00), though Sam was one of the case-teachers who experienced no mean change. Thad (M=2.75), Claire (M=3.25), and Ben (M=3.75) had the lowest post Wicked

Instructional Problems mean with both Thad (ΔM=1.50) and Ben (ΔM=1.25) demonstrating the greatest positive mean change.

Table 3.5

Pre- and Post-Mean Scores on the Wicked Instructional Problems Sub-Scale by Case-Teacher

	Pre		Post		
Case-Teacher	M	SD	M	SD	ΔM
Colin (P1)	4.25	.500	4.00	.000	-0.25
Evan (P2)	4.00	.816	3.75	.500	-0.25
Claire (P3)	3.25	.957	3.50	1.000	0.25
Angelica (P4)	4.25	.500	4.75	.500	0.50
Thad (P5)	2.75	.500	4.25	.500	1.50
Sam (P6)	5.00	.000	5.00	.000	0.00
Ben (P7)	3.75	1.258	5.00	.000	1.25
Zane (P8)	4.25	.500	4.25	.500	0.00
Leslie (P9)	4.25	.500	4.00	.816	-0.25
Lou (P10)	4.50	.577	5.00	.000	0.50

Note. DTIP = Design Thinking Instructional Problems. Likert-type items were developed using *a priori* literature from Head (2008) and used a scale of 1 to 5, with 1 being *not at all* and 5 being *a great deal*.

RQ2: How and to what extent did the DTIP professional development sessions resonate with teacher participants?

The results for research question two were determined through the post-program DTIP survey responses. This section is broken into two parts to include the post-program DTIP professional development sessions sub-scale and post-program DTIP survey open-ended items. The open-ended items section is further broken into three sub-parts by item:

general RET program influences, DTIP professional development sessions value, and DTIP professional development challenges.

DTIP Professional Development Sessions Sub-Scale

The last sub-scale of the post-program DTIP survey asked teacher participants to determine their perception of the DTIP professional development sessions (PDS). The nine-item sub-scale used a 1 to 5 Likert-type scale with 1 being *not at all* and 5 being *a great deal*. On average, as shown in Table 3.6, the all teacher participant group (n=16; M=3.79) and case-teacher group (n=10; M=3.70) found that the sessions *somewhat* to *very much* influenced the development of their RET instructional lessons.

Both the all teacher participant group (M=4.56) and the case-teacher group (M=4.50) found PDS6 *I believe having access to colleagues influenced how I created my instructional lesson* to be their strongest influencer. They also both found PDS3 *I believe the "Wrong Theory" activity influenced how I created my instructional lesson* to be the weakest influencer (All Teacher Group M=3.06; Case-Teacher Group M=2.80). The all teacher group much more strongly perceived a change in their initial lesson plan over time (PDS8 M=3.94) than did the case-teacher group (PDS8 M=3.60). Whereas, the case-teacher group much more strongly viewed themselves as having adequate time to create their instructional lesson plan (PDS9 M=4.30) than did the all teacher participant group (PDS9 M=4.00).

Professional Development Sessions Open-Ended Items

As part of the post-program DTIP survey, all RET teacher participants (n=16) were asked to respond to four professional development sessions open-ended (PDSOE) items. The first three items directly tied to teacher participants' perception of the DTIP

Table 3.6

Mean Scores on the Professional Development Sessions Sub-Scale

Sub-scale Items	Teacher Participants n=16		Case-Teachers n=10	
	M	SD	M	SD
1. I believe the "5 Whys" activity influenced how I created my instructional lesson.	3.69	.793	3.50	.707
2. I believe interviewing a young student similar in age to my students influenced how I created my instructional lesson.	3.56	1.031	3.40	1.075
3. I believe the "Wrong Theory" activity influenced how I created my instructional lesson.	3.06	.998	2.80	.919
4. I believe the sketching activity influenced how I created my instructional lesson.	3.44	1.209	3.20	1.317
5. I believe formally sharing my instructional lesson with other teachers influenced how I created my instructional lesson.	4.13	1.088	4.20	1.135
6. I believe having access to colleagues influenced how I created my instructional lesson.	4.56	.629	4.50	.707
7. I believe that participating in reflection influenced how I created my instructional lesson.	3.75	1.065	3.80	1.229
8. I believe that my instructional lesson plan has changed from when I first started thinking about it.	3.94	.854	3.60	.699
9. I believe I had adequate time to focus on the creation of my instructional lesson plan.	4.00	.894	4.30	.823
Scale Mean	3.79		3.70	

Note. Likert-scale items were developed based on the activities used during the DTIP professional development sessions as part of the RET summer program and used a scale of 1 to 5, with 1 being *not at all* and 5 being *a great deal*. DTIP = Design Thinking Instructional Problems; RET = Research Experience for Teachers.

professional development sessions. Results on teacher responses for each item are presented and examples of teacher participant responses are integrated in the text. All teacher participant names are represented by pseudonyms they self-selected.

General RET program influences (PDSOE1). Open-ended item PDSOE1 *What experiences from the RET summer program do you believe influenced the creation of your instructional lesson plan?* may have seemed to only refer to the RET program, rather than the DTIP professional development sessions. However, findings from the pilot study suggest that teacher participants had difficulty separating aspects of the DTIP professional development sessions from aspects of the RET program (Elwood et al., 2017). Therefore, PDSOE1 was jointly about understanding the direct value of the DTIP professional development sessions and what aspects of the RET program could be best capitalized upon to support and strengthen the DTIP professional development sessions and vice versa.

In response to item PDSOE1, the 16 teacher participants referenced five themes in PDSOE1 as influencing the development of their instructional lesson. One of the most referenced themes (six references) was authentic research: *Time to work in the research lab. This created authentic learning experiences for my teaching practices [Colin P1].* Collaboration, mentors, and ambiguity were the next most referenced themes (five references each). Collaboration included working with teacher participants from within their RET program, teacher participants from other RET programs, and undergraduate and high school students from other summer programs. This collaboration often helped teacher participants see their instructional design approach from another perspective:

Talking with my peers about different lesson ideas made me think about different ways I could incorporate solar into my lessons [Emily P13].

Mentoring referred more specifically to the RET graduate students and faculty who provided support for the lab research. Teacher participants felt that it was through the assistance of the mentors that they better understood the technical research: *My mentors contributed to my lesson development by sharing their knowledge and instrument assistance [Thad P5].*

Teacher participants also felt that being forced to experience the ambiguity that is inherent in research provided them with heightened learning and additional possibilities for their lesson planning: *Keeping an open-mind to what the limitless possibilities were [Leslie P9]* and *learning from failure helped me understand that it's OK to fail; you try again [Sara P12].* Lastly, teacher participants were also somewhat influenced by the RETsolar and RETsoil content (three references): *I think learning about solar really helped me see the huge benefits of solar, but also the restrictions [Andrea P11].*

DTIP professional development sessions value (PDSOE2). In response to item PDSOE2 *What aspects of the Design Thinking approach did you find to be the most valuable as you created your instructional lesson plan during the RET summer program? Why were they valuable?,* the 16 teacher participants referenced four themes: reflection, an authentic problem, the process, and iteration. Reflection was referenced the most often (five references) and included being required *to think deeply about my knowledge [Simon P14]* and *constantly rethinking [Bo P16].* Also, teacher participants valued thinking about their instructional lesson as a complex real world problem (four references) and how students might learn by working through content situated in such a problem: *Wicked problem—understanding that the problem has many layers and variables, which lead to many other paths and other layers and variables [Lou P10]* and *Inquiry base is very important to me now. It's more student driven, with questioning the students to find their answers [Sara P12].*

In addition, the DTIP approach itself was considered valuable (four references). Some references indicated that the teacher participants saw the approach as closer to how actual researchers work: *it promotes the scientific process that scientists use every day [Angelica P4].* Others saw it as a helpful way to guide their lesson development approach: *Helps to get the flow of the lesson [Zane P8]* and *I would follow that cyclical process as I refined my ideas [Andrea P11].* One teacher participant saw it as a way to shift her lesson design perspective: *Understanding the fluidity and strength of Design Thinking is critical to shifting ways of engaging with the teaching/learning process [Leslie P9].* Lastly, iteration and redesign were also valued as part of the DTIP approach (two references each).

DTIP professional development sessions challenges (PDSOE3). In response to item PDSOE3 *What aspects of the Design Thinking approach did you find to be the most challenging as you created your instructional lesson plan during the RET summer program? Why were they challenging?,* the 16 teacher participants referenced four aspects of the DTIP approach as being a challenge: transforming content, defining the problem, critique, and control. Five references were made to the challenge of transforming college level research content into grade-appropriate learning objectives for their students. They not only had to first understand the content for themselves, but then find a way to incorporate the content within the teaching framework of their school and their own teaching style. *The content is still new and not as familiar to me [Lou P10].* [I needed to find a way to] *integrate my cultural stories [Sara P12].*

There were four references to the difficulty of defining and situating a problem within the instruction. These references primarily referred to the difficulty of narrowing such broad content: *Defining the instructional problem. It started off very vague and uncertain as to what I wanted to do [Bixby P15].* Two teacher participants found the public critique aspects challenging. One teacher found the peer critique by fellow RET teacher participants to be less than valuable: *Being critiqued often leaves you feeling like people are telling you things you already know which is frustrating as a time sensitive teacher [Ben P7].* In contrast, the other teacher participant found the student critique to be less helpful: *Having young students critique my lesson was the hardest part. While they provide some input to the lesson, they do not understand the required material that must go into a lesson [Simon P14].*

One teacher participant found that fighting her teacher instinct to control the class was the most challenging aspect to a DTIP approach: *Giving up control and designing a lesson that includes trust with your students. I am a teacher who likes to have control, but am learning organized chaos creates great learning opportunities [Claire P3].* Finally, two teacher participants felt that they had no perceived challenges with the DTIP approach.

RQ3: How and to what extent did the DTIP model resonate with teacher participants?

Results supporting research question three are broken into two parts that include the perceived DTIP model value and the perceived level to which the DTIP model corresponded with individual case-teacher lesson development approaches. The results were determined through the post-program DTIP survey open-ended item responses and the post-implementation interview transcripts.

Professional Development Sessions Open-Ended Item on the DTIP Model

The post-program DTIP survey included a fourth open-ended item, PDSOE4a *In what ways, if any, did the rainbow-colored Design Thinking model help you understand the Design Thinking process,* which specifically targeted teacher participants' perceptions of the DTIP model. This open-ended item produced inconclusive results. Six of the 16 teacher participants did not understand and/or remember what was meant by the "rainbow-colored Design Thinking model," and the ones who did remember provided only vague responses: *It showed the stages of the process* [Claire P3]. I therefore decided to create a follow-up open-ended item to better clarify this question. The one-page follow-up survey item included a color copy of the DTIP model as a response aide (Weisberg, 2005). It asked teacher participants the following: *Do you feel that participating in an RET program that used this model as a guide for creating your instructional lesson provided added value? Why or why not?*

In keeping with Yin (1989), who suggested that case studies use a variety of analytic techniques, I developed a holistic ranking system in which teacher participant responses were ranked as having strong, moderate, or weak perceived value. Responses which focused on only positive aspects of the DTIP model, described ways in which the teacher participant used the approach to develop their instructional lesson, and/or described a future intent to use some aspect of Design Thinking were coded as having *strong* perceived value. Responses which described some positive aspects of the DTIP model, but also described an uncertainty as to the level of influence on their instructional design as a whole or in part, or saw certain activities within the model as less helpful, were coded as having *moderate* perceived value. Any response in which the teacher participant felt that the model, whether they liked it or not, did not provide additional influence or direction in their instructional design was coded as having *weak* perceived value.

Of the 16 RET teacher participants, five teacher participants found the DTIP model to developing their RET instructional lesson to have strong value, nine found it to have moderate value, and two found it to have weak value, as shown in Table 3.7.

Post-Implementation Interview Question on DTIP Model Correspondence

Results for the perceived level to which the DTIP model corresponded with individual case-teachers' development of instructional lessons were determined from the transcripts of the post-implementation interviews conducted with the 10 case-teachers. They were asked to think about the first day they began their RET program, through implementation, until that moment at the interview. They were asked to visualize the development of their instructional lesson and were given several minutes to simply reflect on that visualization. Then I asked them to look at a color copy of the DTIP model, which I either handed them or asked them to open as an attachment (and which I requested that they not look at until asked to do so).

They were then asked to describe ways in which their approach was similar or different, if at all, to the DTIP model. I holistically assigned their descriptions to a level of completely corresponded, mostly corresponded, or somewhat corresponded, as shown in Table 3.8.

Table 3.7
Teacher Participant Responses on the Perceived DTIP Model Value

Reference Examples	No. of Teacher Participants (n=16)
Strong Perceived Value	
Through reflection I came up with my year's plan—as well as lesson ideas. Without the above mentioned processes—I don't think my vision for the upcoming year would have been so clear. [Lou P10]	
This is an effective model for curriculum design. It's not my typical approach or even a traditional approach but it has lots of potential for good design. Its good to have an iterative process in place where you evaluate and redesign as you create lessons. [Bixby P15]	5
I used your lesson to generate my lesson plan by defining the problem, collaborating with [colleagues], constantly critiquing—rechecking myself—redirecting and problem defining. Like my colleague says, Circle of Life. [Bo P16]	
Moderate Perceived Value	
I'm not sure if the design thinking helped mold my lesson plan, but it certainly helped in my personal problem solving ability which in turn will help my students. I can see introducing the wheel to help students tackle difficult problems. [Evan P2]	
I found a lot of value in the "5 Why" for defining the problem. The wrong theory was not valuable. I know what I wouldn't want. Sharing is always beneficial; I really liked hearing all of the ideas. Overall the structure model was helpful. [Claire P3]	9
While I found the reflective process associated with design thinking valuable, I am not yet sure if that reflection added value to the lesson itself. Once I have a chance to test my prototype, I will feel more confident. [Ben P7]	
Weak Perceived Value	
For me, it was a nice visual but I didn't use it explicitly. I think for teachers who are new to PBL and the process of Design Thinking this would add a lot of value to our work. With my understanding of DT, it added some value as a reminder of the process. [Colin P1]	2
I don't feel like I used this information or model very much in my planning, honestly. I view it as a helpful way to process through what my thinking process is, but I don't think it influenced my planning process. [Andrea P11]	

Note. DTIP model value levels were determined from the follow-up DTIP professional development sessions open-ended item (PDSOE4b). References were holistically organized into strong, moderate, or weak value levels.

Completely corresponded. Four case-teachers described their individual approaches in a way that suggested the development of their RET instructional lesson completely corresponded (Colin, Claire, Angelica, and Lou). Their descriptions coincided with the Design Thinking elements as depicted on the DTIP model graphic.

Colin noted that he did not allow space for his students to reiterate and redesign. He felt this was an example of his approach not quite corresponding. However, I am most interested in the level to which his *approach* to the development of his RET instructional lesson corresponded with the model and not the instruction itself. The fact that he reflected on what he considered to be an issue in his instructional lesson, and then he continued to think about how he could possibly include an outside expert in the lesson in the future, demonstrated that he was reiterating and redesigning, even if he did not have his students do so.

Similarly, Angelica initially felt that her approach did not completely correspond because she did not view the Design Thinking approach as difficult and, therefore, did not view herself as having a wicked instructional problem. However, she later realized that she had a difficult time transforming the instructional lesson in her head into the lesson plan format required by the RET program. This became her wicked instructional problem. This resulted in her perspective of her work corresponding more completely to the model than she initially thought.

Mostly corresponded. Two case-teachers (Ben and Leslie) viewed the DTIP model as corresponding with their approach, but they felt that the way in which certain aspects of the graphic were visualized were not quite accurate to their experiences. Ben felt his approach corresponded, but that as he continued to iterate, he did not necessarily

Table 3.8
Case-Teacher Responses on the Perceived DTIP Model Correspondence

Case-Teacher (n=10)	Reference Examples
	Completely Corresponded
Colin (P1)	Did I give time in order to be able to go back and remix their design? The answer is no. Just thinking we have an expert, in our classroom, of a student in our class, we should have brought them in.
Claire (P3)	I see these different avenues I could take. This cycle of going through the problem. I wanted to make sure that the students were able to use the prototype testing, solution exploring, reflecting, all of it.
Angelica (P4)	It wasn't the design thinking that was the hardest part. I think [my process] would be more of a triangle shape, instead of flowing in and out, but you're right. It got harder when I had to do the [lesson plan].
Lou (P10)	The great thing about that picture is that it's not linear. All those little curves and crevices are little variables that we have to figure out to get to that pinpoint. It's got a direction, but it's not a defined direction.
	Mostly Corresponded
Ben (P7)	I think really there are a lot of similarities, but I see those parts as being a little bit more fluid. They don't go in a perfect wheel and keep evolving. I'm making little changes along the way without doing another test of this plan.
Leslie (P9)	Although I can see the movement in your model, it appears more uniform than my mental processes were. The model indicates that if you are at point X, then you go in a specific direction. It has not always happened that way.
	Somewhat Corresponded
Evan (P2)	I think I started off almost too narrow. I didn't do prototype testing, which would have helped. The thing that helped me the most was the white boards. I went into school and mapped out the entire semester.
Thad (P5)	As soon as I discovered there were things I actually already teach, it was pretty easy to frame it up. I can feel my way by actually doing it.
Sam (P6)	I think I might have fewer steps in my process. The problem defining, the solution exploring, and reflecting. My circle's a little smaller. I'm thinking that it's a good assignment. Then I realize, nope.
Zane (P8)	I need to know that we can mimic this [science] process in our classroom. I'm still working, even in my head as we speak. Even once you get to the satisfied solution, the problems just start over.

Note. Results for the Perceived DTIP Model Correspondence were determined from the post-implementation interview transcripts. Levels were holistically determined. DTIP = Design Thinking Instructional Problems.

go through each of the five stages in order all over again. Instead maybe he did some additional reflecting and revision without gaining added perspective or running another test of his ideas. Leslie felt her instructional design experience was similar to "controlled chaos," which made her view the DTIP representation as too uniform. She felt the DTIP model graphic still suggested a specific forward direction, which she did not always feel as she was developing her instruction because she often found herself stepping backward in order to move forward. Note that while both of these case-teachers felt the model did not fully visualize these aspects of their experience, Design Thinking assumptions are actually supported by their descriptions (Cross, 2001, 2011).

Somewhat corresponded. Four case-teachers (Evan, Thad, Sam, and Zane) provided descriptions which only somewhat corresponded with the DTIP model. These case-teachers selected a few aspects of the approach as their main focus. They primarily defined the problem and reflected, but either did not mention other aspects at all or explicitly noted they did not experience the other aspects. Also, three of those four case-teachers initially viewed their wicked instructional problem as determining how the RET lab experience could be accurately mirrored in their own classrooms, though Evan eventually moved away from that view of the problem.

RQ4: What are the characteristics of, and the teacher participants' perspectives on, the lessons developed in conjunction with the DTIP approach within the RET summer program?

Results supporting research question four are broken into four areas: classroom context, lesson descriptions, perceived student outcomes, and RET instructional lessons embedded with Design Thinking student learning strategies. The 10 case-teachers had their own ways of integrating the RET research concepts as instruction within their classrooms. Two case-teachers selected gaming and hands-on student learning strategies as their primary method for supporting learning. The other eight case-teachers embedded some type of Design Thinking practice as a student learning strategy as part of their overall lesson unit. Of those eight, five of the case-teachers worked for a STEM-designated school and three worked for a traditional public school.

RET Instructional Lesson Classroom Context

Results describing the classroom context in which the RET instructional lessons were implemented were determined from a combination of background interview transcripts and implementation observation field notes. As shown in Table 3.9, half of the case-teachers taught at STEM-designated schools and half at traditional schools, which were generally described by case-teachers as being general public education schools. Seven of ten case-teachers taught at a school with students who were of low socio-economic status (SES). All of the K-12 teachers participated in school-directed professional learning communities (PLCs), whereas the two college case-teachers did not.

All ten case-teachers indicated that they believed they had the authority to revise and/or design new curriculum to be implemented in the classroom; however, three of them felt that they should be prepared to justify their choices through evidence-based student outcomes. All 10 taught some type of science subject area. However, one case-teacher was an instructional coach. This moved her focus more toward the teachers than the students. The K-12 case-teachers primarily taught classes with 25 to 30 students while the college case-teachers taught with smaller class sizes of 10 to 20 students.

Table 3.9
Summary of Classroom Context Characteristics by Case-Teacher

Case-Teacher	STEM School	SES[a]	PLC	Authority[b]	Grade Level & Subject	Class Size	Student Demo-graphics[c]
Colin (P1)	Y	Low	Y	Y	4th, All Subjects	28	Hispanic
Evan (P2)	N	High	Y	Y-N	High School Environ Biology	32	White
Claire (P3)	Y	Low	Y	Y	6th, Math Science	28	Hispanic Black
Angelica (P4)	Y	Mod	Y	Y	7th, Science	28	White
Thad (P5)	N	Low	N	Y	College Chemistry	12	Hispanic Native American
Sam (P6)	N	Low	N	Y	College Geology Climate	18	White Hispanic Male
Ben (P7)	Y	Low	Y	Y-E	8th, Science	30	Hispanic
Zane (P8)	N	Low	Y	Y-E	8th, Science	28	Hispanic Black
Leslie (P9)	Y	Low	Y	Y-E	Instruction Coach	30	Hispanic
Lou (P10)	N	Mod	Y	Y	4th, Science Social Studies	25	White

Note. The data for this summary were compiled from background interviews and implementation observation field notes. STEM = Science, Technology, Engineering, and Math subject areas. PLC = Professional Learning Community. Y = yes; N = no.

[a] SES = socio-economic status. The SES was determined holistically based on the perceptions of the teacher participants as shared during their background interview.

[b] The Y-N teacher participants felt they were given authority to implement instruction even though they were Novices and were often unsure how to utilize that authority; Y-E teacher participants felt they had authority to implement instruction as long as they could provide Evidence of positive student outcomes.

[c] The largest race/ethnicity population in the class is listed first, the second largest population is listed second. If a gender is listed, it was in the majority; otherwise they were approximately equal.

The student gender was approximately equal across case-teacher classes, except for the college geology course taught by Sam, which had a higher number of male students. Lastly, six of 10 case-teachers taught in classes with a large majority of Hispanic students.

RET Instructional Lesson Descriptions

Of the 16 original teacher participants, 10 were selected as case-teachers. I observed the RET instructional lesson implementation of these 10 case-teachers. The following provides brief descriptions of each case-teacher's instructional lesson. All names are self-selected pseudonyms to maintain study confidentiality.

Colin (P1), a fourth-grade teacher, developed a month-long unit in which students learned about the engineering career field, what the purpose of that field is, and specifically what biogeotechnical engineers do. As part of this unit, students identified the societal impact of engineers, scientists, and innovators, and Colin described examples of how the initial experiments leading to those inventions did not always work or may have resulted in unintended outcomes. Colin then had his students work in learning clubs to determine the appropriate location for a concrete dam, how it should be built to best meet the needs of all the community stakeholders, and construct a scaled prototype.

The lesson Evan (P2), a high school teacher, developed asked students to think about the meaning of inspiration and how nature has often been used as inspiration for some well-known inventions. He had them play a short memory game in which the students matched an aspect of nature to the product that it inspired. Then he created a scenario in which his students were hired by a company to develop an innovative product inspired by something in nature. He had them practice as a whole group in class using the Howler Monkey as a model. Then he asked students to work in groups to develop their own products. Later, the groups pitched their proposals to him as though the class were the television show *Shark Tank*, a show where wealthy business people offer to invest funding in people who had creative well-developed products and business plans.

Claire (P3), a sixth-grade teacher, developed an instructional unit on soils. She integrated it into her curriculum over several weeks. First, students learned to discuss and identify different types of soils. Second, they conducted a sieve analysis, which involved sifting soil through several stacked pans with a variety of mesh sizes. Third, they weighed each soil type using a manual scale called a triple-beam balance. Finally, she had students work in design teams to use their knowledge of soil to develop various problem-based soil solutions, such as fixing a crack in the road, building a retention wall, or developing a garden.

Angelica (P4), a seventh-grade teacher, presented her class with a problem scenario where oil had contaminated a local water supply and was killing their vegetation. Angelica explained that researchers were currently studying microorganisms that remove oil contamination through a special process. Students were split into groups that were then given the task of developing a plan for their experiment on collecting data to better understand the use of microorganisms to solve oil contamination. For the first part of the unit, students collaborated through the use of Google Docs to assign each student with a specific role during the experiment and to develop a working plan for how they would conduct their experiment. Later, the groups were given flowers or vegetables, which were then fed water contaminated with oil. The groups introduced the microorganisms into the plant system and then conducted observations and collected data on the effects.

Thad (P5), a college instructor, introduced his students to the concepts of bio-mimicry, bio-remediation, and bio-inspiration. They watched a few video clips about products inspired by natural events, such as the fox's ability to target mice through layers of snow. This was the inspiration for NASA to use the Earth's magnetic field for its own targeting system. Then Thad had students participate in a memory game. If the students were able to match the two bio-inspiration images, they then had to explain what the image represented. Thad reiterated the importance of current and relevant research being conducted at large universities and described the research study in which he was involved during his RET program. To better connect that research to the chemistry skills he was developing in his students, he walked them through several of the calculations utilized as part of that research. Afterward students participated in a post-test survey to demonstrate their knowledge gains.

Sam (P6), a college instructor, suggested to students that engineers need to be as aware of the soil as of the buildings. They do this by conducting soil classifications and analysis. She broke the class into groups and gave each group a different type of soil. She asked them to use their five senses to try and classify the soil. Then Sam gave them a larger amount of the same soil and had them conduct a manual sieve analysis, similar to the one Claire (P3) had students conduct in her class, using several stacked pans with varying mesh sizes. Following this, the students were asked to weigh each soil level type and classify the soil using that new data. Finally, she asked the students to develop a report based on their collected data.

Ben (P7), an eighth-grade teacher, developed a lesson that was one part of a larger unit. The lesson was introduced to his students in collaboration with Leslie (P9), his school's instructional coach and fellow RET teacher participant. Leslie presented Ben's students with a discussion on liquefaction, a phenomenon wherein soil loses strength due to an earthquake and as a result acts like a liquid. Connecting to Leslie's lesson, Ben asked his students to research possible solutions to liquefaction. As a class, they determined that adding certain types of material to the soil has demonstrated positive results. They conducted further research on types of material that might be used as part of an experiment. Ben selected a few of the materials suggested by the students. Students then worked in small teams to test the effectiveness of their material in deterring liquefaction. The focus of the lesson was to assist students in developing a stronger understanding of the scientific method to include hypothesis, independent and dependent variables, control groups, and data collection.

Zane (P8), an eighth-grade teacher, developed a lesson that was part of a larger unit on dust mitigation. First he defined dust mitigation as a process in which the adverse impact of loose dust, or fugitive dust, was reduced. Then he described spraying water on top of the ground around large construction sites as the current fugitive dust remediation method, and they discussed the challenges this presents in a desert climate. They further discussed current research utilizing microorganisms to help provide stabilization. In small groups, students created controls for a fugitive dust experiment in which they packed sand into small cups and then spritzed them with distilled water. The groups then measured the mass of each cup of soil and covered them with aluminum foil. Later in the unit, the students hypothesized other materials that could be added to the soil to use as alternate methods for stabilization and would then conduct their own tests.

Leslie (P9), an instructional coach who collaborated with Ben (P7) to implement her RET instructional lesson during his eighth-grade class, developed a lesson that would provide students with the knowledge necessary to later conduct an experiment on liquefaction. Leslie outlined a variety of engineering careers and invited her RETsoil lab mentor to visit the class and describe what it meant to be a civil engineer. Leslie had students read about a school in California that was being closed due to concerns over liquefaction. Leslie then presented students with several prototype buildings made of Legos and asked students to reflect on the aspects of the building that might make them less likely to survive a liquefaction event. Afterwards, students observed the guest civil engineer test the models using a shake table, which is a small machine that simulates an earthquake. Leslie also shared with students a few real-life videos of buildings and roads caught in liquefaction events. Students were then asked to summarize their thoughts through the use of a graphic organizer.

Lou (P10), a fourth-grade teacher, developed a unit that introduced students to solar energy and sustainability issues. Students were broken into groups and given a simple motor and a plastic fidget spinner toy. They were asked to bring in recyclable materials from home and were tasked with attaching the motor to the spinner in such a way that it would infinitely self-propel once attached to a solar cell. While groups worked on designing their product, Lou facilitated testing procedures with a high-powered work light he aimed at the solar panel to simulate sunlight within the confines of the classroom. Students used alligator clips to test their infinite spinner with the solar cell and then returned to their desks to redesign their spinners. Afterwards, they would reflect on aspects that worked and challenges for the next design iteration.

Post-Implementation Interview Question on Perceived Student Outcomes

After implementing the RET instructional lesson in their classroom, all 10 case-teachers participated in a post-implementation interview. Results suggest that all of them seemed to feel that students demonstrated increased engagement as part of the lesson implementation, as shown in Table 3.10. Eight of 10 case-teachers noted an increase in knowledge, whether that be use of vocabulary, process skills, or some other content learning objective. Four of 10 case-teachers also noted increases in observed critical thinking, acceptance of ambiguity, and growth in students as agents of change.

Embedded Design Thinking Student Learning Strategies

I first present the results from the Implementation Observation field notes that demonstrate the types of Design Thinking practices used by case-teachers. Then I present a description of how the majority of the case-teachers chose to embed Design Thinking as a type of student learning strategy in their instructional lessons.

While coding the implementation observation field notes for Design Thinking practices, I also coded for other general teaching practices that I felt might connect to the overall context. The results from that coding process are included in tables presented in Appendix F. I also developed case-teacher vignettes that are included in Appendix G. While these represent important data collected during this study, they did not explicitly support the study research questions.

Table 3.10

Case-Teacher Responses on Perceived Student Outcomes

Thematic Category	Reference Example	No. of Case-teachers (n=10)	No. of References
Increased Engagement	They were a lot more engaged and willing to try to help solve the problem. [Zane P8]	10	14
Knowledge Gain	To watch students discuss an experiment that they designed and then to relate that to issues like liquefaction. [Ben P7]	8	16
Critical Thinking	They were really processing through the data. Why did theirs and not ours, how much oil did they add, versus how much you added. It really prompted a huge discussion at the end of why you and not us? [Angelica P4]	4	7
Acceptance of Ambiguity	Okay, now let's try this thing instead of dwelling on it the way they would've done in the past. Again, it was painful the first couple times, but, after a while, they said, okay, we'll try my idea, or right in the middle of failing, they would look at each other and say, okay, I think your idea is going to work better. [Lou P10]	4	7
Agents of Change	My sixth grade students shared with two groups of eighth graders. Everything I heard from the eighth grades was, "Well, that's interesting. Why did you choose this? Why did you do that? You're layering it?" The eighth graders wanted to learn more about it, too. [Claire P3]	4	6

Note. Perceived Student Outcome thematic categories were determined using thematic analysis (Creswell, 2013) on individual post-implementation interview transcripts, which were based on the perceptions of the case-teacher who developed and implemented the RET instructional lesson. RET = Research Experience for Teachers.

Data which did explicitly relate to the research questions dealt with observed Design Thinking practices. To better understand how those Design Thinking practices were being used in individual classrooms, I wished to first understand patterns across the 10 case-teachers as a group and then within individual case-teachers.

Design Thinking practices observed across case-teachers. I developed a holistic approach to understanding the extent to which these 10 case-teachers used Design Thinking practices as student learning strategies within their RET instructional lessons. As shown in Table 3.11, codes were holistically divided into three sections (strong, moderate, and rare) by the extent to which they were used by case-teachers as determined by both the number of case-teachers referenced and the percentage of codes referenced overall. The *strong-use* section included Design Thinking codes which were referenced by nine to 10 case-teachers, and represented over 10% of the overall total number of codes referenced. The *moderate-use* section included codes referenced by four to eight case-teachers, with over 8% of the overall codes referenced. Lastly, the *rare-use* section included one to six case-teachers referenced and below 8% total codes referenced overall. The sections may seem to overlap in that codes referenced across five case-teachers could be either moderate or rare; however, the overall percentage would then determine into which use level it was organized.

Strong-Use. The Design Thinking practices designated as strong-use included codes used by almost all of the case-teachers to some extent. *Providing ambiguity* was the most strongly referenced code at 17%. *Defining the Problem* was used across all 10 case-teachers and represented 13% of codes referenced. Both *providing ambiguity* and

Table 3.11
Frequencies of Design Thinking Practices across Case-Teachers

Category Codes	Code Definitions	No. of Case-teachers (n=10)	No. of Codes	Total No. (%)
	Strong-Use			
Provide Ambiguity	Leaves aspects of learning open-ended. Failure is a part of learning.	9	46	17.2
Define Problem	Situates the learning objectives within a larger real-life problem.	10	34	12.7
Collaborate	Includes social norming to foster collaboration toward a shared goal.	9	32	11.9
	Moderate-Use			
Test Ideas	Tries out aspects of a design to gather information and make sense.	6	34	12.7
Explore Solutions	Considers multiple ideas before selecting one. Brainstorm, gallery walks, sharing.	8	30	11.2
Use Design Language	Fosters students' view of themselves as designers by using design terms.	9	26	9.7
Reflect	Provides space for students to write down or share their thoughts, to revise/iterate.	7	23	8.6
	Rare-Use			
Sketch	Provides space to sketch ideas as a way to explore or prototype.	4	21	7.8
Discover Perspectives	Fosters student empathy toward others who have a perspective on the problem.	6	12	4.5
Include Constraints	Ensures that the problem involves real-world constraints and contingencies.	2	6	2.2
Critique	Provides opportunities for students to receive critical feedback assessing their work in a public setting.	3	4	1.5

Note. The Design Thinking category codes were holistically divided into levels of use: strong, moderate, and rare. Strong-Use: nine to ten case-teachers referenced, above 10% of codes referenced overall; Moderate-Use: four to eight case-teachers referenced, above 8% of codes referenced overall; Rare-Use: one to six case-teachers referenced, below 8% of codes referenced overall.

collaborating were used across nine case-teachers, with *collaborating* (12%) being referenced across nine case-teachers.

Moderate-Use. While several of the moderate-use Design Thinking codes were referenced at approximately the same percent as some of the strong-use codes, they were not used by as many case-teachers. For example, both the codes *test ideas* (13%) and *explore solutions* (11%) were referenced as often as *providing ambiguity* and *collaborating*; however, *exploring solutions* was referenced across eight case-teachers and *testing ideas* across six. Nine of the 10 case-teachers purposefully *modeled design language* in their instruction, resulting in 10% of the overall codes referenced. Lastly, *reflection* was referenced across seven case-teachers for 9% of the overall codes referenced.

Rare-Use. The Design Thinking codes designated as rare-use were distinct in that certain concrete practices were observed; however, they were referenced infrequently by only a handful of case-teachers. This rare-use section included *sketching, discovering perspectives, including constraints,* and *critiquing*. *Sketching* was utilized more heavily at 8%; however, this was only across four case-teachers. Six of 10 case-teachers used some type of practice to help students *discover the perspective* of some other stakeholder, but at 5% of the overall codes referenced, it was infrequently practiced. Utilizing the practices of *including constraints* (across two case-teachers at 2%) and *critiquing* (across three case-teachers at 2%) were the least used practices.

Design Thinking practices observed within case-teachers. I observed 10 case-teachers implement instruction. However, two of the case-teachers, Ben and Leslie, developed and implemented their instruction collaboratively. As Leslie taught, Ben was in the classroom supporting and adding clarification. As Ben taught, he often referred back to instruction that Leslie introduced. It is difficult to explore how they utilized teaching practices as separate teachers because of how heavily they integrated their work. Therefore, while I will provide their individual findings, I will also provide their combined findings as Ben/Leslie because I believe this provides a richer view of how they used Design Thinking practices in their RET instructional lessons.

The description of Design Thinking practices within case-teachers is described using the same holistic use-level process as for the description across case-teachers, as shown in Table 3.12.

Strong-Use. All 10 case-teachers situated their instruction within a real-world wicked problem context. However, Thad was the only case-teacher who was referenced with *Defining the Problem* as his only observed Design Thinking practice. Each case-teacher was referenced with one of the strong-use codes (*Defining the Problem, Providing Ambiguity*, or *Collaborating*) as one of their most used Design Thinking practices. Colin and Sam most heavily *Provided Ambiguity*, while Angelica most strongly focused on *Collaboration*.

Moderate-Use. In the moderate-use section, all of the case-teachers except Thad model some level of *Design Thinking Language*. Colin, Evan, and Claire were referenced *Exploring Solutions* as one of their most used practices; while Zane, Lou, and Ben/Leslie were referenced *Testing Ideas* for their most used practice. *Reflection* was not a practice highly used by any of the case-teachers except for Lou and Ben/Leslie. Likewise, Colin, Claire, Angelica, and Zane used *Reflection* infrequently.

Table 3.12

Frequencies of Design Thinking Practices by Case-Teacher

	Strong-Use			Moderate-Use				Rare-Use			
Case-teacher	PA	DPr	CO	TI	ES	DL	R	S	DPe	IC	CR
Colin (P1)	8	2	3	0	4	4	1	7	6	0	1
Evan (P2)	3	5	1	0	6	1	0	0	0	0	0
Claire (P3)	5	7	3	0	7	4	3	1	1	4	1
Angelica (P4)	9	2	11	1	3	2	3	6	2	2	2
Thad (P5)	0	2	0	0	0	0	0	0	0	0	0
Sam (P6)	4	2	1	2	0	2	0	0	0	0	0
Ben (P7)	5	3	3	4	6	2	5	0	1	0	0
Zane (P8)	2	1	1	4	1	1	1	0	1	0	0
Leslie (P9)	2	7	1	7	1	7	2	0	1	0	0
Lou (P10)	8	3	8	16	2	3	8	7	0	0	0
Ben/Leslie	7	10	4	11	7	9	7	0	2	0	0

Note. The Design Thinking Practices category codes were holistically divided into levels of use: strong, moderate, and rare. Strong-Use: nine to ten cases referenced, above 10% of codes referenced overall; Moderate-Use: four to eight cases referenced, above 8% of codes referenced overall; Rare-Use: one to six cases referenced, below 8% of codes referenced overall. Design Thinking Practices category codes are abbreviated as follows: Providing Ambiguity (PA), Defining the Problem (DPr), Collaboration (CO), Testing Ideas (TI), Exploring Solutions (ES), Design Language (DL), Reflection (R), Sketching (S), Discovering Perspectives (DPe), Including Constraints (IC), and Critique (CR).

Rare-Use. Three case-teachers, Evan, Thad, and Sam, were not referenced practicing any of the rare-use Design Thinking practices. Claire, Zane, and Ben/Leslie (one to four references) were referenced as occasionally practicing a rare-use Design Thinking practice, with Claire being referenced with the highest use of *Including Constraints* (four references). Colin, Angelica, and Lou (five to seven references) were referenced with the highest level of rare-use practices, with the highest use referenced in *Sketching*.

Selection of a Design Thinking student learning strategy. All 16 teacher participants were involved in the use of the DTIP approach for developing an instructional lesson during the RET summer program. However, neither the RET program nor the DTIP study communicated any expectation that teacher participants embed a Design Thinking approach into their lessons as a strategy for student learning. Teacher participants were at complete liberty to select whichever learning activities and strategies they felt would best meet the lesson objectives and the needs of their students.

While all of the case-teachers (n=10) described outcomes that suggested they perceived their RET instructional lessons to have provided innovative and/or creative learning opportunities and strengthened student learning, I was particularly interested in those lessons in which the case-teacher made a choice to use some type of Design Thinking approach as a student learning strategy. Therefore, since Thad (P5) and Sam (P6) chose to focus primarily on gaming and hands-on student learning strategies, I do not refer to their RET instructional lessons beyond this point. This does not suggest that the instructional lessons they developed are less innovative or creative. I am simply more interested in the instructional lessons that included a heavier focus on a Design Thinking approach as a perceived way to heighten student learning,

Eight case-teachers chose to embed a Design Thinking approach as a student learning strategy into their instructional lessons. Note that five case-teachers did work for STEM-designated schools that required some use of a Design Thinking or engineering design process as part of their curricular expectations. Therefore, those five case-teachers were probably already oriented toward utilizing some kind of Design Thinking approach with their students. However, three of those case-teachers worked for traditional public schools and had not utilized Design Thinking before participating in the DTIP professional development sessions.

Coding data from the Implementation Observation field notes suggest two types of Design Thinking student learning strategies were embedded into those eight RET instructional lessons: Scaffolded and Reframed.

Scaffolded Design Thinking student learning strategy. Five case-teachers (Evan, Claire, Ben, Zane, and Leslie) integrated a scaffolded form of the Design Thinking approach into their instructional lessons. The lessons for these case-teachers took place across several days and/or weeks; however, only a few days of the implementation were observed. It is possible that certain of these Design Thinking practices were implemented on days that were not observed.

Both Evan (P2) and Zane (P8) were not observed with as many references to Design Thinking practices as Claire (P3), Ben (P7), and Leslie (P9); however, both Evan and Zane described the use of Design Thinking in either their RET instructional lesson plans or as part of their post-implementation interview. I observed Evan (P2) during the first day of a week-long lesson and saw that he was providing his classes with the background context for the overall lesson. On the day I observed, students had not had a chance to fully immerse themselves in the project, yet.

Due to scheduling conflicts, I was only able to observe one of Zane's (P8) class periods; however, his description of the rest of the lesson suggested the use of a Design Thinking student learning strategy. Therefore, I included both Evan and Zane's instructional lessons in this description because of their intent and some initial observed practices supporting that intent.

For this Scaffolded Design Thinking student learning strategy, the majority of the five case-teachers were observed practicing strong-use Design Thinking practices. These practices involved defining the problem, providing ambiguity, and including some level of collaboration that often seemed to lean more toward grouping or cooperation, as shown in Table 3.13. They also demonstrated moderate-use practices, which depended upon where in the lesson they were when I happened to observe. If they had just begun the lesson, they often had high levels of problem defining. If they were in the middle of the lesson, then they often had high levels of solution exploring or prototype testing. Because of the seemingly linear way in which the Design Thinking strategy was utilized during these implementations, I often did not observe any other Design Thinking stages being facilitated. Also, the rare-use practices of sketching, critique, and constraints—which research has suggested support and foster the Design Thinking approach—were not seen during the implementation observation of most of these case-teachers.

In connection to the use of Design Thinking, these five case-teachers were observed using several general teaching practices to complement or foster the scaffolded strategy. Both Evan (P2) and Zane (P8) utilized direct instruction for portions of the instructional lesson that were observed. Zane combined this further with modeling. Claire (P3) and Ben (P7) also utilized modeling. Leslie (P9) was seen to frequently use question-asking techniques.

Table 3.13

Characteristics of a Scaffolded Design Thinking Student Learning Strategy

	Case-teachers				
Characteristics	Evan (P2)	Claire (P3)	Ben (P7)	Zane (P8)	Leslie (P9)
Context	High School, TRAD, 1-3 yrs	6th, STEM, 1-3 yrs	8th, STEM, 4-6 yrs	8th, TRAD, 4-6 yrs	Instr/8th, STEM, 10+ yrs
Complementary Learning Style	Direct Instruction	Modeling	Modeling	Direct Instruction, Modeling	Question Asking
Define Problem	High	High	High	Low	High
Provide Ambiguity	Moderate	Moderate	Low	Moderate	Low
Collaboration	Low	Moderate	Low	Low	Low
Design Language	Low	Moderate	High	Low	High
Explore Solutions	High	High	Moderate	Low	Moderate
Reflection	None	Moderate	High	Low	High
Testing Ideas	None	None	High	High	High
Discover Perspectives	None	Low	Low	Low	Low
Sketching	None	Low	None	None	None
Critique	None	Low	None	None	None
Include Constraints	None	Moderate	None	None	None

Note. Characteristics were determined as part of a coding process derived from the RET instructional lesson implementation field notes of DTIP case-teachers. High, moderate, low, and none categories refer to a holistic approximation of times case-teachers were observed facilitating that Design Thinking practice during the RET instructional lesson implementation. DTIP = Design Thinking Instructional Problems; RET = Research Experience for Teachers.

Though these five case-teachers all seemed to have selected a Scaffolded Design Thinking student learning strategy, they had a variety of reasons for supporting this decision. As a novice teacher and first-time user of Design Thinking, Evan (P2) was seemingly concerned with meeting the learning objectives and keeping students from developing misconceptions. Even with the use of the scaffolded learning strategy, he still found that some of his students misunderstood the nature of the learning.

The other issue I had was some of the ideas were so outrageous, there was just no chance for me to even [relate it back to the lesson]. Students commented with things like, "What if we took a turtle shell and wore it as a helmet?" I told them, "No. We have helmets already. That's not anything that's going to be revolutionary." The proposal is supposed to be bio-inspired, not using the bio itself as in wearing a turtle shell as a hat. [Evan P2, post-implementation interview transcripts]

Claire (P3) found that as much as she wanted to provide strong ambiguity to allow students to struggle with the learning, her desire to support the needs of her students outweighed that intent. She has also stated in the post-program DTIP survey that her challenge with the Design Thinking approach was that she prefers to have control in the classroom.

> *They were not moving forward or working well with their group. I needed to be able to get them to that place—though I realized that it's more enriching to do it on your own—but that wasn't something that they were doing, so I needed to bring them as a whole group*. [Claire P3, post-implementation interview transcripts]

Both Ben (P7) and Zane (P8) purposefully used Design Thinking as way to help students build their understanding of the scientific method. They heavily aligned the two processes while pointing out key vocabulary, modeling, and practicing along with the students.

> *We just kept a record of our ideas in our notebook. Then from there, what I was able to do was actually pull out of their ideas four materials that I'd already identified and then actually test them out. They played a role in it, but I knew in the back of my head they're probably going to say some of these things on their own if I prompt them in the right way. It was just a perfect opportunity to connect their prior knowledge to what we were learning in the class.* [Ben P7, post-implementation interview transcripts]

> *It worked out a lot better this time around mirroring the procedures of a real lab. Getting the students to feel like they're actually an engineer or a scientist helped them become more engaged with the lesson*. [Zane P8, post-implementation interview transcripts]

Leslie (P9), an instructional coach, saw the scaffolded strategy as a solid first step toward integrating engineering processes and higher level critical thinking in the classroom. However, it was her hope that teachers using Design Thinking can begin to push past that initial method. Because her instructional lesson was one part of a larger lesson implemented in Ben's (P7) classroom, she was limited in the practices she chose to integrate.

> *I would hope that we can push Design Thinking, to permeate the experience of learning in classrooms versus just to do an event. I think that's a*

huge win to have gone as far as we have in one year as a STEM school. But now it's taking away the scaffold and making it more just a way of thinking, of how to engage learners. [Leslie P9]

These five case-teachers purposefully chose to embed a Design Thinking student learning strategy that would provide a strong support to help build their students' knowledge and skill base. Three other case-teachers used a slightly different approach to using Design Thinking as a student learning strategy.

Reframed Design Thinking student learning strategy. Three case-teachers (Colin, Angelica, and Lou) decided to embed a Reframed Design Thinking student learning strategy within their RET instructional lessons. For this Reframed Design Thinking student learning strategy, all three case-teachers were observed practicing strong-use Design Thinking practices. These practices—similar to case-teachers who used the scaffolded strategy—involved defining the problem, and providing ambiguity and collaboration, as shown in Table 3.14. However, in the scaffolded strategy, case-teachers spent a substantial amount of time defining the problem with students before moving into the rest of the Design Thinking process. After that, they were rarely observed referring back to it. The three case-teachers who used a reframed strategy spent less time at the beginning defining the problem, but then had students revisit the problem as they worked on their solutions.

While the case-teachers using a scaffolded strategy seemed to purposefully provide a low to moderate amount of ambiguity in the problem, case-teachers using a reframed strategy developed a problem that presented stronger ambiguity and a higher

Table 3.14

Characteristics of a Reframed Design Thinking Student Learning Strategy

	Case-teachers		
Characteristics	Colin (P1)	Angelica (P4)	Lou (P10)
Context	4th, STEM, 1-3 yrs	7th, STEM, 10+ yrs	4th, TRAD, 10+ yrs
Complementary Learning Strategy	Question Asking	Question Asking	Hands-On
Define Problem	Low	Low	Low
Provide Ambiguity	High	High	High
Collaboration	Moderate	High	High
Design Language	Moderate	Low	Low
Explore Solutions	Moderate	Low	Low
Reflection	Low	Low	High
Test Ideas	None	Low	High
Discover Perspectives	High	Low	None
Sketching	High	High	High
Critique	Low	Low	None
Include Constraints	None	Low	None

Note. Characteristics were determined as part of a coding process derived from the RET instructional lesson implementation field notes of DTIP study case-teachers. High, moderate, low, and none categories refer to a holistic approximation of times case-teachers were observed facilitating that Design Thinking practice during the RET instructional lesson implementation. DTIP = Design Thinking Instructional Problems; RET = Research Experience for Teachers.

likelihood of student failure. These three case-teachers were also seen heavily integrating group norming practices throughout the learning.

In addition, the case-teachers who used a reframed strategy were observed facilitating several Design Thinking stages—discovering perspectives, exploring solutions, testing ideas, and reflecting—simultaneously. While all three case-teachers used sketching to foster the Design Thinking strategy, two included critique strategies, and one included constraints on the problem.

In connection to the use of Design Thinking, these five case-teachers were observed using several general teaching practices to complement or foster the reframed strategy. Colin (P1) and Angelica (P4) heavily utilized open-ended question asking techniques, while Lou (P10) relied heavily on hands-on learning to drive students' understanding of the problem.

All three case-teachers seemed to perceive the reframed strategy as a way to develop a learning environment that would cultivate the higher types of critical thinking and innovative problem-solving that they wanted to see in their students. Colin (P1), as a fourth-grade teacher, felt he had to provide a bit more structure, but still provided strong ambiguity. Therefore, he often allowed students room to explore problem solutions while using open-ended questions to help them think about possible challenges they may not have originally considered.

> *Facilitative questioning is probably one of the greatest [strategies] for Design Thinking. Actually guiding students through reflective questions about whatever phase they're on [was valuable]. [While students were] designing their prototypes, I think questioning them was really helpful because then the next day they had enough time to be able to process what we had talked about. Then they*

wanted to make some adjustments for themselves. [Colin P1, post-implementation interview]

Angelica (P4) felt that the work involved in implementing a reframed strategy was valuable because it provided a stronger learning connection with students as compared to when she just had them participant in a standard science experiment.

> *It was a struggle for me mentally to switch from [my original teaching style which was] step by step. I [wondered], "How are the kids going to figure it out?" But they do. You just have to give them the right questions for them to go, "Oh." It gives them more of an "a-ha" moment than the "okay we're doing an experiment" style*. [Angelica P4, post-implementation interview]

Lou (P10) wanted to more heavily highlight the importance of productive failure as a way of fostering innovative and creative problem-solving. He wanted his students to understand that in complex problem-solving there can be multiple possible solutions.

> *It wasn't so much about what the design looked like or what was right or wrong. It was what [design] was right or wrong for the students. That was the concept that I really wanted—collaboration and reaching a consensus. That what you build and what I build—if they both work—neither one's right, neither one's wrong. They both work. [Lou P10]*

These three case-teachers purposefully chose to embed a Design Thinking student learning strategy that would foster innovative and creative problem-solving. All three of them mentioned an intention to continue to develop instructional lessons that incorporate Design Thinking.

Summary

The results presented in this chapter addressed four research questions regarding how the DTIP approach to developing RET instructional lessons was perceived by K-14 STEM case-teachers. In keeping with Yin's (1989) case study methods, I presented findings across and within individual teacher participants. I also presented the data through a variety of analytic techniques to better discover patterns within the data.

CHAPTER 4

DISCUSSION

In this chapter, I interpret the results of the study. I provide a summary of the study and discussion of the results. The discussion of results is organized by the original four research questions. I then conclude with study limitations, implications, and future research.

Summary of the Study

Design Thinking is a creative problem-solving approach developed through research on the design processes of engineers, architects, and designers (Cross, 2001, 2011). Though it has been used in business and healthcare for several decades (Kimbell, 2011), it has only recently been implemented in education. Some research has been conducted on its affordances as an approach to student learning (Blizzard et al., 2015; Carroll et al., 2010; Leverenz, 2014).

However, some scholars are now suggesting that teachers begin to consider themselves as designers (Jordan et al., 2014; Svihla et al., 2015). Therefore, I have conducted a study in which I explored how a DTIP approach to developing instructional lessons was perceived by 16 teacher participants during an RET summer program. As part of this study, I suggested that the DTIP approach is best used to either solve wicked (Buchanan, 1992) instructional problems, or as a way to creatively innovate instruction (Henriksen et al., 2018).

The study design involved a convergent parallel mixed-methods design, which included a survey instrument and a multiple case study approach conducted across three phases (Creswell, 2013; Tracy, 2013; Yin, 1989). Phases I and II were conducted with

16 teacher participants and involved the collection of pre- and post-program DTIP surveys and open-ended responses and background interview transcripts. During Phase III, 10 case-teachers were selected for continued study. I observed their RET instructional lesson implementation and conducted post-implementation interviews with each of them.

Data analysis included descriptive statistics, direct interpretation (Creswell, 2013), thematic analysis (Creswell, 2013), and open coding combined with the constant comparative method (Charmaz, 1995; Creswell, 2013; Tracy, 2013). Qualitative data results were presented in a variety of arrays, matrices, and tables to better understand holistic patterns across and within case-teacher data (Yin, 1989). Results from these data sources supported four research questions:

1. To what extent did teacher participants view themselves as designers solving complex instructional problems?
2. How and to what extent did the DTIP professional development sessions resonate with teacher participants?
3. How and to what extent did the DTIP model resonate with teacher participants?
4. What are the characteristics of, and the teacher participants' perspectives on, the lessons developed in conjunction with the DTIP approach within the RET summer program?

Discussion of Results

This section of the chapter is broken into four areas. First, I discuss the extent to which teacher participants viewed themselves as designers solving complex instructional problems. Second, I discuss how the DTIP professional development sessions resonated with the teacher participants. Third, I discuss how the DTIP model resonated with the teacher participants. Fourth, I describe the characteristics of and teacher participants' perspectives on the RET instructional lessons.

RQ1: To what extent did teacher participants view themselves as designers solving complex instructional problems?

Teacher participant responses to the pre- and post-program DTIP survey sub-scales provided some context for understanding the extent to which they saw themselves as designers solving complex instructional problems. However, the sub-scales did not provide as much insight as the qualitative data and may not be the best measure for such a small homogenous sample.

Teacher Participants' Design Dispositions

The change in pre- and post-program responses to the Design Disposition sub-scale resulted in mean scores that suggest that the 16 teacher participants did not experience strong change in their design dispositions. This may have occurred because the majority of teacher participants already viewed themselves *very much* as innovative designers as evidenced by their high pre-program DTIP survey responses on the DD sub-scale. Teacher participants who use most of their summer to return to school specifically to participate in STEM lab research in order to provide unique learning experiences for both their students and themselves may already have an orientation that corresponds with Design Thinking assumptions. This very slight change could also simply be a result of error. Therefore, the Design Disposition sub-scale may not provide much insight for this particular group.

Teacher Participants' Belief in Wicked Instructional Problems

Results of the responses on the Wicked Instructional Problems sub-scale did suggest that on average the 16 teacher participants viewed developing instructional lessons as *very much* a wicked problem. These findings provide some insight as to why certain teacher participants may or may not have found value in the DTIP model; however, this sub-scale is not as reliable as it could be. Though Streiner (2003) asserts that the coefficient alpha for small homogeneous groups often demonstrates smaller alphas—meaning that small sample sizes often result in smaller coefficient alphas—some item revision is still recommended. All four WIP items were overly long, which could suggest that more than one construct was being interpreted. Therefore, the original items may need to be made more concise and the sub-scale should include more items to better target the intended constructs.

RQ2: How and to what extent did the DTIP professional development sessions resonate with teacher participants?

As a group, the sixteen teacher participants found the Design Thinking Instructional Problems professional development sessions to have *somewhat* to *very much* influenced how they created their instructional lessons. They found the Wrong Theory activity the least helpful. During this Wrong Theory activity, teacher participants were asked to sketch and describe the worst possible way to develop an instructional lesson based on the problem, context, and students. The purpose of the activity was to help make them more aware of their own beliefs concerning learning theory and to help view the learning from another lens, as a method for helping them think of other solutions beyond the initial one they may have already chosen. Two teacher participants specifically described the activity as less helpful because they felt they already knew what did not work in the classroom.

Conversely, the 16 teacher participants found having space and time to collaborate with colleagues the most helpful. Also, their greatest challenge was to understand how to transform the RET research content into age-appropriate learning objectives for their students while they were still trying to understand the research content themselves. This then connects well with their greatest RET influencer being time in the research lab. In addition, while some teacher participants had never heard of Design Thinking, others had been trained in a Design Thinking or engineering process and were employed at schools requiring its integration.

DTIP Professional Development Sessions Recommendations

These findings suggest that future DTIP professional development sessions during RET programs incorporate the following five aspects: research time, grade-level collaborative groups, norming procedure development, mini-teach critiques, and differentiation practices.

Research time. RET teacher participants should be given some time to conduct research in the lab with their research mentors to better provide a working understanding of the concepts being studied before beginning the DTIP approach. Cognitive load theory (Sweller & Chandler, 1994) suggests that it might be challenging for a person to learn the content while simultaneously making decisions on how to teach it. This was supported by the teacher participants' experiences.

Grade-level collaborative groups. The majority of teacher participants found working informally with their colleagues to be beneficial, but a few did not find the formal presentations of their work as helpful. These findings suggest that teacher participants may need to be guided more explicitly toward forming grade-level groups. This conclusion supports current findings in the professional development literature (Desimone, 2009).

Norming procedure development. The way I facilitated the Wrong Theory activity did not seem to provide added benefit. This may be due to a lack of developing explicit connections between the "wrong-way" learning activities teacher participants brainstormed and possible new effective solution paths. Because of this, the teacher participants were probably unable to see its value. Therefore, I would either need to find a way to develop those connections or remove the activity. Possibly, more time and space could be spent on providing opportunities for the teacher participants to develop norms within grade-level groups and develop a guiding problem for themselves as a group to solve. This might be achieved by implementing a group-developed lesson plan. Achinstein (2002) suggests that successful teacher collaboration is fostered through the development of explicit roles and norms, critical reflection, identifying group borders, and shared ideology.

Mini-teach critiques. Several teacher participants mentioned that being critiqued by a Young Scholar (high school-aged student) was not fully beneficial, possibly because they were either the wrong age to accurately provide feedback for the teacher participant's particular class or did not provide meaningful feedback. Therefore, instead of sharing their lesson ideas with high school-aged Young Scholars, teacher participants could be asked to develop a draft version of some aspect of their instructional lesson. The teacher participant could then pair up with a Young Scholar not overly familiar with their particular lab research to simulate with them a version of that learning experience as a prototype test. This might allow the teacher participant to test and evaluate that aspect of the instruction and receive valuable data before implementation.

Differentiation practices. Design Thinking assumptions suggest that designers must have a minimal level of expertise in their field in order to consider the various possible ways to change or adapt common patterns of knowledge into creative or innovative problem solutions (Lawson, 2006; Hoadley & Cox, 2009). This suggests that novice teachers may not be able to fully utilize a DTIP approach without a more scaffolded system of guidance. This conclusion is also supported by cognitive load theorists (Kang & Anderson, 2015; Kirschner, Sweller, & Clark, 2006) who suggest that complexity for novice teachers be reduced by focusing on one teaching aspect at a time. In addition, those who have already been utilizing the Design Thinking approach in their school may not find value in sitting through a Design Thinking basic introduction, since this lacks challenge for them (Strati, Schmidt, & Maier, 2017). This further suggests that pre-determining the level to which teacher participants know of and/or use Design Thinking could be valuable. Likewise, developing ways by which to differentiate the DTIP experience for those at different levels would also be recommended.

RQ3: How and to what extent did the DTIP model resonate with teacher participants?

The case-teachers perceived the DTIP model graphic as providing additional value to the way in which they developed their RET instructional lessons. Fourteen of 16 teacher participants found the DTIP model to have *moderate* to *strong* value. In addition, all of the 10 case-teachers described their approach to developing the RET instructional lesson in way that minimally suggests *some* correspondence with the DTIP model, with the majority describing *most* or *complete* correspondence.

Perceived DTIP Model Correspondence Levels

The majority of case-teachers seemed to perceive the DTIP model as having at least *moderate* additional value to their RET instructional lesson design, and they all viewed their instructional lesson development approach as *somewhat* corresponding to the DTIP model graphic. Four case-teachers described a lesson design approach that *somewhat* corresponded and four that *completely* corresponded to the DTIP model. Two case-teachers felt their lesson design approach *mostly* corresponded. However, their descriptions suggest that their approaches *completely* corresponded, but that the DTIP model graphic did not cleanly visualize the approach for them.

Somewhat corresponded. Four case-teachers only viewed their lesson design approach as *somewhat* corresponded to the DTIP model graphic. These four found themselves specifically utilizing certain aspects of the model, but not others. Additionally, they did not see themselves fluctuating in and out of problem framing as much as the model implied. All four of these case-teachers seemed to begin the RET program planning to find ways to directly integrate the RET research experiments into their classrooms. This may have limited their need to fully embrace a process primarily intended to solve complex problems. The way in which a teacher chooses to frame his or her initial instructional problem may affect the overall lesson development (Svihla et al., 2015).

Completely corresponded. Four of the ten case-teachers described their approach as completely corresponding to the DTIP model. These case-teachers developed their RET instructional lessons in a way that seemed to embody the abductive reasoning inherent in problem framing and reframing (Dorst, 2011). They were excited about a model that demonstrated the Design Thinking approach as iterative and fluid. Lou even used the graphic as a way to help visualize the way in which he wanted to develop the instruction for his whole RET instructional unit. Each of these teachers developed instructional units that included some concepts or methods used within the RET, but largely transformed them to better resonate with the age group, learning objectives, and needs of their students.

DTIP model adjustments. Two teacher participants, Ben and Leslie, perceived their instructional lesson design approach to mostly correspond with the DTIP model. These two teacher participants developed an innovative instructional solution by deciding to collaborate. However, though they both described examples of ways in which their approach did not correspond with the DTIP model, what they described actually supported Design Thinking assumptions. This suggests that the visualization of the model did not clearly depict certain aspects of their individual approaches, but probably should have.

Primarily, their descriptions suggest that two aspects of the model need to be better clarified. First, the stages should be depicted as less linear and fixed. While the DTIP model does provide a circular five-stage process, in practice, the Design Thinking stages might be conducted simultaneously. Additionally, the iterative Design Thinking approach suggests that stages are repeated; however, this does not mean all of the stages are repeated with the same level of depth and in the same order. Instead, some stages, such as reflecting or testing, might be implemented over and over again, perhaps without utilizing the other stages.

Second, the model should better visualize the chaotic fluctuating nature of the approach. Leslie mentioned that she often felt she was taking two steps back for every one step forward. Yet to her, the visualization of the model implied a consistently forward-moving direction. Though the model was depicted with a variety of randomly shaped hills and valleys in an attempt to visualize this struggle, the way in which the circular stage graphic points to those hills and valleys may lead to interpreting the approach as more organized than it really is.

The feedback from these ten case-teachers suggests that the DTIP model can correspond to their instructional lesson development approaches. Some case-teachers chose not to follow certain aspects of the model, perhaps because they already felt they had a working solution for their instructional problem, but they still agreed to its potential. Some case-teachers provided a description which suggested they followed an approach that more closely corresponded to the Design Thinking approach than the graphic was capable of demonstrating. It is probably impossible to create a graphic accurately depicting an approach that is so fluid and imprecise. However, some thought should be given to this feedback and how best to depict those particular aspects of Design Thinking. In addition, the problem framing process is still unclear, especially as it applies to instructional lesson development. More research into problem framing as it applies to instructional problems is needed.

RQ4: What are the characteristics of, and the teacher participants' perspectives on, the lessons developed in conjunction with the DTIP approach within the RET summer program?

The 10 case-teachers each had their own ways of integrating the RET research concepts as they developed an RET instructional lesson for classroom implementation. Of the 10 case-teachers observed, eight case-teachers chose to embed a type of Design Thinking student learning strategy: Scaffolded or Reframed. While both types of learning strategies utilized the five stages of the Design Thinking approach, as shown in Table 4.1, the reframed strategy more heavily incorporated both the Design Thinking stages and assumptions inherent in the approach. However, case-teachers demonstrated practical reasons for selecting one strategy over the other.

Scaffolded Design Thinking Student Learning Strategy

Five case-teachers integrated a scaffolded form of the Design Thinking process into their instructional lessons. In their classrooms, these case-teachers developed a careful dance between teacher direction and student inquiry. They seemed to believe in the importance of student-centered learning and providing students with a voice, but they also seemed to believe in building a strong system of guidance to lead their students toward those pre-determined objectives.

Additionally, four of the five case-teachers asked their students to work cooperatively in groups. Claire pushed her students a little farther by asking them to collaborate toward a shared goal; however, for several activities, students simply worked in groups without mention of norming, cooperation, or collaboration practices.

Table 4.1

Characteristics of Design Thinking by Student Learning Strategy Type

Observed Characteristics	Strategy Type: Scaffolded (n=5)	Strategy Type: Reframed (n=3)
Design Thinking Purpose	Build Foundation Knowledge	Build Innovative/Creative Thinking
Teacher Role	Learning Guide	Learning Facilitator
Groups	Cooperative	Collaborative
Problem Ambiguity	Purposefully Weak	Purposefully Strong
Problem Defining	Before	Throughout
Complementary Teaching Practices	Modeling Hands-On	Group Norming Question Asking
Reflection	Summative Reflection-on-Action	Formative Reflection-in-Action

Note. Characteristics were determined as part of a coding process derived from the RET instructional lesson implementation field notes of DTIP case-teachers.

This scaffolded Design Thinking student learning strategy seems to be closely related to problem-based learning or inquiry learning (Elwood et al., 2016). These case-teachers heavily defined and scoped the problem with students before moving forward with the rest of the approach. Then they seemed to systematically moved their classes through each stage of the Design Thinking approach as a group. They utilized modeling as a way to have students practice their learning with guided support from the teacher. They discussed the importance of collaboration, but may not have always spent time facilitating the strategies necessary for optimizing group cohesion. These case-teachers may have cooperatively "divided [the work] in a systematic way," but may not have fully developed a "truly joint effort" to best foster collaboration (Dillenbourg, 1999, p. 2).

While Claire was observed including some sketching, outside perspectives, and discussion of design constraints, she seemed to battle against her desire to keep the class organized and moving forward. Ben and Leslie also integrated some outside perspectives, but did not seem to include sketching, constraints, or critique. These five case-teachers heavily believed in reflection, but perhaps more as a culmination of the learning than as a method for redesigning or reframing the problem. It is possible that this seemingly controlled approach to Design Thinking resulted in a more linear process; however, that seemed to be the goal of the strategy.

The instructional lessons that Evan, Ben, Zane, and Leslie implemented connected to real-world problems, were hands-on, and provided opportunities for critical thinking and reflection. However, the inherent ambiguity seemed to be low. Students seemed to have no real avenue for struggling with the concepts on their own. The instructional unit that Claire implemented included strong elements of ambiguity that more closely paralleled a reframed Design Thinking student learning strategy; however, students did not seem to be directing the solution path. She noted herself that she considered the giving up of control to be one of the most challenging aspects to using a Design Thinking approach.

Kloser (2014) conducted a Delphi study of 25 science education researchers, science teacher educators, scientists, and science teachers to identify the core practices of science teaching. The practices most suggested involved, "Engaging students in investigations and facilitating classroom discourse to promote an interactive and dialogic science classroom" (p. 1185). Case-teachers who used a Scaffolded Design Thinking student learning strategy seemed to support the results of the Kloser Delphi study as they worked to include hands-on opportunities for students to participate in a problem investigation. However, the seemingly linear way in which they walked students through the Design Thinking approach also suggests an agreement with Kirschner et al. (2006), who claimed that cognitive load theory and countless empirical studies support the need for direct instructional guidance.

Though the term Design Thinking was not explicitly mentioned by Kirschner et al. (2006), it is possible that these scholars would also deem Design Thinking to be a minimal guidance instructional approach. However, empirical evidence supporting Design Thinking as a learning approach for novices does not currently exist. Instead, Design Thinking scholars suggest that problem framing depends on the experiential schemata (Lawson, 2006) and the design patterns (Hoadley & Cox, 2009) of individual designers. This implies a difficulty for novice teachers who may not yet have strong teaching schemata or patterns. If teachers intend to use a Design Thinking approach with their students and know the students lack basic understanding of the foundational content, teachers may need to either use the Scaffolded Design Thinking approach as integrated by these case-teachers—similar to the heavily scaffolded process in problem-based or inquiry learning (Hmelo-Silver, Duncan, & Chinn, 2007)—or may need to more explicitly guide student collaboration.

Reframed Design Thinking Student Learning Strategy

Three case-teachers decided to integrate a Reframed Design Thinking student learning strategy into their RET instructional lesson. The case-teachers situated the learning within a real-world problem that was relevant to their students and that did not have an already accepted solution. In most cases, these case-teachers were expecting the solutions to fail and were prepared to integrate that failure into the learning. Similar to the idea of the *zone of proximal development* (Vygotsky, 1980), they cultivated this environment by purposefully developing a challenge that placed learning on the knife-edge (Perry, 1999; Elwood, Henriksen, Mishra, & Deep-Play, 2017), teetering precariously between being so frustrating that a learner decides to give up and being so creatively interesting that he or she is driven to solve the challenge.

Most strongly, the three case-teachers were observed consistently fostering high levels of ambiguity. The teachers seemed to expect their students to try some ideas, fail, reflect, and try again. Possibly, they wanted this fluctuating iterative approach to be part of what guided students toward heightened learning. Because of this, they could be seen using question-asking techniques that required the students to use their own knowledge to make decisions.

Each teacher situated the learning in an authentic real-world problem, but they did not seem to linger on defining the problem. They ensured that there was time and space to explore solutions through sketching strategies and allowed student teams to follow whichever solution paths seemed best at the time. These case-teachers also included public critique strategies. Students were asked to reflect back on their initial problem to better scope and reframe it as they went along. Some groups moved quickly through some stages, others spent great amounts of time sketching or building ideas, while others ping-ponged between stages—all in an effort to better understand the problem and which possible solutions might work best.

These three case-teachers seemed to largely spend their time reminding students of norming practices which included explicit roles for each member of the team, rotating team leaders, methods for dealing with conflict, and a need to reach consensus.

Students were observed running into the classroom, immediately getting out their supplies and getting to work. As lesson time began to run out, students would work faster and use positive language to encourage their teammates. Students always complained when the teacher told them it was time to clean up. In addition, in each of these case-teachers' classrooms, at least one to two groups continued to work on their project even as other classmates were lining up. One group of students even huddled together during cleanup and made a plan to meet at recess to continue figuring out what they should do for their next prototype test.

Similar to the way in which Claire's implementation seemed to lean more toward a reframed strategy at times, the instruction that Colin implemented occasionally seemed to lean toward a scaffolded strategy. However, the high level to which he asked his students to collaborate and deal with ambiguity suggests that his implementation seemed to more closely embody the reframed strategy.

These three case-teachers seemed to feel that their students were heavily engaged in the learning and demonstrated innovative and creative problem-solving. Angelica and Lou also seemed to feel their students' ability to accept ambiguity and learn from productive failure increased. Angelica additionally saw heightened critical thinking and Lou saw his students acting as agents of change regarding recycling materials and solar power with their families and friends.

Kirschner et al. (2006) might argue that a minimally guided learning approach does not provide enough structure to sufficiently reduce the cognitive load that may occur as students try to both learn the content and the Design Thinking approach. Hmelo-Silver et al. (2007) might argue that problem-based and inquiry learning are heavily scaffolded, providing necessary guidance, similar to the scaffolded Design Thinking student learning strategy used by case-teachers in this study. Both groups of scholars support the need for some structured guidance.

Additionally, scholars suggest that novice designers do not yet have the pattern knowledge necessary to innovate as part of the Design Thinking approach (Kangas, Seitamaa-Hakkarainen, Hakkarainen, 2013; Razzouk & Shute, 2012). This suggests that students lacking fundamental content knowledge may not be able to develop strong learning outcomes through a Design Thinking approach. However, Design Thinking literature also suggests that designers are highly systematic and collaborative (Cross, 2001, 2006; Lawson, 2006; Rowe, 1991). I suggest that highly developed systems of collaboration may provide the necessary structure needed to foster effective learning outcomes using a Reframed Design Thinking student learning strategy.

The three case-teachers who used a reframed strategy provided space for their students to develop group norms, roles, and processes toward ensuring consensus. As defined by De Backer, Van Keer, and Valcke (2015), these case-teachers developed learning contexts which invited students to "collectively undertake regulation activities by projecting and transferring this individual process to other students, creating an opportunity to demonstrate metacognitive regulation at a social level" (p. 64). Collaboration may heighten the likelihood of innovative outcomes; however, working in groups can also result in increased conflict (Achinstein, 2002; Svihla, 2010). Therefore, to foster group cohesion and increase the probability of productive learning interactions, Dillenbourg (1999) suggests that thought be given to the "careful design of the situation" (p. 5).

Dillenbourg (1999) suggests that the use of group roles, guided interactions through talking stems and role play, and consistent monitoring of those interactions could heighten the likelihood of productive learning interactions. This explicit facilitation of group norming behavior is supported by a study of design teams in which group cohesion promoted better applied knowledge (Svihla, 2010). In addition, recent studies on undergraduate collaborative groups who utilized heedful interrelating, a process by which group members were asked to pay attention to the problem task and their own actions as they affect the group, were associated with both group and individual increases in learning outcomes (Daniel & Jordan, 2017; Jordan & Daniel, 2010).

Case-teachers who used a Reframed Design Thinking student learning strategy included an open situation that allowed for ambiguity and productive failure (Kapur & Bielaczyc, 2012). However, they did not seem to simply leave their students to discover their own learning; instead they seemed to heavily incorporate collaboration roles, norms, and interaction procedures to provide structure and facilitate group cohesion, consensus, and innovative learning outcomes.

Limitations

The study sample size of 16 teacher participants limits the generalizability of the findings. However, as an exploratory study most heavily focused on how a DTIP approach was perceived by individual teacher participants, the intention was not to generalize (Creswell, 2013; Tracy, 2013). On the other hand, the large number of observed cases (n=10) also made it difficult to provide extensive detail for each case-teacher (Yin, 1989). In addition, I was able to observe some case-teachers in less depth than others, which could result in a less detailed understanding of their views on the DTIP approach (Creswell, 2013; Tracy, 2013; Yin, 1989).

Some of the data were collected through self-report surveys and interviews, which can only be interpreted as the individual self-perception of the teacher participants (Weigold, Weigold, & Russell, 2013). However, my study was specifically interested in participant perceptions. Even so, I still sought to reduce this issue by aligning the self-report data with the observation data for the 10 case-teachers. I therefore consider the interpretation of the data from the case-teachers to be the most trustworthy. It is possible, though, since I am relying on my interpretation as the research observer, that my interpretation of teacher participants' beliefs toward the DTIP approach may be skewed or biased in some way (Creswell, 2013). To mitigate this, I used several qualitative validation strategies (Creswell, 2013).

Implications

It is rare to be given access to the instructional lesson approaches and implementation practices of teachers. The 16 teacher participants from this study provided one possible look into how a DTIP approach might be perceived by various K-14 STEM teachers. The DTIP approach was viewed as having potential and interest across teacher participants. The implemented instructional lessons were perceived by case-teachers to strengthen student knowledge, critical thinking and engagement, and provided some suggestion for fostering acceptance of ambiguity and developing agents of change.

The results suggest that teachers who positively perceive the DTIP approach as having value may attempt to integrate the approach within their lessons as a student learning strategy. Teachers who are interested in integrating a reframed strategy and who are also accustomed to a highly organized or controlled classroom environment may need to participate in the approach several times and/or view its implementation in another teacher's classroom before integrating it.

The study also provides evidence that the Design Disposition sub-scale may not provide valuable data for a study of such a small homogenous group. In addition, the Wicked Instructional Problems sub-scale provided some worthwhile data for interpretation, which suggests that continued exploration may yield promising results.

It may not be possible to create the graphic for a model that fully depicts the fluctuation and chaos inherent in the actual Design Thinking approach, but I suggest that the DTIP model more closely corresponds with how teachers develop instructional lessons than many popular Design Thinking models currently do. Using feedback provided by two case-teachers, the DTIP model can be revised to more clearly depict a representation of that chaos, if not the actual chaos that might make a graphic difficult to follow.

Lastly, this study provides an initial foundation for possible practices that can be used within workshops and professional development sessions to provide teachers with a creative approach to the development of instructional lessons.

Future Research

The findings from this study provide a foundation for integrating Design Thinking in education; however, much of that research is theoretical, which suggests there is still much to discover. Though Design Thinking was first developed in the engineering and design fields (Kimbell, 2011; Razzouk & Shute, 2012) and pairs well with the inquiry mindset of science (Elwood et al., 2016), there is an assumption that Design Thinking, at its heart, is simply a thought process. This implies it could have potential for other fields (Dorst, 2011). More importantly, because of the orientation of Design Thinking toward complex and wicked problems (Buchanan, 1992), it might be a valuable approach for more interdisciplinary styles of instruction. I, therefore, recommend more empirical research with teachers as an instructional lesson approach and with students across classroom contents.

Also, the DTIP approach seems to work best when it is iterative and fluctuating through the various stages, in whichever way best helps a group to understand and reframe the problem (Dorst, 2011). However, according to Dorst, the practices that designers use to foster reframing are not easy to describe or facilitate. More research into practical strategies for fostering reframing for educators would be valuable.

The Wicked Instructional Problems sub-scale demonstrated a moderate level of consistency, but it also demonstrated some contradictions. This suggests it may not have provided the most reliable measure of the construct. The sub-scale should be lengthened to include more items and the items should be made more concise. There is still a suggestion that teachers who view their instructional lesson approach as a wicked problem may find greater value in the DTIP approach. Therefore, it may be valuable to continue to explore and test a Wicked Instructional Problems sub-scale.

Though the DTIP professional development sessions were viewed as valuable by most teacher participants, the sessions were far from perfect. More research needs to be conducted on the types of strategies that will best support teachers towards innovative instructional lesson development through a DTIP approach. There is also a need for research into possible avenues for professional development differentiation strategies for novice teachers and for those more experienced in Design Thinking.

Lastly, though the study itself did not involve a social justice aspect, Design Thinking assumptions include an iterative process for connecting to a variety of stakeholder perspectives through empathy strategies (Brown & Wyatt, 2010), which could easily include aspects of social justice. Also, the RET programs, which are funded through NSF, have a vision towards growth in STEM fields for traditionally underserved populations. Therefore, the majority of the RET teacher participants in this study worked in schools with large Hispanic and Native American populations. RET programs might provide an avenue for further DTIP studies focused more specifically on leadership, inclusion, and social justice issues.

Conclusion

This study used a convergent parallel mixed-methods design to simultaneously conduct survey and multiple case study measures with STEM K-14 teachers (n=16) who participated in an RET summer program embedded with a DTIP approach to developing instructional lessons. The study was conducted in three phases and included five data sources. Together, they addressed four research questions regarding how the DTIP approach was perceived by teacher participants. Ten of the original teacher participants were selected for further study as cases. Data from the survey and multiple case study measures were integrated and then interpreted.

Findings indicated that all 16 teacher participants seemed to have found value in using a DTIP approach to developing their RET instructional lessons. Additionally, eight of the ten case-teachers chose to embed a Design Thinking student learning strategy into their RET instructional lessons even though there was no expectation from the RET program or the DTIP study to do so. Five of those case-teachers were employed by STEM-designated schools who usually expected them to incorporate some level of Design Thinking or engineering process practices in their curriculum, but three were employed by traditional public schools who had no Design Thinking expectations. Of those eight, five case-teachers integrated a Scaffolded Design Thinking student learning strategy and three case-teachers integrated a Reframed Design Thinking student learning strategy.

The Reframed Design Thinking strategy included thoughtful fostering of ambiguity through the design of the problem with explicit space for trial and error. Though Design Thinking could be likened to a minimally guided instructional approach (Kirschner et al., 2006), case-teachers who embedded the reframed strategy provided structured guidance through consistent question asking and collaboration techniques that involved explicit and continuous norming practices.

These three case-teachers also utilized public critique strategies to uncover possible misconceptions and foster creative solution paths. They seemed to understand that Design Thinking is not a simple or quick approach. They developed long complex units in which to incorporate the approach. Lou even mentioned an intention to think about how he could utilize a Design Thinking problem across all his curricular units so that his students could keep iterating throughout the year.

Though it can be difficult to quantify the level to which the teacher participants found value in the DTIP approach to developing innovative or creative learning experiences for their students, several individual case-teachers saw it as being a meaningful part of their RET summer program experience.

> *"That's what I really need everyone to know. This was very motivating for me and I thank you."* [Angelica P4, Post-Implementation Interview Transcripts]
>
> *"Understanding the fluidity and strength of Design Thinking is critical to shifting ways of engaging with the teaching and learning process*." [Leslie P9, PDSOE Item Responses]
>
> *"There were different things that resonated with me in the teacher part of what we did in our RET program. A big one was—from you was that diagram. I diagrammed off of that lesson what I wanted my school year to look like. That was powerful for me. I still keep referring back to it."* [Lou P10, Post-Implementation Interview Transcripts]

There is still much to uncover concerning the use of Design Thinking in education. However, this study provided response and observation data that demonstrated that the DTIP approach to developing instructional lessons was positively perceived by teacher participants. This study also provided practical strategies for professional development and learning design that seemed to embody Design Thinking assumptions, thereby moving the field forward.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

ASU Knowledge Enterprise Development

APPROVAL: MODIFICATION

Wilhelmina Savenye
Division of Educational Leadership and Innovation - Tempe
480/965-4963
Willi.Savenye@asu.edu
Dear Wilhelmina Savenye:

On 5/26/2017 the ASU IRB reviewed the following protocol:

Type of Review:	Modification
Title:	RET Design Thinking Study
Investigator:	Wilhelmina Savenye
IRB ID:	STUDY00004405
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• ConsentForm_RET_DT2017.pdf, Category: Consent Form; • RET_DT2017_instruments.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • ConsentForm_RET_DT2017_observation.pdf, Category: Consent Form; • HRP-503a-RET_DT2017_IRB_mod.docx, Category: IRB Protocol;

The IRB approved the modification.

When consent is appropriate, you must use final, watermarked versions available under the “Documents” tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

EXEMPTION GRANTED

Wilhelmina Savenye
Division of Educational Leadership and Innovation - Tempe
480/965-4963
Willi.Savenye@asu.edu

Dear Wilhelmina Savenye:

On 5/26/2016 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	RET Design Thinking Pilot
Investigator:	Wilhelmina Savenye
IRB ID:	STUDY00004405
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• ConsentForm_RET_DTpilot.pdf, Category: Consent Form; • RET_DT_Pilot_Documents.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • HRP-503a-RET_DTPilot_IRB.docx, Category: IRB Protocol;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (1) Educational settings, (2) Tests, surveys, interviews, or observation on 5/26/2016.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

APPENDIX B

DTIP STUDY INSTRUMENTS

Design Thinking Instructional Problem Survey (PRE)

This survey invites you to explore how you create instruction for your students. There are no right or wrong answers to the following questions. Your participation is voluntary and you may stop at any time. The information will not affect your participation in the summer program in any way.

Demographic Information							
Your Name:							
1. Gender (select one):	______ Female ______ Male						
2. Race/Ethnicity (select all that apply):	______ American Indian or Alaska Native ______ Asian ______ Black or African American ______ Hispanic or Latino ______ Native Hawaiian or Pacific Islander ______ White						
3. Age in years (circle one):	15-18	19-29	30-39	40-49	50-59	60+	
4. Years teaching K-14 (circle one):	1-3	4-6	7-9	10+			
5. Current school level you teach (circle one):	Elementary	Middle/Jr	High School	College			
6. Current STEM subject(s) you teach:							
7. Years teaching that STEM subject (circle one):	1-3	4-6	7-9	10+			
8. Your highest degree level (circle one):	BA	BS	MA	MS	MEd	EdD	PhD

A. To what extent do you perceive yourself as being a designer?					
Circle the level which best reflects your current beliefs:	not at all	very little	somewhat	very much	a great deal
9. I am comfortable exploring conflicting ideas.	1	2	3	4	5
10. I am comfortable deviating from established practices.	1	2	3	4	5
11. I am comfortable with occasional failures from trying out new approaches.	1	2	3	4	5
12. I am comfortable seeking ways to turn constraints into opportunities.	1	2	3	4	5
13. I am comfortable incorporating innovative technologies into my practices.	1	2	3	4	5

B. To what extent do you perceive creating instruction as being a complex design problem?					
Circle the level which best reflects your current beliefs:	not at all	very little	somewhat	very much	a great deal
14. I believe that the process of creating a new instructional unit is similar to the process of solving a complex problem.	1	2	3	4	5
15. I believe that the process of creating a new instructional unit involves interconnected variables that influence each other in unpredictable ways.	1	2	3	4	5
16. I believe that the process of creating a new instructional unit involves uncertain outcomes.	1	2	3	4	5
17. I believe that the process of creating a new instructional unit involves a diverse group of stakeholders who have differing perspectives and values regarding the instruction.	1	2	3	4	5

C. Instructional Design Sketch

18. Think about your typical process for creating a new instructional lesson. DRAW a sketch of the process by which you go about creating that lesson. There are no right or wrong ways to do this as long as it makes sense to you. Feel free to use this space in any way that best helps you visualize your process.

Design Thinking Instructional Problem Survey (POST)

This survey invites you to explore how you create instruction for your students. There are no right or wrong answers to the following questions. Your participation is voluntary and you may stop at any time.

Your Name:	
For confidentiality purposes, I will need to create a first-name pseudonym for you. It needs to seem like a real person's first name, but still somehow reflect you. What would you like it to be?	____ Pseudonym: ____________________ ____ I give you permission to choose for me. ____ You choose, but check it with me.

A. To what extent do you perceive yourself as being a designer?					
Circle the level which best reflects your current beliefs:	not at all	very little	somewhat	very much	a great deal
1. I am comfortable exploring conflicting ideas.	1	2	3	4	5
2. I am comfortable deviating from established practices.	1	2	3	4	5
3. I am comfortable with occasional failures from trying out new approaches.	1	2	3	4	5
4. I am comfortable seeking ways to turn constraints into opportunities.	1	2	3	4	5
5. I am comfortable incorporating innovative technologies into my practices.	1	2	3	4	5
B. To what extent do you perceive creating instruction as being a complex design problem?					
Circle the level which best reflects your current beliefs:	not at all	very little	somewhat	very much	a great deal
6. I believe that the process of creating a new instructional unit is similar to the process of solving a complex problem.	1	2	3	4	5
7. I believe that the process of creating a new instructional unit involves interconnected variables that influence each other in unpredictable ways.	1	2	3	4	5
8. I believe that the process of creating a new instructional unit involves uncertain outcomes.	1	2	3	4	5
9. I believe that the process of creating a new instructional unit involves a diverse group of stakeholders who have differing perspectives and values regarding the instruction.	1	2	3	4	5
C. To what extent do you perceive the creation of your RET instructional lesson plan to be influenced by the Design Thinking approach?					
Circle the level which best reflects your current beliefs:	not at all	very little	somewhat	very much	a great deal
10. I believe the "5 Whys" activity helped reframe my understanding of what I wanted my students to learn.	1	2	3	4	5
11. I believe interviewing or sharing with Young Scholars or other youth provided valuable perspective for my RET instructional lesson plan.	1	2	3	4	5
12. I believe the "Wrong Theory" activity helped me express what I value when I create instructional lessons for my students.	1	2	3	4	5
13. I believe the "Wrong Theory" activity led me to change some aspects of what I was initially planning for my instructional lesson plan.	1	2	3	4	5
14. I believe sketching activities helped me move forward with aspects of my instructional lesson plan.	1	2	3	4	5
15. I believe having access to colleagues for collaboration was valuable to the creation of my instructional lesson plan.	1	2	3	4	5

Circle the level which best reflects your current beliefs:	not at all	very little	somewhat	very much	a great deal
16. I believe having access to colleagues for critical feedback was valuable to the creation of my instructional plan.	1	2	3	4	5
17. I believe that participating in reflection was valuable to the creation of my instructional lesson plan.	1	2	3	4	5
18. I believe that my instructional lesson plan changed from when I first started thinking about it to now.	1	2	3	4	5
19. I believe I had adequate time to focus on the creation of my instructional lesson plan.	1	2	3	4	5
20. I believe the Design Thinking approach helped me think about ways to critically engage my students through the lesson I create.	1	2	3	4	5

21. What experiences from the RET summer program do you believe influenced the development of your **instructional lesson plan**?

22. What aspects of the Design Thinking approach did you find to be the most **valuable** as you created your instructional lesson plan during the RET summer program? Why were they valuable?

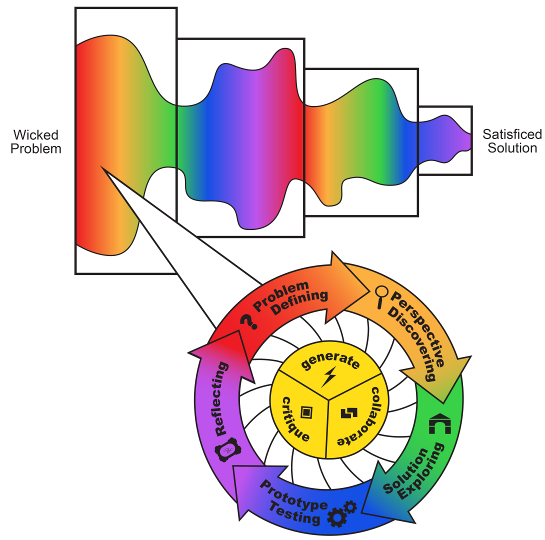
23. What aspects of the Design Thinking approach did you find to be the most **challenging** as you created your instructional unit during the RET summer program? Why were they challenging?

24. In what ways, if any, did the rainbow colored Design Thinking model help you understand the Design Thinking process?

D. Instructional Design Sketch

25. Think specifically about the process you went through to create an instructional lesson plan during this summer RET program. Create a sketch of the **PROCESS** by which you went about creating that lesson—NOT a sketch of what you will be teaching your students, but how you went about making decisions as to what should be in that lesson. There are no right or wrong ways to do this as long as it makes sense to you. Feel free to use this space in any way that best helps you visualize your design process.

DTIP SURVEY FOLLOW-UP QUESTION



This is the Design Thinking model that was used to help us think about the creation of an instructional lesson as a complex or wicked problem in need of a creative solution. We (1) used 5 Whys to begin defining our problem frame, (2) interviewed a young person and shared with young scholars to gain perspective, (3) explored our solution ideas by thinking of the Wrong Theory way of creating instruction, as well as initial brainstorming and sketching, (4) shared a prototype of our instructional solution with fellow teachers, and (5) reflected formally and informally with colleagues.

QUESTION: Do you feel that participating in an RET program that used this model as a guide for creating your instructional lesson provided added value? Why or why not?

Your Name: ____

Use the space below to write your explanation concerning the value of this model. Use the back as needed.

APPENDIX C

DESIGN THINKING OVERVIEW WORKSHOP MATERIALS

Design Thinking Team Charter

Team Name: ____

Members of the Team:	Team Role:
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________

We plan to respectfully **communicate** our thoughts by using the following rules:

We plan to ensure that all members of the team **collaborate** by using the following rules:

We find **critical feedback** to be the most useful when it is given in the following ways:

We plan to use the following question to frame our primary problem:

— Design Thinking Workshop —

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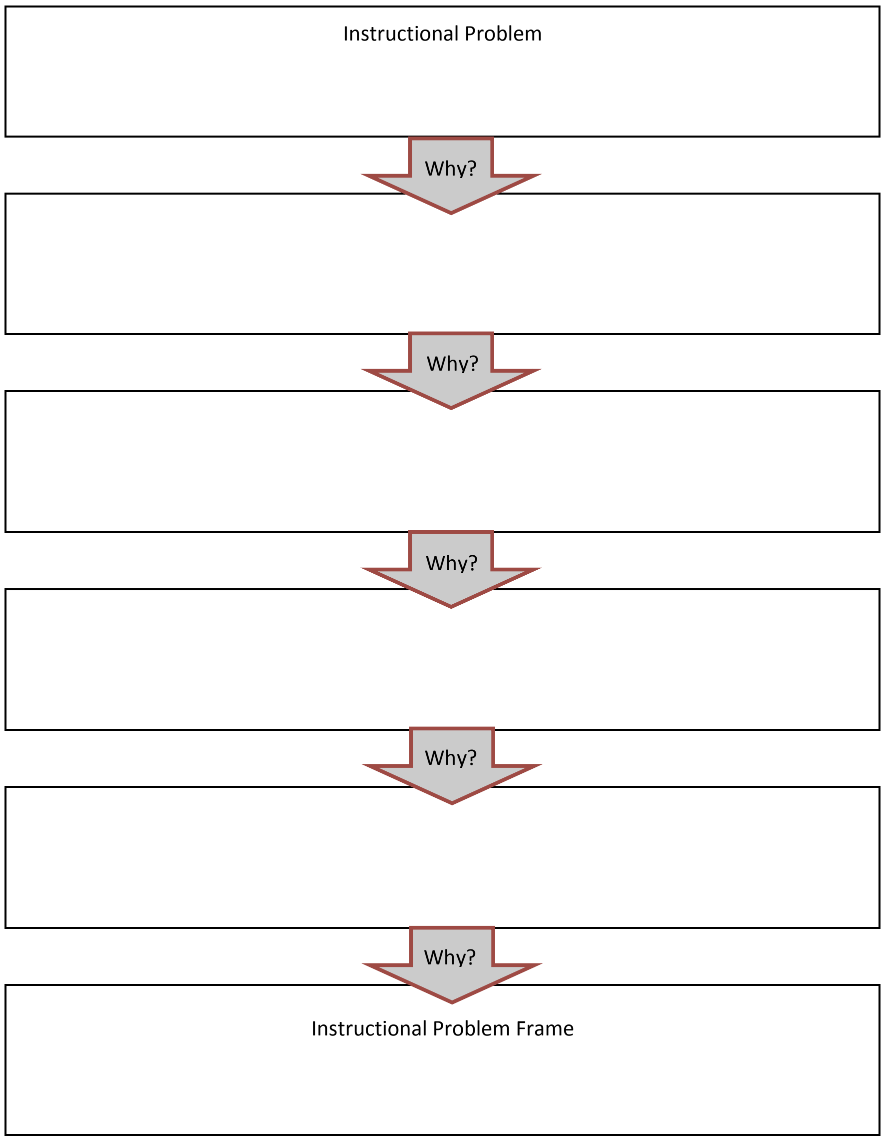
APPENDIX D

DTIP PROFESSIONAL DEVELOPMENT SESSIONS MATERIALS

5 Whys Root Cause Analysis

DTIP: Problem Defining

Your Name: ______________________________________



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Design Thinking Instructional Problem Model

Interviewing for Perspective

DTIP: Perspective Discovering

Directions: Think about the typical student in your classroom or the student to whom you most want your instruction to connect. For this activity, interview someone who you believe to be similar in age, background, and motivations as those students for whom you are designing instruction. This could be a family member, neighbor, or any other youth to whom you have access.

Your Name: ____________________________________

1. First name of your interviewee and how this person is connected to you:

   ____

2. Describe how you intend to explain your problem frame to your interviewee in order to help them understand what you are trying to do and why you want their help:

3. Write three (3) open-ended questions that you intend to ask during your interview. Try to get your interviewee to discuss their past experiences, frustrations, things that might motivate them to learn, or what they would love to experience as part of learning if they were participating in your lesson.

4. Describe the results of your interview. What feedback did you receive?

5. Think about the interview feedback, your problem frame, and the Wrong Theory activity that we did (demonstrating what not to do). On the back of this paper, or a separate sheet of paper, brainstorm some elements/strategies/practices that you think you would like to include when you create your instructional unit as a result of this RET program.

Wrong Theory

DTIP: Solution Exploring

Your Name: ____________________________________

1. List the primary stakeholders who will participate in the instruction you create as a result of this summer RET program and/or who have some expectations regarding the instruction (within your classroom, school, community, or this summer program).

2. Based on your problem frame and the needs of the above stakeholders, what do you think should be included in the instruction you design as a result of this RET summer program? (This could change.)

3. Thinking of those same stakeholders, what kind of constraints do you have to consider?

4. Think back over the problem frame, needs, and constraints. NOW VIOLATE THESE! Your task is to come up with the worst possible design—one that violates the constraints and does not consider needs.

   Don't focus on trying to get the best idea. Instead be open and generative. Suspend judgment: don't discount or eliminate any ideas. Think about how others have solved the problem and turn it on its head. Try pretending you are the student. Sketch ideas (stick figures are great). Try telling a story to get ideas flowing. Consider using "What if . . . ." What if learners were all on a 3-month space voyage and the instruction had to keep them from getting bored? What if the learners were all color blind?

   Use the back of this paper to sketch/draft your WRONG THEORY lesson. Be ready to share your design ideas and defend why it is the absolute worst.

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Design Thinking Instructional Problem Model
Wrong Theory (Svihla & Reeve, 2016)

Design Thinking RET Study

Reflection Questions

Directions: Please incorporate the following questions into your reflection instrument on Thursdays.

Second Week

1. How would you currently describe the problem frame for the RET instructional lesson you are attempting to create? (What is it you believe your students need to learn?)

Third Week

1. Regarding your RET instructional lesson plan, in what ways has your problem frame (what you want your students to learn) changed from when you first began thinking about it?

2. What aspect of yesterday's RET sharing lunch session did you find the most valuable for helping guide your creation of your instructional lesson plan?

Fourth Week

1. To the best of your ability, describe the RET instructional lesson you developed in its current form.

2. Describe any challenges or issues you experienced as you created your RET instructional lesson.

3. What was your process for moving forward passed those challenges?

APPENDIX E

EXCEL AND NVIVO CODEBOOKS

Excel Codebook (Working)

Implementation Observation Field Notes Data Source

Abbrev	Code Name	Definition
		Collaboration Strategies
C1	Grouping	Promotes collaboration by having students work together in a group of two or more to produce something. Grouping does not always result in collaboration.
C2	Norming	Promotes collaboration by creating an opportunity for students to define their goal and develop agreed upon group norms.
C3	Cooperation	Promotes collaboration by developing roles and breaking aspects of the larger goal into smaller parts to be individually attained. The purpose of cooperation is for efficiency not innovation.
C4	Collaboration	promotes students working together simultaneously toward a shared goal decided upon by the group. Though cooperation may happen, any member of the group should be equally aware of outcomes and decisions being made.
		Expectation Strategies
E1	Learning Expectations	Makes the learning expectations and objectives clear, often through operational definitions (making measurable). Reminders that connect back to these expectations. This could be spoken, written on the board, or given in the form of a rubric or checklist. It does not really provide a way to learn the content, but instead helps students understand what grades they will earn based on certain criteria, like the best way to format a research poster. Getting out notebooks, being asked to take notes, being asked to read slowly or actively.
E2	Behavior Expectations	Makes the behavioral and social classroom expectation explicitly clear. Demonstrates what type of behavior students should exhibit, and is obvious students are aware and/or are reminded of consequences for not meeting those expectations. This could be spoken, hung as posters in the room, or given in syllabai or student contracts. Could take the form of verbal reminders of how students should behave, or be consequences of not following those reminders.

Attention Focusing Strategies		
AF1	Time on Task	Helps students to know how much time they have in order to complete a task. This could be telling them how much time they have to work on something, how much time is left, displaying a timer, a timer going off, or anything else that suggests you will have to move on when it stops (such as music playing in the background).
AF2	Grabbing Attention	Helps students to know when to stop what they are doing and focus on the instructor/speaker.

Learning Strategies		
L1	Prior Knowledge	Connects the new content to the student through knowledge they are likely to have, or have recently learned.
L2	Question Asking as Learning Facilitation	Asks open-ended or close-ended questions for which there can be several possible answers in order to promote the students' own thought process. Though some answers may be better than others, the point of the strategy is to break down the learning to help students move forward in their understanding. It could be part of scaffolding. Does the question being asked help the teacher or the student (if the student, then its purpose is for learning).
L3	Direct Instruction	Requires the students to take notes on content knowledge provided directly from the teacher, often in a lecture style. It must have to do with learning objectives, but is often viewed as the teacher sharing information. Could include content facts, process information, examples of how used, anecdotes, or hypothetical situation. Displaying visuals, though more engaging, is also direct instruction, if a video it moves into L9 motivation. It only becomes something else if the teacher has students interact with concepts in a way other than taking notes.
L4	Hands-on	Requires the students to apply concepts to a real-world situation, in which they demonstrate their knowledge through doing. Though the teacher may scaffold or ask questions to help guide the doing, students often make their own decisions as to how to move forward (which could include failure).

L5	Critical Thinking	Asking students to make their thoughts observable in the moment, in order to help them analyze or synthesize complex ideas. Often involves writing: summary, short answer, essay, brainstorming, graphic organizers, calculations, graphs, tables. It can also be peer shared through "think-pair-share," sharing aloud with other groups or the whole class, or being called on to share. Not just taking notes. Not reflection unless it involves evaluation on some level. Not public critique unless the audience is asked to provide evaluation in return.
L6	Modeling	Walks students through the process of the learning objective, in order for them to mimic or follow along. This could also include using vocabulary terms in speech to model how those terms are used, and reinforce students using them.
L7	Differentiation	allows students to work at different levels of ability or speed based on their individual needs. Different students in the class might be working on different concepts at different times depending upon needs.
L8	Scaffolding	Breaks complex concepts into smaller pieces, building more complex concepts on top of basic concepts until the student can achieve the whole thing on their own. Could do this for the whole class, or for individuals as an aspect of differentiation.
L9	Motivation	Utilizes strategies that raise the engagement of students, therefore heightern learning indirectly. Selecting topics that interest specific students, using games, or videos. Making students feel heard and part of the classroom so they want to be there. Connecting learning to real-world problems that resonate with students. Sharing with them the purpose of the learning, and ensuring it connects to them somehow.
	Assessment Strategies	
ASM1	Question Asking as Check for Understanding	Formative. Asks close-ended questions to determine the level to which students are remembering or understanding the instruction. It is usually clear that the teacher has a specific correct answer in mind. Might help clarify communication. Does the question being asked help the teacher or the student (if the teacher, then its purpose is for assessment).

ASM2	Teacher Feedback	Formative, as long as provided in progress, and students can still revise. Written or spoken feedback concerning the level to which they are meeting learning and/or behavior expectations, usually from the teacher. This could involve a rubric or checklist, or pointing to a poster of expectations. Often involves approval, disapproval, or sense of validation.
ASM3	Public Critique	Formative. A discussion between the student and someone else to evaluate the level to which the product has met its purpose or as a way to explore alternative possibilities. Is often paired with reflection strategies to facilitate innovative revision.
ASM4	Test	Is summative in nature, given at a mid-point or end of learning to determine what aspect of the learning has been retained. Usually multiple-choice, true/false, fill-in-the-blank, or short answer--with right and wrong answers.
ASM5	Product	Is summative in nature, as a demonstration of level of learning towards a given objective. Though specific criteria should be given, individual products can vary widely. This could be a summary, an essay, a poster, a presentation, a journal, etc.--with levels of mastery demonstrated.
ASM6	Reflection	Can be both formative and summative, depending on how facilitated. An internal process in which students are asked to think about what went well and what could have gone better. Sometimes made explicit, through journaling, goal setting, and revision. Requires simultaneous critical thinking.
ASM7	Progress Check	A process of observing student actions and listening to student conversations, teacher makes decisions as to whether they might need more time, are on task, or need learning support.
		Design Thinking Practices
DTP0	Design Language	The instructor uses the word design, designer, or engineer, to model language for students.
DTP1	Problem	The instructor develops the learning in such a way that it refers to a larger real-life problem.
DTP2	Perspectives	The instructor provides an opportunity for students to think about other people who might have some perspective on the problem from their point of view.

DTP3	Ambiguity	The instructor uses a practice that leaves aspects of the learning open. It is clear that there is more than one solution and there isn't a perfect right or wrong answer. The instructor suggests that failure is okay and is a useful part of learning.
DTP4	Sketch	The instructor provides students with an opportunity to sketch.
DTP5	Test	The instructor provides students with an opportunity to try out some aspect of their design, to gather information on it, and make sense of that data in some way.
DTP6	Reflection	The instructor asks students to think about the learning, and provides space for students to write down or share their reflections, which then become the motivation for revision and the next iteration.
DTP7	Collaboration	The instructor provides grouping and norming practices for students to work togther toward a shared goal.
DTP8	Critique	The instructor provides opportunities for students to receive critical feedback evaluating their work in a public setting.
	Student Engagement	
SE1	Fully engaged (1)	Students are focused on the learning, and are demonstrating critical thinking, participation, and excitement. Asking their own questions, answering in unique ways, helping others with learning, sharing their thoughts.
SE2	Somewhat engaged (0)	Students are following along with the learning, but perhaps they are doing so mechanically, without critical thinking or depth. They may be participating, but perhaps in a way unintended by the teacher. Maybe they aren't a distraction, but aren't really learning either. Answer questions in short phrases that are expected. Follow-through on expected procedures.
SE3	Off-Task (-1)	Students doing something other than the learning at hand: talking, moving, sleeping, technology, etc. Purposefully bringing up topics to get class off-topic. Not participating in learning.

NVivo Codebook
General Teaching Practices
(Implementation Observation Field Notes Data Source)

Nodes	Description	Files	References
General Teaching Practices Category		10	1156
Assessment		10	238
ASM1 Understanding Check	Asks close-ended questions to determine the level to which students are remembering or understanding the instruction. It is usually clear that the teacher has a specific correct answer in mind. Might also be used to help the teacher clarify communication. Does it help the teacher or the student (if the teacher, then its purpose is for assessment). A teacher can be simultaneously assessing understanding of expectations and learning while the act of asking the question aloud reinforces learning expectations.	10	116
ASM2 Teacher Feedback	Formative, as long as provided in progress, and students can still revise. Written or spoken feedback concerning the level to which they are meeting learning and/or behavior expectations, usually from the teacher. This could involve a rubric or checklist, or pointing to a poster of expectations. Often involves approval, disapproval, or sense of validation.	8	51
ASM3 Test	Is summative in nature, given at a mid-point or end of learning to determine what aspect of the learning has been retained. Usually multiple-choice, true/false, fill-in-the-blank, or short answer--with right and wrong answers.	1	2
ASM4 Product	Is summative in nature, as a demonstration of level of learning towards a given objective. Though specific criteria should be given, individual products can vary widely. This could be a summary, an essay, a poster, a presentation, a journal, etc.--with levels of mastery demonstrated.	5	5
ASM5 Reflection	Can be both formative and summative, depending on how facilitated. An internal process in which students are asked to think about what went well and what could have gone better. Sometimes made explicit, through journaling, goal setting, and revision. Requires simultaneous critical thinking.	6	11

Nodes	Description	Files	References
ASM6 Progress Check	Through the process of observing student actions and listening in on student conversations, teacher makes decisions as to whether they might need more time, are on task, or need learning support. Could include simply walking around to determine progress, or other checks like “thumbs up,” raising hands, verbally asking.	9	53
Attention-Focusing		9	104
AF1 Time on Task	Helps students to know how much time they have in order to complete a task. This could be telling them how much time they have to work on something, how much time is left, displaying a timer, a timer going off, or anything else that suggests you will have to move on when it stops (such as music playing in the background).	9	49
AF2 Grab Attention	Helps students to know when to stop what they are doing and focus on the instructor/speaker.	8	55
Collaboration		10	83
C1 Grouping	Promotes collaboration by having students work together in a group of two or more to produce something. Grouping does not always result in collaboration.	10	22
C2 Norming	Promotes collaboration by creating an opportunity for students to define their goal and develop agreed upon group norms. Includes developing roles within the group and how those roles will be enacted.	6	27
C3 Cooperation	Promotes collaboration by breaking aspects of the larger goal into smaller parts to be individually attained. The purpose is often for efficiency not innovation.	8	17
C4 Collaboration	promotes students working together toward a shared goal decided upon by the group. Though cooperation may happen, any member of the group should be equally aware of outcomes and decisions being made.	5	17

Nodes	Description	Files	References
Expectations		10	287
E1 Learning Expectations	Makes the learning expectations and objectives clear, through operational definitions (measurable). Reminders that connect back to these expectations. Could be spoken, written on the board, or given in as a rubric or checklist. It does not provide a way to learn the content, but instead helps students understand what grades they will earn based on certain criteria, like the best way to format a research poster.	10	158
E2 Behavior Expectations	Makes the behavioral and social classroom expectation explicitly clear. Demonstrates what type of behavior students should exhibit, and is obvious students are aware and/or are reminded of consequences for not meeting those expectations. This could be spoken, hung as posters in the room, or given in syllabi or student contracts. Could take the form of verbal reminders of how students should behave, or be consequences of not following those reminders.	9	129
Learning		10	444
L1 Prior Knowledge	Connects the new content to the student through knowledge they are likely to have, or have recently learned.	7	18
L2 Question Asking	Asks open-ended or close-ended questions for which there can be several possible answers in order to promote the students' own thought process. Though some answers may be better than others, the point of the strategy is to break down the learning to help students move forward in their understanding. It could be part of scaffolding. Does the question being asked help the teacher or the student (if the student, then its purpose is for learning).	9	76
L3 Direct Instruction	Requires the students to take notes on content knowledge provided directly from the teacher, often in a lecture style. It must have to do with learning objectives, but is often viewed as the teacher sharing information. Could include content facts, process information, examples of how used, anecdotes, or hypothetical situation.	10	89

Nodes	Description	Files	References
L4 Hands-On	Requires the students to apply concepts to a real-world situation, in which they demonstrate their knowledge through doing. Though the teacher may scaffold or ask questions to help guide the doing, students often make their own decisions as to how to move forward (which could include failure).	7	63
L5 Summarizing	Any strategy that has students make their thoughts observable through writing, in order to help them analyze or synthesize ideas. It often took the form of a written short answer, essay, reflection, or graphic organizer	8	40
L6 Modeling	Walks students through the actual process of some aspect of the learning objective, in order for them to mimic or follow along. This could also include using vocabulary terms in speech to model how those terms are used, and reinforce students using them.	7	49
L7 Differentiation	allows students to work at different levels of ability or speed based on their individual needs. Different students in the class might be working on different concepts at different times depending upon needs.	6	16
L8 Scaffolding	Breaks complex concepts into smaller pieces, building more complex concepts on top of basic concepts until the student can achieve the whole thing on their own. Could do this for the whole class, or for individuals as an aspect of differentiation.	7	27
L9 Motivation	Utilizes strategies that raise the engagement of students, heightens learning indirectly. Selecting topics that interest specific students, using games, or videos. Making students feel heard and part of the classroom. Connecting learning to real-world problems that resonate with students. Sharing the purpose of the learning, and ensuring it connects to them somehow.	10	41
L10 Share Aloud	Strategies require students to make their thoughts verbally observable. Though these strategies could also be used as an assessment understanding check, on some level the teacher seems to be purposefully providing an environment in which students can learn from each other by sharing their ideas aloud, peer to peer, group to group, or peer to class. If it is sharing just with the teacher then it is assessment.	6	25

NVivo Codebook

Design Thinking Practices

(Implementation Observation Field Notes Data Source)

Nodes	Description	Files	References
Design Thinking Practices Category		10	268
DTP0 Design Language	The instructor uses the word design terms to model language for students.	9	26
DTP01 Problem	The instructor develops the learning in such a way that it refers to a larger real-life problem.	10	34
DTP02 Perspectives	The instructor provides an opportunity for students to think about other people who might have some perspective on the problem from their point of view.	6	12
DTP03 Ambiguity	The instructor uses a practice that leaves aspects of the learning open. The instructor makes it clear that there is more than one solution and there isn't a perfect right or wrong answer. The instructor suggests that failure is okay and is a useful part of learning.	9	46
DTP04 Explore	The instructor provides opportunities for students to consider multiple ideas before selecting just one. This could involve brainstorming, gallery walks, sharing out. Anything to provide alternative ideas that might build upon or change the original idea.	8	30
DTP05 Test	The instructor provides students with an opportunity to try out some aspect of their design, to gather information on it, and make sense of that data in some way.	6	34
DTP06 Reflection	The instructor asks students to think about the learning, and provides space for students to write/share reflections, which then foster motivation for revision and the next iteration.	7	23
DTP07 Collaboration	The instructor provides grouping and norming practices for students to work together toward a shared goal.	9	32
DTP08 Critique	The instructor provides opportunities for students to receive critical feedback evaluating their work in a public setting.	3	4
DTP09 Sketch	The instructor provides students with an opportunity to sketch ideas as a way to explore, prototype, or even do initial testing.	4	21
DTP10 Constraints	The instructor ensures that some element of the problem involves real-world constraints that students will need to grapple with as part of understanding the problem.	2	6

NVivo Codebook

Student Engagement Levels

(Implementation Observation Field Notes Data Source)

Nodes	Description	Files	References
Student Engagement Category		10	583
SE-1 Weak Engagement	Student is talking, moving, sleeping, using technology. If students are moving around, singing, talking, etc. BUT they are critically thinking and/or applying learning as they do so, that is still Strong Engagement. It is only weak, if these things become a distraction and/or move them away from the learning.	10	115
SE0 Moderate Engagement	Students are following along with the learning, but perhaps they are doing so mechanically, without critical thinking or depth. Taking notes, following directions to move from place to place, listening, nodding, answering close-ended questions, raising hands—participation, but only on the surface level.	10	248
SE1 Strong Engagement	Students are focused on the learning, and are demonstrating critical thinking, participation, and excitement. There is a depth to what they are doing.	10	220

APPENDIX F

ADDITIONAL CASE-TEACHER CONTEXT TABLES

Table 3.15
Frequencies of Teaching Characteristics by Group

Teaching Characteristics	All Teacher Participants (n=16) n	%	Case-teachers (n=10) n	%
Years Teaching K-14				
1-3	4	25	3	30
4-6	6	38	3	30
10+	6	38	4	40
School Level				
Elementary School	5	31	3	30
Middle/Jr High School	6	38	4	40
High School	3	19	1	10
Community College	2	13	2	20
STEM Subject				
Biology/Environmental Biology	2	13	1	10
Chemistry	1	6	1	10
Climatology	1	6	1	10
Physics	1	6	0	0
Science (general)	8	50	6	60
Non-Response	3	19	1	10
Years Teaching STEM				
1-3	6	38	4	40
4-6	5	31	3	30
10+	3	19	2	20
Non-Response	2	13	1	10
Highest Degree Earned				
BA/BS	7	44	3	30
MA/MS	8	50	6	60
EdD/PhD	1	6	1	10

Note. Several teacher participants taught more than one specific STEM subject area. For this study, the subject area they listed first was designated their primary subject area and was the only one utilized in the data analysis. STEM = Science, Technology, Engineering, and Math subject areas. BA/BS = Bachelor of Arts and Bachelor of Sciences; MA/MS = Master of Arts and Master of Sciences; EdD/PhD = Doctorate of Education and Doctorate of Philosophy.

Table 3.16
Frequencies of General Teaching Practices as Observed across Case-teachers

Sub-Category	Sub-Category Definition	Codes	No. of Case-teachers (n=10)	No. of Codes	Total No. (%)
Learning	Any practice which develops engagement through critical thinking or learning of concepts to a level pre-determined by the teacher.	Direct Instruction	10	89	451 (39.0)
		Question Asking	9	76	
		Hands-On	7	63	
		Modeling	7	49	
		Motivating	10	41	
		Summarizing	8	40	
		Scaffolding	7	27	
		Share Aloud	6	25	
		Prior Knowledge	7	18	
		Differentiation	6	16	
Expectations	Instructions that support student learning or behavior, but do not actually provide learning.	Learning	10	158	287 (24.8)
		Behavior	9	129	
Assessment	A method by which teachers determine the level to which students are progressing.	Understanding Check	10	116	238 (20.6)
		Progress Check	9	53	
		Teacher Feedback	8	51	
		Reflection	6	11	
		Product	5	5	
		Test	1	2	
Attention-Focusing	A practice used by teachers to guide on-task behavior.	Grab Attention	8	55	104 (9.0)
		Time on Task	9	49	
Collaboration	A method which has students work in groups to varying degrees.	Norming	8	27	83 (7.2)
		Grouping	10	22	
		Cooperation	6	17	
		Collaboration	5	17	

Note. The data for this frequency table were compiled from RET instructional lesson implementation observation field notes using open coding (Creswell, 2013; Tracy, 2013) and the constant comparative method (Charmaz, 1996). Some references were coded as more than one General Teaching Practice.

Table 3.17
Frequencies of the *Learning* General Teaching Practice by Case-teacher

Case-teacher	DI	QA	HO	MOD	MOT	SUM	SCAF	SA	PK	DIF	Total
Colin (P1)	3	10	3	4	5	4	4	3	7	3	46
Evan (P2)	14	9	0	0	12	5	1	6	3	0	50
Claire (P3)	9	7	8	14	3	8	12	6	0	4	71
Angelica (P4)	3	14	9	0	1	3	6	2	1	6	45
Thad (P5)	23	0	0	3	7	0	1	0	2	0	36
Sam (P6)	12	1	13	0	1	0	0	0	1	1	30
Ben (P7)	3	8	7	12	1	5	2	4	1	1	44
Zane (P8)	10	4	7	6	1	1	0	0	0	1	30
Leslie (P9)	9	19	0	6	9	12	1	4	0	0	60
Lou (P10)	3	4	16	4	1	2	0	0	3	0	33

Note. The learning sub-category codes are abbreviated as follows: Direct Instruction (DI), Question Asking (QA), Hands-On (HO), Modeling (MOD), Motivating (MOT), Summarizing (SUM), Scaffolding (SCAF), Share Aloud (SA), Prior Knowledge (PK), Differentiation (DIF).

Table 3.18
Frequencies of the *Expectations* General Teaching Practice by Case-teacher

Case-teacher	Grade Level	Learning (+)	Behavior (-)	Difference
Colin (P1)	4th	10	16	-6
Evan (P2)	11th-12th	16	14	2
Claire (P3)	6th	24	27	-3
Angelica (P4)	7th	37	18	19
Thad (P5)	college	11	0	11
Sam (P6)	college	12	2	10
Ben (P7)	8th	11	19	-8
Zane (P8)	8th	10	6	4
Leslie (P9)	8th	11	12	-1
Lou (P10)	4th	16	15	1

Note. Learning expectations were given a (+) designation and behavior expectations were given a (-) designation. These designations do not suggest one is positive while the other is negative. Instead they were utilized to better visualize which type of expectations a case-teacher tended to lean toward and how heavily.

Table 3.19
Frequencies of the *Assessment* General Teaching Practice by Case-teacher

Case-teacher	Understand Check	Progress Check	Teacher Feedback	Reflect	Product	Test	Total
Colin (P1)	18	3	8	1	1	0	31
Evan (P2)	9	3	8	0	1	0	21
Claire (P3)	21	9	3	3	1	0	37
Angelica (P4)	22	14	10	1	0	0	47
Thad (P5)	15	0	5	0	1	2	23
Sam (P6)	3	4	0	0	1	0	8
Ben (P7)	14	3	5	3	0	0	25
Zane (P8)	2	7	3	0	0	0	12
Leslie (P9)	10	4	0	1	0	0	15
Lou (P10)	2	6	9	2	0	0	19

Note. These findings are based on the observations of these ten case participants as they implemented certain practices during a specific period(s) and day, and should in no way be taken as a summation of all of the practices that they ever can or will use within a lesson or as teachers.

Table 3.20
Frequencies of the *Attention-Focusing* General Teaching Practice by Case-teacher

Case-teacher	Time on Task	Grabbing Attention	Total
Colin (P1)	7	11	18
Evan (P2)	6	3	9
Claire (P3)	7	15	22
Angelica (P4)	18	10	28
Thad (P5)	0	0	0
Sam (P6)	1	0	1
Ben (P7)	2	5	7
Zane (P8)	1	2	3
Leslie (P9)	3	1	4
Lou (P10)	4	8	12

Table 3.21

Frequencies of the *Collaboration* General Teaching Practice by Case-teacher Collaboration Type

Case-teacher	Grouping	Norming	Cooperation	Collaboratio n	Total
		Norming/Collaboration Focused			
Colin (P1)	1	3	2	4	10
Angelica (P4)	3	13	5	4	25
Lou (P10)	1	7	0	6	14
		Group/Norming/Collaboration Focused			
Claire (P3)	7	2	1	2	12
		Cooperation Focused			
Evan (P2)	2	0	2	0	4
Ben (P7)	1	1	3	0	5
Zane (P8)	1	0	1	0	2
Leslie (P9)	2	0	2	0	4
		Group Focused			
Thad (P5)	1	0	0	0	1
Sam (P6)	3	1	1	1	6

Note. Case-teachers were organized into sub-category collaboration types (norming/collaboration focused, group/norming/collaboration focused, cooperation focused, or group focused) by determining which collaboration codes were most often observed in the RET instructional lesson implementation field notes. RET = Research Experience for Teachers.

APPENDIX G

CASE-TEACHER VIGNETTES

Case-teacher Vignettes

Creswell (2013) suggested that beginning a case study narrative with a vignette allows the reader to "develop a vicarious experience" (p. 236) with the material. I have therefore developed case-teacher vignettes that integrate *in vivo* terms quoted directly from case-teacher background interview transcripts (Tracy, 2013) with other data extracted from the pre-program DTIP survey and implementation observation field notes. Pseudonyms, which were self-selected by the case-teachers, are used throughout. In addition, each vignette was sent to individual case-teachers for feedback and revision. In order to provide a consistent organization, the vignettes are arranged chronologically by their participant number, in keeping with how they are represented in the data tables.

Colin: case-teacher 1. Colin was from the Midwest and began his university career by exploring environmental studies. However, a change in university programing led him to education. He quickly realized that high school education was not a good fit for him, but he enjoyed working with people and studying human development. This prompted him to declare Early Childhood and Elementary Education as his major.

He began his fourth year of teaching as a fourth-grade teacher at the Southwest STEM Academy. He had 28 students, who were mostly Hispanic with approximately an even split between girls and boys. His classroom had a reading nook in one corner and a white board, a projector screen, a wall of cabinetry, and a desk with computers in the far back corner. There were long rectangular tables with small chairs all around. Each table had potted plastic flowers on them and boxes filled with markers and other classroom supplies. The walls were filled with world and state maps, super hero posters, and motivational sayings. He had a large poster outlining behavior expectations with the word SLANT: Sit up, Listen, Ask questions, Nod head, Track the teacher. He had this class all day except when they went to special extension activities such as art. He was expected to teach his students all the core subject areas including language arts (reading and writing), math, science, history, and geography.

He found the environment at his school to be professional with an administration that supported collaboration and encouraged teachers to step outside of traditional methods. He felt his administration focused on authentic assessment that showcased students' critical thinking abilities. Because students actively chose to attend this STEM-focused school, Colin saw an excitement in his students that was encouraged by his administration. He believed the vision of the school was to more actively put the power into the hands of the students. Colin believed education should be about encouraging an environment in which the students' decisions and voices mattered. His focus in the classroom was to develop a personalized learning environment in which he spent the majority of his time working with students in small groups or one-on-one with individual students.

Additionally, at his school, he primarily saw people using Design Thinking as an event that might last a week or a day, but was specifically about building something. He felt Design Thinking, as used at his school, might include collecting data, but that aspect was often rushed or incomplete. He wondered if Design Thinking could be implemented in a more meaningful way:

> "I'm wondering if the error on our part for rolling out this idea of Design Thinking as a process that our students go through rather than a process we use when lesson planning is a really key piece to the rollout. . . . I'm having to go through the

Design Thinking process in planning versus the students taking each of the steps on their own. So I'm just grappling with that, and hoping I can find, by the end of this program, at least some closure to that thought."

He saw himself as a life long learner who was drawn to the RET experience for the opportunity to participate in a professional development experience that was more about working pedagogically with innovative science content than what he typically classified as "training."

Colin developed a month long unit in which students would learn about the engineering career field, what the purpose of that field is, and specifically what biogeotechnical engineers do. As part of this unit, students will identify the societal impact of engineers, scientists, and innovators, and Colin will describe examples of how the initial experiments leading to those inventions did not always work or may have resulted in unintended outcomes. Colin will then have his students work in learning clubs to determine the appropriate location for a concrete dam, how it should be built to best meet the needs of all the community stakeholders, and construct a scale prototype.

Evan: case-teacher 2. Evan knew he liked supporting his community and so initially contemplated being either a police officer or a teacher. However, during his junior year of high school he participated in a police ride-along and realized that it just was not for him. In comparison, that same year he experienced learning from a teacher that integrated concepts so well that students were not even aware they were learning. He therefore learned to see teaching as a way to give back to the community, and as "a lot of fun."

He began his second year as a teacher at the same traditional public high school he attended as a student. At this school, he taught four sections of Environmental Biology, in which his largest class had 32 students who were primarily white. He actually taught across the hall from the same teacher who originally inspired him to teach, and found it a bit strange to call her by her first name. The school itself was a traditional high school in a relatively affluent community with little diversity. He primarily had juniors and seniors who took his class to avoid math-intensive sciences like chemistry and physics. However, he still had to meet the needs of students who were truly interested in the course while managing to engage students who viewed the course as their third required science credit. He felt like it was his job to wake them up from their low expectations.

Evan recognized that there are challenges to teaching, but excitedly believed he would choose teaching over again many times. He was bright-eyed about the possibilities. He felt that his school administration encouraged teachers to collaborate with other teachers. However, the only time provided for collaboration was during the professional learning communities, which only took place on half-days, once a month. It therefore rarely happened. The teachers located nearby did share and brainstorm together, but only in an informal in-the-moment way, nothing fully structured. As a novice teacher, he would have preferred a bit more structure; not necessarily with a full team, but at least one person asking him to outline his progress and share his thoughts—so there would be some consistency.

Evan was certified to teach biology, but ended up teaching environmental biology which had a different focus, particularly in the area of sustainability. He had no initial background knowledge of the content for this course. The key question he consistently asked himself was "How is this concept important for the students to know?" He would put himself in the role of the student and ask himself why a student would ever need to know this. What was its relevance. This focus led him to situate each new learning concept in real-world events through news clips or online articles.

He felt that his administration provided him with full rein over the curriculum, which he saw as good and bad. He was the only one teaching the course, which gave him complete freedom over the schedule and content. However, explicit guidelines as to what should be taught were not in evidence, and all of the assessments and curriculum had to be developed from scratch. The text book was the only real resource he was given, which resulted in a moral dilemma for him. He had been taught to never teach directly from a text book, but that was all he had, and so it was what he used as the foundation of the course. He was just trying to keep one step ahead of the textbook as he thought to himself, "What am I doing the next day; what am I doing the day after that; and what about the day after that?" Little by little, he began to see whole instructional units and what they should look like with the students, but he felt it was like "trying to retroactively put together a puzzle."

Evan agreed to participate in the RET program primarily because he was invited, though he was not sure why they chose him, especially since he was still in the process of trying to figure out who he was as a teacher. However, he thought "it sounded like fun." Once there, he realized that he was spending three hours every day in a real-world university lab that provided him with a "mind-numbing, awesome opportunity to use cool machines you would normally only see on TV." He found that he was collaborating with researchers to solve problems that would benefit society, in addition to working on his own professional knowledge to become a better teacher. He also discovered that he was learning something new every day, which to him, represented the ultimate goal of being human.

The lesson Evan developed asked students to think about the meaning of inspiration and how nature has often been used as inspiration for some well-known inventions. He had them play a short memory game in which students matched an aspect of nature to the product that it inspired. Then he created a scenario in which his students were hired by a company to develop an innovative product inspired by something in nature. He had them practice as a whole group in class using the Howler Monkey as a model. Then he asked students to work in groups to develop their own products. Later, the groups pitched their proposals to him and the class in a fashion similar to the television show *Shark Tank*, in which wealthy business people offered to invest funding in people who had creative well-developed business plans.

Claire: Case-teacher 3. Claire grew up in the Midwest hoping to one day become an architect. After her first CAD course as a freshman in high school, in which she was the only female in the course, she began to rethink her career choice. At the same time, she began doing part-time work as a swimming instructor at a local public pool and realized how much she loved working with children. This inspired her to change her path toward education.

She began her fourth year as a teacher at the Southwest STEM Academy teaching two sixth-grade blocks of math and science. She coordinated with another teacher who handled the language arts and social studies subject areas. Her largest class had 28 students, with primarily Hispanic students and a few African-American students. She had a bank of cabinetry along one wall with a small sink and a countertop where she kept apples and cartons of milk for her students. There were a few metal book shelves for Chromebooks and resources in the back corner, and desks clustered throughout the room in groups of four to five. There was a bit of room along the back for a table or two, which was where she assembled the equipment for the science portion of the lesson. Prominently displayed along one wall was a behavior expectation poster that read CHAMPS: Conversation, Help, Activity, Movement, Participation, Success. In addition, sprinkled throughout the room were several motivational Dr. Seuss posters.

She found that her students had many gaps in their basic science and math concepts. Because she tutored others in math all throughout her own high school and college days, she was passionate about ensuring that students gain strong mathematical foundations. However, she also recognized the importance of science. She therefore often found herself trying to balance between science and math so that one was not left out for the sake of the other. She felt that her biggest challenge was that as a relatively new teacher, she had not yet accumulated many of the disposable resources that other teachers had. She felt this made it difficult for her to develop hands-on experiences for her students.

She believed her school administration at the Southwest STEM Academy was supportive of the teachers. She was aware that the foundation for the curriculum was the state standards, but noted the teachers at her school were encouraged to bring in any resources that would help them develop innovative thinking. She appreciated this approach because it resonated with her belief that teachers must first meet the needs of the students. She also noted that many administrative programs were never fully embedded because often "the teachers who began the programs were the ones who had left, leaving newly hired teachers to begin again from scratch." In the three years she had taught at this school, she had participated in three different professional learning teams, each with three to four people on them, and she was the only teacher still there. She was familiar with Design Thinking and had been utilizing it somewhat in her classroom. However, she felt that at her school they primarily thought of Design Thinking as a way to develop a design product. She also believed that they were working towards broadening the approach to include other less tangible products such as essays or posters.

At one point, Claire told her students that she would love to be an engineer, and they told her they could not picture her as one. This made her realize that "I want to have that voice for the girls, or maybe those other students in the classroom that feel like they can't become an engineer; I want to have that engineering piece and expose them to all the different opportunities." She felt the RET program represented such an opportunity to be involved in the hands-on science and math she loved so much, while simultaneously integrating an engineering learning opportunity for her own students. Additionally, she also wanted the opportunity to collaborate with other teachers and see how they developed their teaching practices.

Claire developed an instructional unit on soils which she integrated into her curriculum over several weeks. First students learned to discuss and identify different types of soils. Then they conducted a sieve analysis, which involved sifting soil through several stacked pans with a variety of mesh sizes. They then weighed each soil type using a manual scale called a triple-beam balance. Then she had students work in design teams to use their knowledge of soil to develop various problem-based soil solutions, such as fixing a crack in the road, building a retention wall, or developing a garden.

Angelica: case-teacher 4. As a youth, Angelica was heavily involved in the Girl Scout program. She earned all of her badges and the Gold Award, which resulted in her eventually becoming a camp councilor and waterfront lifeguard. As she thought about her career options, she had several friends share with her how much she had taught them about tying knots, rowing, canoeing, and sailing. They recommended she become a teacher, since she seemed to be naturally drawn to the craft. She took all of her general college credits and transferred them into an education degree with an emphasis in science.

She taught sixth grade for awhile in another state, moved around a bit, and eventually ended up in a southwestern state where her school administrator decided her strength was working with seventh graders. Then she found she needed a change and decided to participate in international education. She attended a job fair to teach in China. However, she ended up with a job offer to teach in Kuwait, where she taught seventh grade science for three years. She then spent another two years as the sustainability director for their school. Eventually, she decided it was time to return to that southwestern state where she has been teaching seventh grade science ever since.

Angelica taught at a STEM designated school that was not the Southwest STEM Academy. She taught four blocks of science with her largest class having had 28 students who were primarily white. Her classroom was a large room broken into two sections. One half included a whiteboard, presentation screen, and tables around which groups of five to seven students typically sat. There was a mobile cabinet that housed Chrome books next to a large cabinet system covered by posters describing the engineering process. The other side of the room had another set of cabinets with a sink near two metal shelves covered with plants in various stages of growth. A piece of strong rope was strung between the cabinets and another wall. Clear gallon plastic bags filled with silk bugs were clipped at intervals across the rope-line. A few tables sat between the shelves of plants and student tables. These tables displayed the habitats for aquatic snails and pill bugs. Around the edges of the room were heaped flattened cardboard boxes, recycled materials, and gardening tools.

Her school was a K-8 school in which the previous administrator had a language arts background. Angelica felt this resulted in a focus on language arts. However, the school was recently STEM certified and they gained a new school administrator with a science background. As part of this STEM certification process, Angelica attended professional development and some large workshops on the engineering process, a process which she believed was similar to the Design Thinking approach.

She had been working on "meshing" the current state science standards with the Next Generation Science Standards (NGSS), in an attempt to unpack her future goals. She often began her instructional lesson approach by looking through standard science kits provided by her district. Then she tried to reflect on ways to provide depth for the concepts beyond just having students work through the provided experiments.

At Angelica's school, Mondays were half-days for training. One day a month, they also had a district training day, in which the district provided teachers with formal trainings they could attend or allowed them to collaborate with other people, either on their campus or on another campus. This formal professional development was "monitored by administrators to ensure teachers were making appropriate progress." Even though this professional development opportunity existed, Angelica noted that by the time she could drive to the other location, they were practically out of time. However, she did feel that the development was positive and helpful overall.

Angelica was often seen drawing in a notebook while she planned or participated in events, and described herself as being easily distracted. She was a "big-picture person" who did not always feel comfortable with overt structure and fine details. She was much more comfortable "allowing the details to organically form and narrow naturally from general to specific." She felt that her administration provided her with wide-open support to develop instruction the way she saw fit, as long as she followed the engineering process.

Because of her unique teaching background, she did not always feel confident in her knowledge of educational discourse. She often questioned her ability to assess her students' learning until someone else pointed out that she asks questions to check understanding and uses rubrics and checklists to evaluate progress. Then she realized she had been assessing, just not with a traditional paper/pencil test. She eventually saw the power behind talking stems—such as *What do you think?* and *What do you claim?*—as a method for verbalizing the thinking process. She was primarily drawn to the RET program as a way to conduct what she called "true science."

Angelica presented her class with a problem scenario in which oil had contaminated local water and was killing their vegetation. Angelica explained that researchers were currently studying microorganisms that remove oil contamination through a special process. Students were split into four groups based on a personality test she conducted earlier in the year with her students, in which respondents are organized into personality groups represented by a color (blue, gold, green, or orange). The groups ranged in size from three to eight students per group. These groups were then given the task of developing a plan for their experiment on collecting data to better understand the use of microorganisms to solve oil contamination. For the first part of the unit, students collaborated through the use of Google Docs to assign each student with a specific role during the experiment and to develop a working plan for how they would conduct their experiment. Later, the groups were given flowers or vegetables, which were then fed water contaminated with oil. The groups introduced the microorganisms into the plant system and then conducted observations and collected data on the effects.

Thad: case-teacher 5. Thad worked with chemistry in the public and private sector, but his father, an elementary school teacher, influenced him to share his love of chemistry with others. He continued to work in the public sector in a regulatory agency, but then he began to teach part-time at a local urban community college. After twenty-six years, he was still teaching Introduction to Chemistry.

The department building where Thad's courses were typically taught was under construction, which led to a last-minute relocation to a geology classroom. Twelve college-aged students, primarily of Hispanic or Native American descent, attended the class. They sat in groups of two and three at large, sturdy lab tables which took up most of the space in the narrow room. They whispered quietly as Thad prepared. The room was dominated by a large blackboard across the front, and a computer station to the side. Rock samples were crowded into wooden cabinets with glass fronts, laid across the cabinet counters, and piled on several large mobile carts at the back of the room.

Thad noted that there really was no direct interaction with college administration. However, he enjoyed his division chair and fellow teachers. He felt that he has had periodic collaboration with several other colleagues and was able to frequently collaborate with another instructor with whom he co-taught for the online lab and lecture.

Thad believed the most important aspect of developing a lesson was to "grab students' attention," whether on-line or in person. He therefore often focused on a central activity. He also liked to include illustrations and assessments. His lesson design often began with determining the objective, connecting that objective to an activity, and then working from there.

Thad decided to participate in the RET program because he was interested in the way the program was described as "harnessing nature to do things more effectively." He felt like he could easily connect the science experience from the program to his chemistry classroom. Once he began participating in the RET research labs, he more strongly realized that the research being conducted at the university labs could easily tie into two or three of his course competencies.

For his RET instructional lesson, Thad introduced his students to the concepts of bio-mimicry, bio-remediation, and bio-inspiration. They watched a few video clips on products inspired by natural events, such as the fox's ability to target mice through layers of snow, which inspired NASA's use of the magnetic field for its own targeting system. Then he had students participate in a memory game. If the students were able to match the two bio-inspiration images, they then had to explain what the image represented. Thad reiterated the importance of current and relevant research being conducted at large universities and described the research study in which he was involved during his RET program. To better connect that research to the chemistry skills he was developing in his students, he then walked them through several of the calculations utilized as part of that research. Afterward students participated in a post-test survey to demonstrate their knowledge gains.

Sam: case-teacher 6. Sam, a doctoral student in a Geographical Sciences and Urban Planning PhD program, was thrown into teaching as part of her graduate program. She was assigned as a teaching assistant or associate for the university for each of the five years of her program. She was also able to work as an adjunct at a community college where she taught an Introduction to Physical Geography course. More specifically, the courses she taught were usually Meteorology and Climatology, or more recently Weather and Climate. She also taught a course on cultural geography, which she viewed as "pulling her out of her element."

At the community college where she implemented her RET instructional lesson, she was an adjunct faculty member in the physical science department. Because the courses Sam taught focused on climatology, she felt her RETsoil instructional lesson should be implemented in a different course. Eighteen students participated in the lesson she implemented as a stand-alone module in a colleague's Geology 101 course. The majority of students were male and were primarily white or Hispanic.

Her lesson was implemented at the same community college where Thad taught. Construction was still being conducted on several buildings. The geology course was temporarily located in a small room in the same building in which Thad had taught his RET instructional lesson. The front of the classroom included a large blackboard with a computer system off to the side, and the back of the room was filled with cabinets for geological maps and rock samples. One side of the room included a wide wooden table filled with a few inches of fine grain sand. In the center of the room were three tight rows of large, sturdy lab tables. The tables were about three feet from the blackboard and backed up into the rock samples at the back of the room.

As an adjunct community college instructor, Sam felt that the only person she interacted with was the person in charge of the college's geosciences division of physical science. She did interact with the colleague who suggested she teach the course at that community college; however, they did not collaborate on instruction. Though they were both in the physical geography field, her colleague dealt with the lithosphere and she focused on the atmosphere. She therefore felt that while she had close colleagues, she did not necessarily collaborate with them because their topics were "specialized and separate."

Whenever Sam developed a course, she felt she had a sense of what the students should know. She used the course competencies, but often did not agree with which competencies were aligned with particular courses. She then tailored the courses so that they were more representative of the actual course topic. She felt comfortable developing the courses in this way because no one had ever told her she could not, even after she had submitted her syllabus. Her only real challenge was "trying to figure out how to retain students who were afraid of math." She felt like the moment those students saw an equation they would decide to drop the course.

The students in her climatology courses were almost never physical geography or meteorology majors, though this last summer she had three meteorology majors and "thought that was a complete anomaly." Even when she taught several sections at a large university, with 35 students in each section, she only ever had one student who was majoring in meteorology per section. She believed it might be that "people do not really know what physical geography is." She thought they might believe it is "memorizing the states and capitals, when physical geography has absolutely nothing to do with that."

She also believed that her typical students vastly underestimate what is expected of them, and she had no intention of "dumbing-down the curriculum." She felt she knew what the competencies were, and she wanted her students to experience the rigor behind the physical sciences. Since her courses were supposed to meet a quantitative science requirement, she ensured that the lessons she developed always included calculations that she aligned with certain course concepts. She believed that if students had a basic understanding of a course concept, then practiced that concept through the math, the calculations would reinforce students' overall understanding of the concept. She also connected the course concepts to previous lessons to demonstrate linkages among them.

She believed in scaffolding the more complex aspects of weather by beginning with the very basics of the sun, energy, and thermodynamics, and then demonstrating how those concepts influence air temperature. Then she would introduce the topics of moisture, stability, and thunderstorms. Sam wanted her students to understand that learning is a building process in which each smaller piece would help them progress towards understanding larger phenomena like thunderstorms and hurricanes. She wanted them to think about that process rather than "trying to jump ahead."

Her physical sciences division chair asked her to apply for the RET program. She was not sure about her qualifications for the program or how the content would connect to her subject area. However, she felt like "she should just go for it."

The colleague who allowed Sam to implement the RET instructional lesson in her Geology 101 course, did participate in the lesson implementation, though Sam took the lead. For the lesson, Sam suggested to students that engineers need to be as aware of the soil as of the buildings. They do this by conducting soil classifications and analysis. She broke the class into groups of three, and gave each group a different type of soil. She asked them to use their five senses to try and classify their soil. Then Sam gave them a larger amount of the same soil and had them conduct a manual sieve analysis, similar to the one Claire had students conduct in her class, using several stacked pans with varying mesh sizes. Afterwards, the students were asked to weigh each soil level type and classify the soil using that new data. She then asked the students to develop a report based on their collected data.

Ben: case-teacher 7. Ben began his college career as a dual English and Religion major. However, in his junior year he was recruited by Teach for America. Their social justice focus appealed to him, making him realize that he was passionate about combatting educational inequities. He remained in the teaching field after the program was over simply because he "fell in love with it."

Ben began his third year as a teacher at the Southwest STEM Academy teaching four blocks of eighth grade science. His classes averaged approximately 30 students who were primarily Hispanic. His classroom had cabinets along one wall, with a sink, and—like Claire's classroom—had milk cartons and yoghurt available for students to eat as they began class. Desks were pushed together to form groups of four or five placed about the classroom. At the front of the room was a white board with a presentation screen where Ben provided an overview of the class objectives for the day. On the whiteboard he also listed the learning and social objectives for the lesson. Across a wall were listed the stages of the scientific process.

Ben viewed his school, the Southwest STEM Academy, as having supportive teachers who valued collaboration and had the goal of being student-centered. However, he noted that the school had not always been that way. He remembered early discussions on "how to shift the mindset away from *being here to serve ourselves* towards *being here to serve our community*." As a teacher, he felt his main goal was to be responsive to the needs of the community and his students.

He felt his administration "fully left the decision-making" to the teachers and their teams. He worked with a "grade-level band," which was a team of four teachers comprised of the language arts, math, science, and social studies teachers. In this team, they again "tried to change their mindset to break down their disciplinary walls." He felt that by "pulling the disciplines away from being stand-alone silos," the teachers as a team could better help students see that "there are big problems that our world is faced with that require all areas of knowledge to come together to find a viable solution." He felt it was important to present students with problems that required them to synthesize their knowledge so that they could better see those connections.

He acknowledged that at his school they have presented Design Thinking as a possible instructional model to be used with their students, but he had not yet had an opportunity to look at the data to determine its affordances for complex critical thinking. He felt that, as a school, they were still "playing around with Design Thinking to see how it might fit in the classroom, and to determine how to grow from there."

He typically began developing his instruction by reflecting on what things he felt were the most essential from a given body of knowledge. He then found standards or curricular materials that aligned with those essential aspects. He used a task-analysis process to determine the steps the students would need to take to be able to reach those standards. That led him to design assessments as a way to incrementally measure student progress throughout his lessons. This provided him with smaller checks along the way, so that he could be aware of when his students were prepared to be successful on the final performance task.

Ben felt that teachers are always somewhat confined by "some kind of boundary or tangible expectations as to how they conduct their instruction." However, he tempered that view by noting that he also felt that teachers first have a requirement to meet the learning needs of their students. For example, using standardized units of measurement was not part of the eighth grade standards; yet he knew it to be an essential science skill. He therefore felt that as long as he could "provide evidence that learning was happening," he was justified in teaching this knowledge in his classroom, and believed his administration would support him.

He was motivated to participate in the RET program because his college background was in the humanities. He wanted the opportunity to more directly learn science at the university level and actually work in a lab. By watching university level researchers, like those mentoring him in his RET lab, he felt he was able to reflect on how they processed their knowledge. He wondered how that process might be integrated and translated to his classroom. He felt participating in the RET program allowed him to bridge some of his own learning gaps.

Ben's lesson was one part of a larger unit which was introduced to his students in collaboration with Leslie (P9), his school's instructional coach, and fellow RET teacher participant. Leslie presented Ben's students with a discussion on liquefaction, a phenomenon wherein soil loses strength, usually due to an earthquake, which causes it to act like a liquid. Connecting to Leslie's lesson, Ben asked his students to research possible solutions to liquefaction. As a class, they determined that adding certain types of material to the soil has demonstrated positive results. They conducted further research on types of material that might be used as part of an experiment. Ben selected a few of the materials suggested by the students. Students then worked in small teams to test the effectiveness of their material in deterring liquefaction. The focus of the lesson was to assist students in developing a stronger understanding of the scientific method to include hypothesis, independent and dependent variables, control groups, and data collection.

Zane: case-teacher 8. After retiring from the military, Zane started a family and moved from job to job. He quickly realized that he needed to find a career that he enjoyed. One day, he woke up and knew he wanted to be a teacher. He had connected well with the soldiers in his command and felt he could connect the same way with students. The irony was that he never saw himself as a good student, especially in math and science; yet, as a teacher he found the scientific process fascinating. He found himself to be more aware of teaching practices and how they could affect students' abilities to engage. He had developed "a love for science through teaching other students to have a love for science."

Zane began his eighth year as a teacher at a traditional K-8 school teaching seventh and eighth grade science, while concurrently working on a doctoral degree in K-

12 Leadership. He typically had 28 students in each class period on average, who were primarily Hispanic or African American. The classroom included a whiteboard and presentation screen with a large lab table in front for modeling lab experiments. Samples from an earlier experiment involving the stages of bacteria growth on slices of bread in plastic bags were taped to one side of the whiteboard. Around the perimeter were hexagonal lab tables jutting out from the side walls, around which four to five students sat. Down the center of the classroom were other tables holding lab supplies. At the rear of the classroom was a standing presentation screen, which allowed the teacher to roam from one side of the classroom to the other as he taught the lesson.

Zane's school was a Title I public school, meaning that his school was eligible to receive United States federal funding due to the legislative Elementary and Secondary Education Act (ESEA) that states that financial assistance will be provided to schools with high numbers or high percentages of children from low-income families to help ensure that all children meet challenging state academic standards (Title I, 2015). As such, he has worked toward finding innovative methods for helping his students attain fundamental science skills. He has, therefore, used scaffolding strategies in order to help his students bridge their knowledge to his current eighth-grade standards.

Zane held the belief that his administration would always support him in the classroom. They even decided to make him the team leader for the upcoming school year. He accepted, but was not fully sure how that would work because he knew he liked things to be structured because it has always been important to Zane that everyone is "on the same page." If his grade-level team made a decision to prohibit headphones, chewing gum, or fidget spinners, but certain "cool teachers" continued to allow them, he felt "things would break down." Though his school had weekly professional learning community meetings, he was unsure as to what extent teachers were actually able to collaborate. Instead he would like to see his grade-level team create a set of common expectations and team roles, whether that be about common classroom rules or developing a teaching process to introduce "makerspace projects" with students.

Zane typically utilized the scores from standardized tests to determine where his instruction was the weakest. This helped him determine which concepts he should highlight the following year. However, he noted that those weaker conceptual areas seemed to be different each year, even though the standardized science test never changed. He often wondered to himself: "How did I do with the students? Did I give them enough homework? Did I not give enough homework? Did I give enough feedback on their assignments?"

He believed in connecting with his students, setting explicit expectations, and consistency. He utilized the "gradual release method" in which he was very strict and stern with students in the beginning, and then slowly, once he saw students beginning to understand his procedures, he would "loosen his hold a bit." Because of this process, he was confident that his students always knew how to move their learning forward.

Science teachers at his school were expected to utilize the district-provided science kits, which sometimes frustrated Zane. He felt using the kits was like "painting by numbers." He argued that "teachers are paid to look at the lesson and standards to figure out what they want the students to know. This may result in the teacher having to learn new content as well, but if it is what the students should know, then I am going to find a way to make it happen." Therefore, though he felt his administration supported what he did in the classroom, he also knew that certain expectations existed.

Zane participated in the RETsoil program two summers in a row. The first year, the lab experience to which he was assigned did not fully align with the objectives for his eighth grade science class. He, therefore, developed his instructional lesson based on another lab with help from colleagues and the RET education coordinator. The RET program administrators asked him to return the following year as a mentor for the incoming teacher participants.

This time, Zane was assigned to the lab that aligned with his classroom content. The first year he participated in the program, he had not dealt with Design Thinking; the year of the study he participated in similar Design Thinking practices as the year before, but was able to more systematically think about how research he was conducting could be modified for classroom use. He often reflected on several controls and processes that he had done incorrectly the year before because he had not actually been in that RET lab and simply did not have the knowledge of how their research was fully conducted. This strengthened his goal to have his students conduct their own research at that same rigorous level.

Zane's lesson was part of a larger unit on dust mitigation. First he defined dust mitigation as a process in which the adverse impact of loose dust, or fugitive dust, was reduced. Then he described spraying water on top of the ground around large construction sites as the current fugitive dust remediation method, and they discussed the challenges this presents in a desert climate. They further discussed current research utilizing microorganisms to help provide stabilization. In small groups, students created controls for a fugitive dust experiment in which they packed sand into small cups and then spritzed them with distilled water. The groups then measured the mass of each cup of soil and covered them with aluminum foil. Later in the unit, the students hypothesized other materials that could be added to the soil to use as alternate methods for stabilization and would conduct their own tests to determine effects.

Leslie: case-teacher 9. Leslie was always interested in working with people. During high school, she volunteered to work with adults with disabilities, which led to an interest in physical therapy. However, once at university, she found that while she loved the science courses involved with her major, she did not look forward to the years of graduate work she would need to do to fully work as a physical therapist. She, therefore, switched to an elementary and special education degree. This allowed her to more immediately follow her passion for working with people. She also went on to earn a Ph.D.

Leslie instructed at universities across the nation, was a director of a primary school in Mexico, and more recently taught fourth grade at the Southwest STEM Academy before "being pulled into a position as one of their instructional coaches." She specializes in curriculum development and bilingual and English as Second Language instruction.

She considered herself a consummate learner. Even after 30 years of teaching, she still felt that "I will always be becoming a teacher—I'm not there yet." She collaborated with Ben (P7) to use his students and classroom to implement her RET instructional lesson. Leslie, therefore, also had approximately 30 students per class who were primarily Hispanic. For her lesson, the groups of desks were positioned to surround some testing equipment in the center of the room; otherwise, the room and students were the same.

Her teaching perspective was unique compared to the other case-teachers since she was not currently in the classroom with students. Instead, she worked as an instructional coach whose main purpose was to work with the teachers to help guide them during their professional learning community meetings and to facilitate professional development opportunities. She worked one-on-one with teachers to model effective practices or take over their classrooms so they could observe someone else's classroom for a new perspective.

Leslie believed that it was important to always start with the learners. She tried to help teachers:

> differentiate between thinking about whether or not *they can teach* certain concepts to thinking about whether or not they can teach those concepts in a way *the students can learn* them. The only thing we as teachers can do is create an opportunity for learning. We can't make anybody learn something they don't want to. But we can create positive opportunities for learning.

She had been focusing on helping teachers understand that teaching was not a "lockstep process." However, she noted that teaching in this state was not "profitable or even sustainable." Therefore, often times, novice teachers only taught for a few years before either moving to a district or state closer to their homes that might provide more income, or leaving the profession completely. This meant that she was constantly working with novice teachers, each one with a different level of experience and background. She therefore had to approach the needs of each of her teachers differently.

However, she did work from an "inquiry mindset, asking the teachers to develop space for their students to talk and explore."

She acknowledged that the school had reconstituted itself as a STEM-focused school that followed a Design Thinking approach. However, she also noted that they were still in an exploratory phase in which they might work with Design Thinking using a packet during professional development or by having a showcase a few times a year. Her own personal goal was to help teachers "embrace Design Thinking as a thought process—for them to constantly think about how they present instruction."

Though Leslie did not see herself as a role model, she had noticed that many of their female students were "turned off" by math and science as they progressed through the grade levels. She decided to participate in the RET program to demonstrate the need for continual learning, and to perhaps find new ways to integrate science and engineering in the classroom. Because she viewed science and engineering as critical to learning, she wanted to try to affect female students' perspectives in a new way.

Leslie collaborated with Ben (P7) to develop a lesson that would provide students with the knowledge necessary to later conduct an experiment on liquefaction. While she was the main instructor for this lesson, Ben was in the classroom the entire time, and provided additional support throughout. Leslie outlined a variety of engineering careers, and invited her RETsoil graduate student mentor to describe what it meant to be a civil engineer. Leslie had students read about a school in California that was being closed due to concerns over liquefaction. Leslie presented students with several prototype buildings made of Legos and asked students to reflect on the aspects of the building that might make it less likely to survive a liquefaction event. Afterwards, students observed the graduate student mentor test the models using a shake table, which is a small machine that simulates an earthquake. Leslie also shared with students a few real-life videos of buildings and roads during liquefaction events. Students were then asked to summarize their thoughts through the use of a graphic organizer.

Lou: case-teacher 10. Lou found himself "bouncing around" within several majors in college and eventually took some "time off to think about things." When he returned, he knew he wanted to "get serious about his path so that he would not waste any more time." He had noticed the rewards his mother received from being a teacher, and this made him realize that he wanted that as well. Therefore, he returned to college and became a teacher.

Lou began his twenty-second year as a teacher at a traditional public elementary school teaching fourth grade science and social studies. The school worked on a block schedule, so he had three 90-minute blocks with approximately 25 students per block each day. One of his blocks was a designated homeroom, and those students traveled together to lunch and special activities (art, music, and PE). Students traveled to other teacher's classrooms for their math and language arts blocks. Lou's classroom had cabinets along two walls filled with supplies, books, and paperwork. The wall with windows had some tables with recyclable materials on them in plastic bags as well as other filing cabinets and containers with building items and what looked like Connectix. He had desks grouped together in pods of five desks per group with each pod having bins filled with tools and supplies like scissors and writing utensils. Along another wall were more cabinets with a counter atop which sat a small solar panel hooked to a high-powered standing work light set up as a testing station.

Lou participated in a professional learning community at his school with other fourth-grade teachers; however, he collaborated most heavily with a colleague who was also a fourth grade teacher, but had the same students all day. They often did their science planning together, and Lou liked to "check in with her to see what kind of lessons she planned to do." He saw his instructional lesson design process as "ever evolving." He asked himself three things: where he wanted to go with the content, how that should look in the classroom, and how it could align with the standards.

He also liked to focus on extending the learning through after school programs and at-home activities. He wanted students to think about sustainability and "get turned-on to technical and engineering ways of thinking." This year he wanted his "driving force" to be about reflecting on the Next Generation Science Standards, which focus on providing learning opportunities for active engagement in problem-solving.

Lou felt he had a strong relationship with his administration. He found that they often visited his classroom just to observe. He believed that they liked what they saw him doing with his students, and he felt supported and complimented by their presence. He described the choices teachers make about the instruction they teach as a "curricular story." He saw curriculum as resources, and felt that each teacher had his or her own way of "weaving those resources" together: "My story will be a little bit different than somebody else's story, because of my teaching style or my students' learning styles—and so I try to touch upon everything I can the best I can."

During the previous year, Lou participated in the RETsoil program. The year of the study, he participated in the RETsolar program. As part of his RETsoil program lesson implementation, Lou provided his students with background information on dust mitigation. Then he walked them through the steps of a successful experiment that was similar to the experiment Zane (P8) conducted with his students. Because Lou had previously participated in the RETsoil program, where I conducted the DTIP pilot study (Elwood et al., 2017), Lou already had a fundamental understanding of the Design Thinking approach before beginning the RETsolar program. Additionally, though he was completely committed to this year's RETsolar experience, he continued to connect with the RETsoil administrators. This provided me with extended access to him as a case-teacher.

Lou believed that these last few years of teaching had been some of the best of his career. He believed the RET programs provided him with a different direction for his teaching. The two programs made him reset the way he taught, which was a benefit to both him and to his students. He looked at his students' standardized science test scores and saw that more than 80% of them demonstrated mastery levels. This suggested to him that his RET experience provided him with a new perspective on teaching that benefited his students. The data also made him begin to reflect on ways to re-engage the group of students that did not demonstrate mastery.

For the RETsolar program lesson implementation, he developed a much larger unit than the one initially created for RETsoil. This new unit introduced students to solar energy and sustainability issues. Students were broken into groups of three to five. They were given a simple motor and a plastic fidget spinner toy. They were asked to bring in recyclable materials from home and were tasked with attaching the motor to the spinner in such a way that it would infinitely self-propel once attached to a solar cell. While groups worked on designing their product, Lou facilitated testing procedures with a high-powered work light he aimed at the solar panel to simulate sunlight within the confines of the classroom. Students used alligator clips to test their infinite spinner with the solar cell and then returned to their desks to redesign them. Afterwards, they would reflect on aspects that worked and challenges for the next design iteration.