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DEVELOPMENT ARTICLE

Development of the Design Thinking and Instructional Lessons (DTAIL) model: a creative approach for teachers

Kristin Elwood[1] · **Michelle E. Jordan**[2]

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Abstract

The educational landscape continues to become increasingly complex, which suggests a need for a teacher-driven creative approach to developing instructional lessons. This article introduces the Design Thinking and Instructional Lessons (DTAIL) model and describes its three-phase development. In Phase I, the Design Thinking literature and the first draft of the model are described. In Phase II and III, two design studies conducted with STEM K-12 public school and community college in-service teachers participating in summer research experience for teachers (RET) programs in the United States are described. In addition, during the second design study, ten teacher-participants were observed as they implemented their lessons and were interviewed concerning how and to what extent they perceived the DTAIL model to resonate with their approach to developing instructional lessons. Revisions to the model were made based on data analysis from those three design phases. Findings suggest that Design Thinking models that facilitate teacher-driven design of instructional lessons might usefully include design stages with an explicit depiction of rotation and recursiveness. In addition, Design Thinking models should also depict (1) iteration, reflection, and revision; (2) a chaotic fluctuating problem–solution space, and (3) circling backward to eventually narrow the problem space toward a satisficed solution. Furthermore, the majority of teacher-participants found the DTAIL model to resonate with their approach to developing instructional lessons.

Keywords Design thinking · Instructional lessons · Lesson planning · Teachers as designers

Scholars and practitioners alike increasingly recognize that teaching is an activity that requires not only implementation expertise, but also design expertise (Bennett et al., 2018;

✉ Kristin Elwood
k.elwood@asu.edu

Michelle E. Jordan
michelle.e.jordan@asu.edu

1 School of International Letters and Cultures, Arizona State University, Tempe, AZ 85287-0202, USA

2 Center for Social Dynamics and Complexity, Mary Lou Fulton Teachers College, Arizona State University, Tempe, AZ 85281, USA

Penuel & Gallagher, 2009; Svihla et al., 2015; Weiner et al., 2020). Yet, many teachers approach lesson development as a simple, linear, and highly bounded process that involves turning to tried and true resources and instructional methods to make day-to-day, routinized, plug-and-play instructional lesson plans (Fernandez & Cannon, 2005; John, 2006; Ornstein, 1997). However, the teachers of tomorrow will need a different approach to designing instructional lessons in order to better align with increasingly complex professional expectations and shifting teaching contexts (Bennett et al., 2018; Huizinga et al., 2014; Ravitch, 2020). Specifically, teachers need to approach lesson development as a complex, creative process that involves iterative framing and re-framing of instructional purposes—seeking out novel resources, instructional methods, and new combinations of resources and methods to develop instructional lesson plans that are responsive to their teaching context (Henriksen et al., 2017; John, 2006; Koh et al., 2014).

This article is about the development of the Design Thinking and Instructional Lessons (DTAIL) model created to support such an approach for K-12 public school and community college teachers. First, an overview of the scholarly Design Thinking literature within the design field, its subsequent alignment with education, and description of the rationale for developing a Design Thinking model specific to instructional lesson design within the field of education is provided. Then, the development phases that resulted in the final DTAIL model, to include findings from two design studies and the resulting design decisions are provided, along with implications for research and practice.

Need for a creative approach to instructional lessons

The role of the teacher has changed over the years. In recent decades, scholars around the globe have noticed the effects of continued standardization within the teaching field at both K-12 public schools and higher education levels (Brint, 2011; J. Buchanan, 2020; Evers & Kneyber, 2015; Finkelstein & Altbach, 1997; Shizha & Kariwo, 2011). Accompanying trends such as teacher-proofing curriculum with pre-approved textbooks, workbooks, and scripted curriculum suggest a de-professionalization of teachers that may have long-term consequences (Debarger et al., 2016; Dee & Jacob, 2011; Penuel & Gallagher, 2009). For instance, positioning teachers as implementers of prepackaged lessons can inhibit teachers' ability to engage in creative approaches to instructional lesson design (Darling-Hammond, 2006; Priestley et al., 2016; Tanggaard, 2011). However, the educational landscape continues to evolve, redefining the traditional concept of teaching as a complex, ill-structured, and reflexive process (Conklin, 2006; Jordan, 2016).

Changing social conditions, workforce development needs, and technological resources, among other changes, continue to shift expectations for teachers (Kalantzis & Cope, 2010). Educational reforms in the United States, such as Common Core, 21st Century Skills, and Next Generation Science Standards have resulted in a drive towards engaging students in critical thinking, inquiry, and innovation practices (Core NASBE, 2016; P21, 2015; Standards, 2016). In addition, teachers are increasingly being asked to integrate new technologies into their instructional practices (e.g., Fullan, 2013; Hokanson & Hooper, 2004; Koehler et al., 2007), a trend further catalyzed by the COVID19 pandemic (Bird et al., 2020; Kraft et al., 2020; Sayer & Braun, 2020; Severino et al., 2021).

We join other scholars in arguing that these increasingly complex curricular expectations for teachers can be met through a creative approach to developing instructional lessons (e.g., Goodyear, 2015; Henriksen et al., 2016; Svihla et al., 2015), and that Design

Thinking might be one such approach (Henriksen et al., 2017; Norton & Hathaway, 2015; Rauth et al., 2010). Interest in such approaches is exhibited, for instance, in recent reviews of the literature related to teachers and design in K-12 and higher education contexts (e.g., Bennett et al., 2018; Dagnino et al., 2018; Warr & Mishra, 2021) and special issues focused on design in education journals (see Dobozy & Cameron, 2018; Kali et al., 2015; Persico et al., 2018).

In addition to theoretical work, a growing number of empirical studies are being conducted on the effects of Design Thinking on teachers' instructional lesson development practices. For example, in a survey study of 201 Singapore teachers, Koh et al. (2014) found that developing lesson design practices that support ideation and iteration can also enhance teachers' technological pedagogical content knowledge. In another example, an interpretive study involving higher education in-service teachers explored the outcomes of using specific tools to foster teacher Design Thinking during professional development workshops (Asensio-Pérez et al., 2017). Furthermore, Henriksen et al. (2018) identified positive outcomes in their use of a Design Thinking framework as the foundation for a teacher education course. However, while Design Thinking research in education is growing, what is meant by the use of a "Design Thinking" model or framework is still quite unclear.

Herbert Simon (1988) provided a general definition of design: "Everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (p. 67). The use of the term *everyone* suggests a wide range of variability and application for design as an ability. Nigel Cross, emeritus Design Studies professor and researcher, built upon this concept by studying and identifying the cognitive skills that have been referred to as "designerly ways of knowing" (Cross, 2011, p. 6), and he argued that everyone has some level of design ability that should be studied and nurtured. Based on research conducted within traditional design fields, Cross (1990) defined this designerly knowing as: "Designers produce novel, unexpected solutions; tolerate uncertainty, working with incomplete information; apply imagination and constructive forethought to practical problems" (p. 130). Around the same time, business organizations began to apply these concepts to their own complex problems (Kimbell, 2011), and simplified the concept of *designerly ways of knowing* to *Design Thinking*. From there, the Design Thinking approach was applied to a variety of fields including education.

Design Thinking in education

This ongoing trend to implement design practices in education has resulted in growing research on teachers and design. However, there are still many research gaps to be found. For one, clarity is needed on the definition of design in educational literature (Warr & Mishra, 2021). For instance, while Henriksen et al. (2018) fully defined the concept of design, described the specific model they chose in their teacher development course, and provided the rationale for its use, many of the existing studies identified did not provide a rich description of the specific Design Thinking model through which teacher-participants were engaged.

Moreover, while there is a growing literature on the use of Design Thinking for teachers developing technology-enhanced learning (e.g., Laurillard et al., 2018; Nguyen & Bower, 2018), there is still a dearth of research on the use of a Design Thinking approach for developing instructional lessons within specific subjects. Other areas of interest include a call for more empirical research exploring the effect of teacher design activities (Kali et al., 2015) and for the development and testing of tools to support teachers' design processes (Conole et al., 2015; Dagnino et al., 2018; Persico et al., 2018), including models that offer conceptual frameworks and procedural methods to support teachers' design practices (Bower & Vlachopoulos, 2018). We join the latter group by proposing a model that facilitates Design Thinking as a creative approach to support teachers' development of instructional lessons.

In the work described here, we follow Penuel and Gallagher (2009) in defining *teaching as design* as "preparing teachers to make effective decisions in designing instructional experiences for students with curricula" (p. 462), and we agree with these authors that teachers' instructional decisions are often complex and ill-defined. In addition, we recognize that many experienced teachers are novice learning designers, since they have not always been expected to develop lessons for their students (Huizinga et al., 2014; Penuel & Gallagher, 2009), and that they therefore may need significant support and resources to adopt a creative approach for developing instructional lessons.

Henriksen et al. (2016) recommended a modified definition of creativity for educational contexts: "We define creativity as both the oft-noted 'novel,' and 'effective,' in addition to the subtler component of 'wholeness' (or context, important to education)" (p. 29). Following that recommendation, we characterize Design Thinking as a creative approach because it is novel, effective, and provides wholeness. When applied to the development of instructional lessons, the approach is *novel* because each teacher who uses it will experience it in a slightly different manner, *effective* because it will provide a useful method for developing lessons in the midst of ever-changing expectations, and provides a sense of *wholeness* for teachers—meaning that they design their lessons within the educational context of their particular student needs. We do not try to suggest that every instructional lesson developed through a Design Thinking approach will result in a creative lesson. Instead, we argue that since the approach is creative in nature, teachers will perceive it to align well with the complex nature of their instructional lesson design context.

Design Thinking lends itself best to ill-structured, complex problems (R. Buchanan, 1992), particularly when viewed through a constructivist lens (Kijima et al., 2021). Therefore, if teachers do not choose to frame the lesson design context as an ill-structured or complex problem, the Design Thinking approach may not foster the envisioned outcomes (Svihla et al., 2015). Moreover, a Design Thinking approach to creating instructional lessons may be most applicable when teachers are creating plans for learning situations that are themselves more ill-structured or open-ended. For instance, instructional activities involving problem solving, problem-based learning, or higher order thinking within Bloom's Revised Taxonomy would align well with a Design Thinking approach (Krathwohl, 2002).

DTAIL model development

The following sections describe how the Design Thinking literature situated within the design field inspired the development of the DTAIL model specific to the field of education. The development of the DTAIL model began while we were developing professional development workshops for K-12 public school and community college science, technology, engineering, and math (STEM) teachers. Recognizing the importance of mediating artifacts to support teachers' design process (Conole et al., 2015; Dagnino et al., 2018) in relation to developing instructional lessons, we sought a visualization of the Design

Thinking process as a tool that might align with our professional development goals and the design literature. Unsuccessful in this search, we decided to develop an original model of Design Thinking that aligned with the scholarly Design Thinking process as we understood it, while also using terminology that resonated with the teaching field.

The model development process we followed can be described as proceeding through three phases. Briefly, Phase I began with the development of a rotating five-stage model. In Phase II, a short exploratory study was conducted in which 16 STEM K-12 public school and community college teachers participated in one of two five-week summer research and instructional lesson development programs. In Phase III, another similar but more in-depth study was conducted. In the sections below, we describe the actions taken in each phase and the resulting design decisions.

Development phase I: iterative rotating stages

As argued by Henriksen et al. (2017), models can usefully guide educators through creative impasses, inspire creative insights, and improve ideation. However, none of the Design Thinking models at the time we began our work explicitly supported the instructional lesson design of teachers. Instead, these models used decontextualized language that did not seem to connect well with teachers (e.g., *prototyping*). Therefore, we began exploring design literature writ large in order to identify and/or develop a model that might resonate with our teacher-participants.

Phase I Design Thinking background

The process of design was first highlighted by Simon (1969) in his book *The Sciences of the Artificial* via a chapter on "The Science of Design." The 1980s furthered Simon's initial research through observing, interviewing, and analyzing architects, engineers, and designers (Johansson-Sköldberg et al., 2013). This research led to a distinction between the project output of professional designers and the cognitive design process they followed to arrive at that output. Schön (1983) suggested that the design process involved not just reflection-on-action, in which designers reflect after they create, but reflection-in-action, in which designers iteratively reflect across design decisions.

Both Lawson (2004) and Cross (2001) utilized ethnographic case study methods to denote common designerly practices and methods utilized by designers. In later works, Cross (2006, 2011) noted that design professionals solve problems in a different way than other professionals. He also posited that the base characteristics and processes of this *designerly thinking* could be learned by others.

Then the business sector popularized their own discourse called *Design Thinking*, which was a simplified reduction of designerly thinking without its scholarship (Kimbell, 2011). In 1991, David M. Kelley, Stanford University professor of mechanical engineering, merged his own design firm with several others to found the global design company IDEO. Because of its global connections and partnership with Stanford, anecdotes surrounding the way in which IDEO practiced and innovated spread (Johansson-Sköldberg et al., 2013).

In 2000, Kelley passed the positions of CEO and president of IDEO to his colleague Tim Brown. In 2005, Kelley partnered with the Hasso Plattner Institute of the University of Potsdam in Germany to create the Hasso Plattner Institute of Design at Stanford University, which became known as the d.School (d.School, 2016). Then, Brown (2009) published his own book *Change by Design*. This publication still focused on the design fields, but in it he suggested that Design Thinking could be applied to any complex problem that needed a creative solution.

Richard Buchanan (1992) furthered this discussion by suggesting that the Design Thinking construct should be heavily influenced by Rittel and Webber's (1973) wicked problems approach. By connecting Design Thinking to Dewey's pragmatism and Rittel and Webber's notion of ill-defined wicked problems, Buchanan also created an alignment between Design Thinking and education. Mishra and Koehler (2006) strengthened the discourse through their technological pedagogical content knowledge framework (TPCK), in which they attempted to better understand the wicked problems inherent in technology integration in education.

Over the years, there has been an explosion of interest in Design Thinking in education. Warr and Mishra (2021) conducted a content and network analysis on 40 selected articles from 2007 to 2017 about teachers and design. They found ten unique education design strands that suggested "teaching could be considered a design profession" and that "professional knowledge [is] constructed through design" (p. 10). However, many of these studies relied on models originally developed through the process experience of IDEO designers. The effectiveness of these popular models and their alignment with the instructional lesson design process of teachers have not been empirically researched.

Critique of popular Design Thinking models

Many Design Thinking scholars and practitioners (though not all) depict the Design Thinking approach as a five-stage process, to include some form of the constructs *definition, perspective, exploration, prototype,* and *reflection,* though not always in that order or by those names (Carlgren et al., 2016; Cross, 1990; IDEO, 2016; Lawson, 2005; Rowe, 1991; Schön, 1983). Although textual descriptions of these popular Design Thinking models express that design is an iterative process and likely to be nonlinear in execution, the relationship among the stages is often shown as sequential and linear. For example, Stanford University d.School (2017) and IDEO (Brown, 2009; IDEO, 2016) have developed their own five-step Design Thinking models, both of which have also been associated with highly structured project management models (Pereira & Russo, 2018).

Dagnino et al. (2018) conducted a review of the literature to explore barriers to the adoption of design process models by teachers. They found that teachers were more likely to use models if they were flexible, reusable, collaborative, reflective, easy to use, time sensitive, and considered teacher design culture. The Stanford and IDEO models were certainly easy for teacher-participants to use; however, in many ways the models oversimplified the Design Thinking approach. Hernández-Ramírez (2018) also doubts that one model could be used across contexts: "Suggesting that one of them is the most adequate for every circumstance would be preposterous simply because it goes against the very idea of what designing means… the very idea that design activities occur in a given order or that they represent identifiable separate events is questionable" (p. 51).

Detractors of Design Thinking have criticized these and similar models for misrepresenting and over-generalizing design methodologies and processes [especially the five-step linear process] (e.g., Hernández-Ramírez, 2018). Other critics claim these models are reductive, uncritical, and they focus too heavily on simplistic processes rather than concrete outputs (Jen, 2018). Some even argue that since much of the Design Thinking discourse surrounding the Stanford and IDEO models began within the field of management, it follows that Design Thinking has less to do with design or social change and more to do with business (Vinsel, 2017). Kolko (2018) even questions one of the touted highlights of the Design Thinking approach, a focus on empathy, as promoting "empathy lite" (p. 8)—as if an empathetic and meaningful connection with people could be forged in hours or even days.

The critical discourse regarding Design Thinking has been influenced by the popular Design Thinking models, such as the Stanford and IDEO models, which originated from the same small group of designers (Carlgren et al., 2016). We contend that a Design Thinking model should fully represent the chaotic tension between the analytical and the creative that designers must navigate (Donar, 2011; Lugmayr et al., 2014; McKenney et al., 2015). If popular Design Thinking models are used with teachers to design their instructional lessons, the teachers might expect their own design process to be as clear-cut as the models depict. They may become frustrated when they find it is much more recursive than they were led to believe. If uncertainty is depicted in the model to explicitly warn users to expect frustration during the process of designing instructional lessons, their uncertainty may be more productive (Kapur & Bielaczyc, 2012).

Phase I initial design decisions

We developed the DTAIL model based on the scholarly literature from the design field because we could not find a current Design Thinking model that fully aligned with the literature and would resonate with teachers as an approach to instructional lesson development. We began our new model development with a discussion of the stages. We noticed that the stages in the popular models were often represented by one-word nouns. However, in the design literature, Design Thinking is described as having movement. Therefore, we determined that the DTAIL model should use active verbs and a circular motion to highlight iteration and reflection, as well as a depiction of each stage cutting into the next one to imply that the stages might overlap or interchange, see Fig. 1.

Development phase II: fluctuating problem space

For the second phase of development, feedback was sought from southwestern United States K-16 public school, community college, and university teachers by pilot-testing the model during professional development events and requesting critique from participants. The goal was to gain a better understanding of how a DTAIL model might resonate with actual teachers and in what ways the model may need to be revised. Based on this pilot-testing, it was concluded that the DTAIL model needed to include a visualization of the problem space to better ensure that key Design Thinking assumptions, such as multiple solution paths, ambiguity, and iteration, are fostered. Then a context in which to engage teachers in extensive engagement with the model was selected, resulting in Design Studies A and B as described below.

Phase II design study A

The next part of the model development took place in the context of two separate Research Experience for Teachers (RET) programs. The study was held for five weeks over the summer on the campus of a large southwestern university in the United States. Both RET

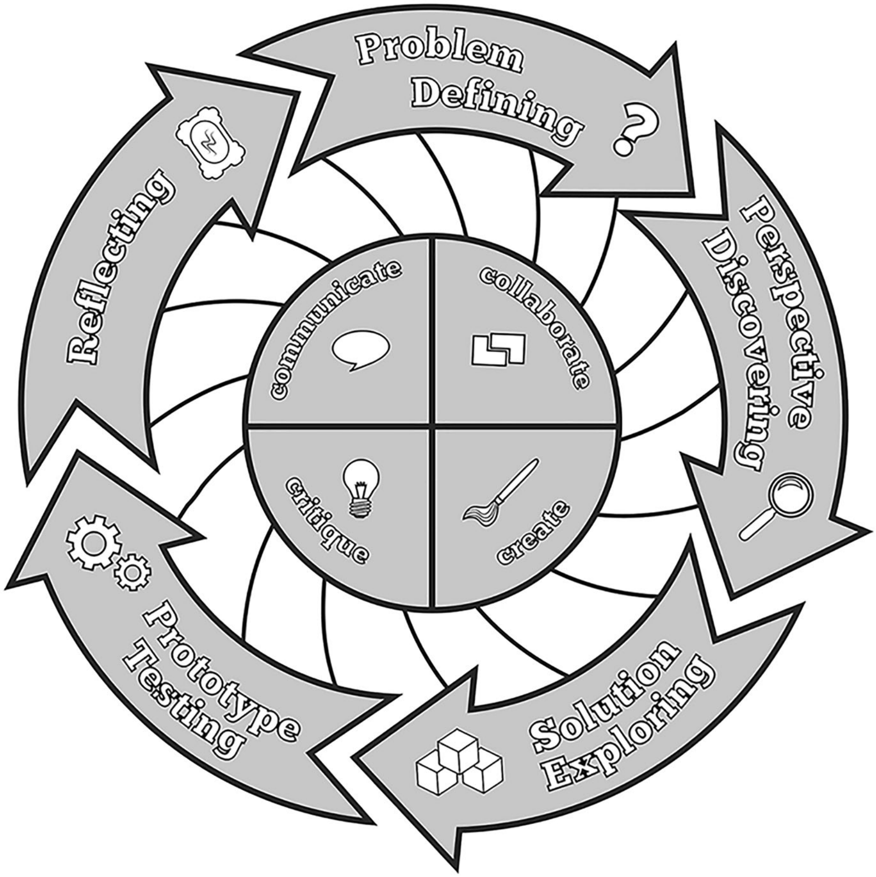

Fig. 1 First draft of the Design Thinking and Instructional Lessons (DTAIL) model that initially included active verb stages, a rotating pattern, and the twenty-first century 4C skills

programs were funded through the National Science Foundation as part of two separate Engineering Research Centers (ERCs). Based on the constraints of the programs, this study was limited to STEM instructional lesson development.

As part of the RET programs, K-12 public school and community colleges from the surrounding community were sent flyers requesting applications from STEM teachers interested in participating in a lab experience and professional development leading to participants' creation of one or more instructional STEM lessons for their individual teaching contexts. *STEM teachers* were defined as those participants who worked for a local K-12 public school or community college in which they have an elementary or secondary teaching certificate or a post-secondary degree that qualifies them to teach at least one course in science, technology, engineering, or math as part of their assigned duties. Approximately 100 teachers applied and 16 were accepted across both RET programs; 15 participated in the study. Demographic data for study participants are shown in Table 1.

We were asked to be part of the educational team that provided professional development support for the teacher-participants (Elwood et al., 2016). At the beginning of both RET programs, we facilitated a three-hour Design Thinking overview workshop. Then

Table 1 Characteristic frequencies of DTAIL model design study A teacher-participants

Characteristics	Teacher-participants ($n=15$)	
	n	%
Gender		
Male	5	33
Female	10	67
Race/ethnicity		
American Indian/Alaska Native	1	7
Asian	2	13
Black/African American	2	13
Hispanic/Latinx	3	20
White	7	47
Age		
19–29	2	13
30–39	7	47
40–49	2	13
50–59	4	27

Design Thinking and Instructional Lessons (DTAIL) model

we worked with the teacher-participants for several hours each week resulting in approximately 15–20 contact hours overall during the program.

During the RET, we facilitated the teachers' engagement with the DTAIL model as a tool for developing their lessons, which ranged from single instructional lessons to instructional units that incorporated a series of interconnected lessons. The lessons were developed for use with the students in their own classrooms, but with enough specificity to share with other subject level teachers within their school, district, or even through online lesson plan repositories. This work included unpacking the DTAIL model through activities coupled with reflective discussion (e.g., team charters, root cause analysis, sketching, student interviews, mini teaches, and design critiques), working with teacher-participants in small collaborative subject-level groups and utilizing the model in individual facilitator-teacher consultations to guide peer critique sessions (Ertmer et al., 2008; Svihla et al., 2015).

As the facilitators of the DTAIL model approach, we were transparent about our belief that it may have potential; however, we also developed facilitation guidelines in which we defined ourselves as non-participant observers (Creswell, 2013). For instance, when teacher-participants asked us for lesson suggestions or examples, we typically asked open-ended questions to help foster new critical thinking pathways or directed teacher-participants to another teacher-participant who might have valuable insight.

Design Study A was exploratory. At the beginning of the RET program, teacher-participants were asked to fill out a survey providing their demographic data. At the end of the program, they were asked to respond to three open-ended survey questions concerning their perception of the purpose of the DTAIL model in education: (1) Describe, if any, the ways in which you think you will apply Design Thinking practices in the future, (2) What are the positive aspects of a Design Thinking model, (3) What are some possible challenges to using Design Thinking practices in education? Teacher-participants in each RET program also engaged in a focus group conversation in which they were asked to share their thoughts concerning Design Thinking and their experiences using the model to create instructional lessons. Teachers' responses were analyzed by first searching for thematic keywords or phrases and then followed the constant comparative method to group similar ideas or pull apart more nuanced ideas (Charmaz, 1995). Finally, each teacher-participant's responses were examined for the presence or absence of each theme.

The frequency of emerging themes in the post-implementation data were tallied across the teacher-participants. Regardless of how many times a teacher-participant mentioned a particular theme, the theme was only tallied once per teacher-participant, i.e., the highest possible frequency was 15, corresponding to the 15 study participants. A breakdown of theme frequencies with examples are shown in Table 2. The theme that was mentioned most often was a description of Design Thinking as representing a problem-solving approach (12 participants). This post-program finding was interpreted as a positive outcome, since we were attempting to develop a creative approach to designing instructional lessons that involve viewing instruction as an ill-defined or wicked problem (Conklin, 2006; Jordan et al., 2014). However, teacher-participants mentioned multiple pathways to solutions, iteration, and the promotion of ambiguity much less frequently (4–5 teacher-participants per each of these themes). This was interpreted to mean that teacher-participants felt the model strongly represented a problem-solving approach, but only somewhat or occasionally viewed it as providing a fluctuating convergence and divergence of ideas that could be fostered through multiple ideas, iteration, and ambiguity.

The next strongest theme focused on the group who was most often perceived to be enacting the Design Thinking approach. Of the 15 teacher-participants, 11 specifically described the DTAIL model as an instructional learning approach or strategy to be enacted by their students. While this might demonstrate an excitement for the approach, it also might suggest the teacher-participants were not viewing Design Thinking as an approach to be used by teachers to develop instructional lessons. Nine of the teacher-participants described the model as fostering the 21st Century 4C Skills, seven of whom also viewed the approach as being a student learning strategy/approach. This was interpreted to mean that embedding the 4Cs in the model was making it difficult for teacher-participants to view the DTAIL approach as a strategy for their own problem-solving rather than for their students.

Lastly, 11 teacher-participants described the model as a helpful guide, framework, or approach—a way for teachers to get started on an often daunting task. While this type of feedback was promising, four teacher-participants also provided feedback that either the model was helpful because of how systematic it was or that they were worried that they would not be able to perfect it. This was interpreted to mean that the rotating stage model did not fully visualize the variability in the process.

In sum, the teacher-participant responses from Design Study A provided several positive elements that were tempered by a few misconceptions. However, the misconceptions demonstrated the ways in which the model needed to be revised.

Phase II design decisions

Through analysis of the design data, three areas of concern were identified. Responses suggested that teacher-participants perceived the initial DTAIL rotating stage model as representing (1) a problem-solving approach with very little focus on other Design Thinking assumptions, (2) an instructional approach to be used primarily with students, and (3) a guiding approach that is methodical and rigid. Each of these weaknesses had to be addressed. First, it was determined that the inclusion of the 21st Century 4C

Table 2 Frequency of themes on the perceived purpose of a DTAIL model in education ($n = 15$)

No. of teacher-participants	Theme	Reference examples
12	Problem-solving approach	Learning to solve a real-world problem (P2) Having a 'problem' is what drives the process (P8) Attacking wicked questions (P13)
11	Student learning strategy	To help students design their experiments (P6) Template for students (P11) Students need to be asking themselves how can I change or design differently (P14)
11	Guiding approach	This could really guide them (P5) Design Thinking sets that framework (P7) Having a place to start is key to get momentum and move forward (P13)
9	Fosters 4Cs	Refers to the 4C's (P1) Design Thinking promotes collaborative critical thinking and communication (P2) It also involves cooperative learning strategies (P6)
5	Multiple paths	The concept of 1 (idea) + 1 (idea) = 3 ideas, not just 2 ideas (P3) There is no one answer (P7) Multiple approaches and responses (P15)
5	Iterative approach	Constant evaluation (P2) Re-evaluate and do it again (P3) Multiple trials over and over until something works (P15)
4	Promotes ambiguity	Uncomfortable but safe (P13) Taking risks (P14) Learn from failure (P15)
4	Methodical approach	Systematic approach (P1) Methodical 'think through' (P4) Follow the model step by step (P16)

Theme frequencies were based on teacher-participants' perceived understanding of the Design Thinking approach after participating in pilot Design Study A for the Design Thinking and Instructional Lessons (DTAIL) model. P refers to the teacher-participant number

Skills—communication, collaboration, critical thinking, and creativity—muddied the model too much. Concerned that the 4Cs promoted the belief that the model was primarily for students, the 4Cs were removed from subsequent drafts.

It was further determined that the fluctuating problem space should be visualized in relation to the stages and that the concept of reframing should be incorporated. In doing this, other valuable Design Thinking assumptions would be better demonstrated. In addition, a visualization of the fluctuation might foster an openness to new solution ideas rather than a dependence on perfecting a methodical framework.

A return to the literature resulted in a visualization method for the fluctuating problem space. Teal (2010) posited that Design Thinking was less like a linear taproot and more like the growth of a rhizome with its variety of root paths:

> Acting rhizomatically says that knowledge of the problem arises by inhabiting an emerging solution, and as solutions are rendered, the problem gains clarity; simultaneously the solution evolves. This process of cultivation is like the literal rhizome: responding concretely (i.e., making solutions) is the growth media for new problem/solution tendrils to sprout. In this growth media the problem reaches out, penetrates and generates plateaus. The dynamism of this process is what allows the complexity and nuance of real problems to enter into the work as, paradoxically, a specific solution. (p. 301)

The rotating stage model was easy to understand and aesthetically pleasing in its simplicity but did not provide a visualization of the fluctuation involved in the actual process. Teal's (2010) rhizomatic image inspired the second draft of the DTAIL model, see Fig. 2.

In this new version, the stages were heavily simplified to highlight the problem space, which was depicted as beginning with a problem that led to a satisficed solution. Design Thinking heavily relies upon the concept of satisficing, the act of being satisfied that a design is good enough to present to a client (or group of students). The design may still need ongoing revision in the future, but it will work for the moment (Lugmayr et al., 2014).

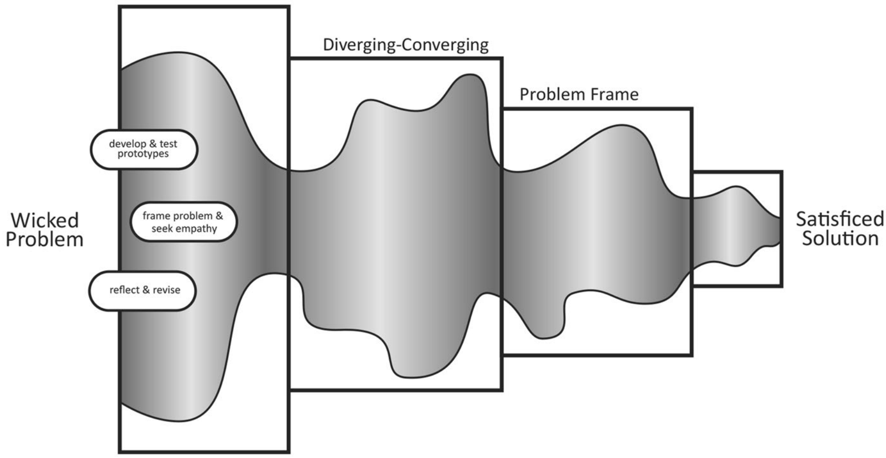

Fig. 2 Second draft of the Design Thinking and Instructional Lessons (DTAIL) model focusing on the problem space with a heavily simplified version of the stages (Elwood et al., 2016)

However, without the circular rotating stages, the sense of iteration seemed to have been lost. We found ourselves returning to the earlier design. In the third draft of the model, the original rotating stages aspect was merged with the problem space resulting in a much more complete version of the model, see Fig. 3.

Development phase III: reframing by circling backward

As part of phase III of the model development, a second design study was conducted. This study followed many of the same strategies as Design Study A with the additional inclusion of post-implementation interviews.

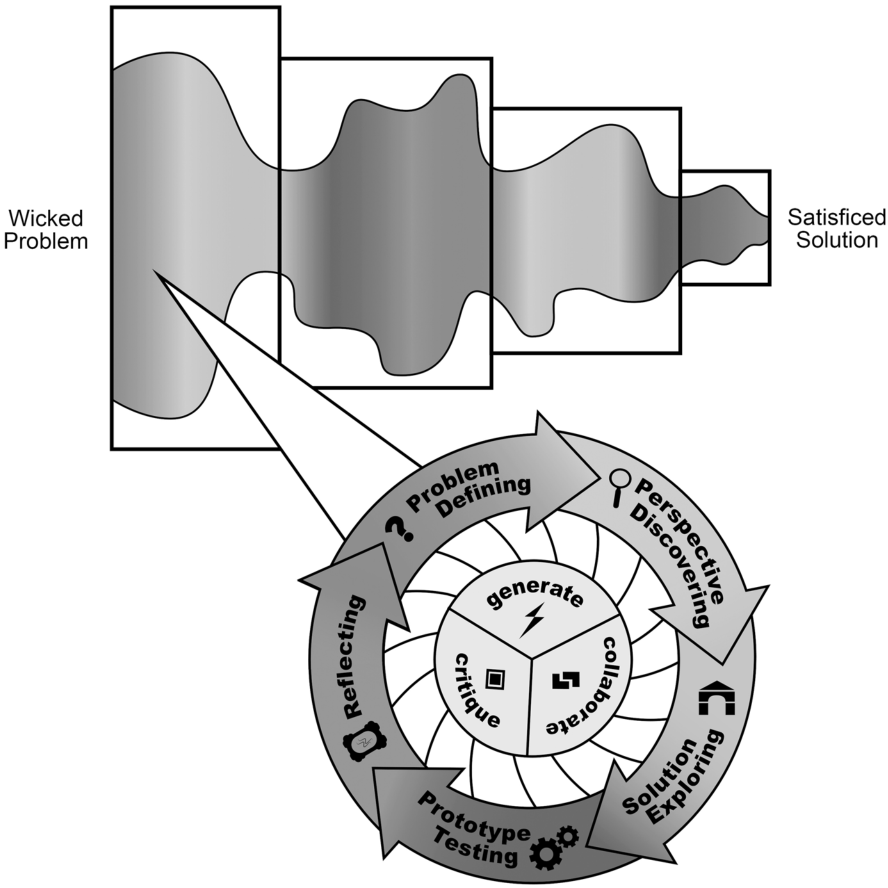

Fig. 3 Third draft of the Design Thinking and Instructional Lessons (DTAIL) model that combined the rotating stages with the problem space

Phase III design study B

The second design study was conducted during two separate but concurrently-run, RET five-week summer programs held at a large southwestern university in the United States. Similar to Design Study A, flyers were sent out to K-12 public schools and community colleges within the community. Sixteen STEM teachers from those schools were accepted to participate in one of two RET programs. These were a different group of teachers from those in Study A. Of the 16 who developed STEM instructional lessons during the summer program, ten teacher-participants were able to implement their instructional lessons during the following Fall semester. Therefore, it was these ten who were asked to participate in the additional interviews. Demographic data for Design Study B teacher-participants are shown in Table 3. Similar to Design Study A, we facilitated a three-hour Design Thinking overview workshop and worked with the teacher-participants for several hours each week resulting in approximately 15–20 contact hours overall. However, for Study B we also spent an additional 40 h the following fall semester observing ten teacher-participants as they implemented their lessons in their own classrooms.

As an introduction to the study, the guiding question, *How and to what extent do K-12 public school and community college STEM teacher-participants perceive the DTAIL model to resonate with their own approach to developing instructional lessons,* was shared with all teacher-participants. Teacher-participants engaged in an overview workshop on Design Thinking, and then in weekly DTAIL design sessions in which they developed new instructional lessons that, as in Design Study A, ranged from one instructional lesson to a unit of interconnected lessons.

In these DTAIL design sessions, teacher-participants engaged in design activities to help promote divergent-convergent thinking as they envisioned the lesson they wanted to

Table 3 Characteristic frequencies of DTAIL model design study B teacher-participants

	All teacher-participants ($n = 16$)		Observed teacher-participants ($n = 10$)	
Characteristics	*n*	%	*n*	%
Gender				
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

Design Thinking and Instructional Lessons (DTAIL) model develop. These design activities involved a *Five Whys Root-Cause Analysis* (Henriksen personal communication, March 13, 2017), an interview of students for empathy, a problem statement development, a *Wrong Theory Design Protocol* (Svihla & Reeve, 2016; Svihla, personal communication, February 23, 2017), a brainstorming activity, a sketching of their typical design process (Cross, 2011; Ertmer et al., 2008), participation in a mini-teach presentation with Research Experience for Undergraduates (REU) and Young Scholar students to test aspects of their designs, and the recording of ongoing ideas in an *Incubation Journal* (Henriksen, personal communication, March 13, 2017). The DTAIL model was used as a guiding visual representation of the Design Thinking approach throughout these sessions.

We also worked with the teacher-participants to gain an exploratory understanding of how the design stages specifically related to their experience developing instructional lessons. The result was authentic and rich dialogue (Lincoln & Guba, 1985) that led to the development of definitions for the stages of the model. In this next section those preliminary stage definitions are provided.

The five iterative stages for developing instructional lessons

A Design Thinking approach seeks to understand diverse perspectives through an empathetic model (Henriksen et al., 2018). The Stanford model highlights this concept by beginning their process with the *Empathize* stage. However, we often found that it was difficult for our teacher-participants to describe the needs of their students without first defining the learning problem. Therefore, the DTAIL model begins by developing a definition of the problem that is iteratively reframed throughout the approach.

During the initial *Problem Defining* stage, teachers were asked to more fully consider why those objectives are important and what larger outcomes they would like to see their students master as part of that learning. We felt that labeling the first stage as *Problem Defining* aligned better with the design literature than IDEO's *Discovery* label and would better connect to the idea of reframing.

While teachers may intend to create multiple learning opportunities to provide differentiation and contextualized content, that instruction is often still built through the lens of the instructor. The *Perspective Discovering* stage of the DTAIL approach encourages teachers to work collaboratively with their students to better determine in what ways the students might or might not be interested in learning the content. *Perspective Discovering* is similar to the Stanford model's *Empathize* stage. However, *Problem Defining* and *Perspective Discovering* work best when teacher-participants are encouraged to revisit these stages as part of reframing the problem.

Once teachers have a stronger understanding of the learning problem and the various stakeholders involved in the learning, they may begin the fluctuating process of *Solution Exploring*. *Solution Exploring* is similar in construct to IDEO's *Ideate* stage. The primary difference is one of language. We found that, if we began with a focus on a *problem*, our teacher-participants often labeled their initial ideas as possible *solutions*. In addition, the pairing of the word *solution* with the word *exploring* suggested that many of those solutions will be discarded or changed at some point. This language shift seemed to better foster reframing with our teacher-participants.

When the DTAIL model approach first began, some teacher-participants again gravitated toward a specific solution—this could be one that has been used with success in the past, one that was recommended to them, or one that they had seen in action. There is nothing wrong with implementing this initial solution; however, by focusing on this one solution, all other potential paths become closed (Dorst & Cross, 2001). However, teachers should be provided with opportunities to diverge from that initial solution path. They should be given permission to use their imaginations and think about what that learning might look like without boundaries.

In the DTAIL model, *Design Testing* involves selecting at least one possible solution and beginning to build it. This stage is similar to the Stanford *Prototyping* and IDEO *Experimentation* stages. However, if we used the terms *prototype* or *experiment* during this stage, teacher-participants began to think of the output their students would create (e.g., an essay, a science experiment, a solar car, etc.) instead of their own output (i.e., an instructional lesson). Therefore, for the DTAIL model we used *Design Testing* for the label to align with instructional lesson development more clearly.

For teacher-participants, *Design Testing* could involve storyboarding or sketching aspects of the learning. It could involve gathering content that might relate to the overall instruction and beginning to create a timeline or map to demonstrate which aspects will be done in which order. Once certain pieces of the learning instruction have been developed, teachers should find ways to test aspects of the instruction. They could share drafts with colleagues for critique and feedback, or with family members to test the clarity of instructions and overall intent. They might even consider returning to the *Perspective Discovering* stage to ask a few students in their class to provide feedback or ask a colleague to have his/her students test some aspect of the learning.

The *Reflective Reframing* stage is one of the most iterative of the stages. With each new piece of information, the teacher-participants' understanding of the problem changes, which in turn reframes the problem. It is this constant reframing that converges the multiple solution ideas into one or two testable designs. Because of this continuous on-going reflection through the development stages, once the instructional lesson is implemented, it might be tempting to put that lesson away until it comes time to teach it again. Instead, during this stage, evaluation data should be collected to determine which aspects of the instructional lesson should be revised. The teacher might even want to again speak to colleagues, students, or other stakeholders to better clarify why certain outcomes resulted, and/or solicit feedback on ways the content may be changed to better foster certain outcomes.

Lesson implementation observations and interviews

In addition to data collection related to teachers' use of the DTAIL model during lesson creations, observation of instructional lesson implementation and post-lesson interviews were conducted with ten of the Design Study B teacher-participants in the Fall (refer to Table 3). The amount of classroom time individual teacher-participants devoted to their instructional lessons ranged from one day to four weeks, see Table 4. For each of the ten teacher-participants, researchers observed over one to three days (approximately one hour per observation) as they implemented their lessons in their own classrooms, after which they engaged in a post-implementation interview.

Before asking the post-implementation interview question *What was your process for creating your RET instructional lesson compared to the DTAIL model*, the researcher included a landmarking memory cue (Weisberg, 2005), in which teacher-participants were asked to think specifically about the first day of the RET program up through the date of the interview. Then they were asked to think about the approach they used during that

Table 4 Summary of implemented RET instructional lessons by observed teacher-participant

Teacher-participant	Overall unit length	Science, technology, engineering, & math (STEM) unit/lesson summary
Colin (P1)	4 weeks	Determine location for and build a prototype concrete dam
Evan (P2)	3 days	Propose a nature-inspired product (shark tank style)
Claire (P3)	4 weeks	Conduct a sieve analysis and design a soil solution
Angelica (P4)	3 weeks	Conduct an experiment using microbes
Thad (P5)	2 days	Determine calculations for soil remediation research
Sam (P6)	1 day	Conduct a soil classification and sieve analysis
Ben (P7)	2 weeks	Conduct a liquefaction remediation experiment
Zane (P8)	2 weeks	Conduct a dust mitigation experiment
Leslie (P9)	2 weeks	Observe liquefaction effects on building models (shake table)
Lou (P10)	3 weeks	Design and test an infinite spinner using a solar cell

For each of the ten teacher-participants, researchers observed over one to three days of the lesson, approximately one to two hours per observation, as lessons were implemented in the teacher-participants' classrooms

RET research experience for teachers

period to develop their instructional lesson, and an image of the DTAIL model was provided as a response aide for this question (Weisberg, 2005).

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

Theme analysis was used to sort the data into categories. All the transcribed responses were reviewed multiple times, highlighting key phrases, while organizing similar phrases into initial categories (Creswell, 2013). The constant comparative method (Charmaz, 1995) was used to continue adding new categories or fragmenting them. After reading through the transcripts three times without any of the categories changing, the analysis was saturated (Creswell, 2013). Based on this analysis, the identified categories suggested that teacher-participants somewhat, mostly, or completely resonated with the DTAIL model. All names used are pseudonyms and were self-identified by the teacher-participants.

Somewhat resonating

Four teacher-participants (Evan, Thad, Sam, and Zane) provided descriptions of their instructional design experiences that were interpreted as somewhat resonating with the DTAIL model. These teacher-participants selected a few aspects of the approach as their focus. Their responses showed that they primarily focused on defining the problem and reflecting, but they either did not mention other aspects of the model at all or explicitly noted they did not experience those other aspects. Also, three of those four teacher-participants initially viewed their complex 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.

These four teacher-participants found themselves specifically utilizing certain aspects of the model, but not others. Additionally, these four teacher-participants did not see themselves fluctuating in and out of problem framing as much as the model implied. All four of them seemed to begin the RET program planning to find ways to directly integrate the RET research experiments into their classrooms, e.g., *"I was trying to connect what was going on in the [RET] lab to the lesson plan [development]"* (Evan, P2); *"I need to know that we can mimic this [RET research] process in our classroom. How can we do this cost effectively and mimic it without using the most expensive material?"* (Zane, P8).

They were not necessarily seeking a creative approach to instructional design issues they faced in their classrooms, but rather a method for replicating the RET experience on a smaller scale for their own students. This may have limited their need to fully embrace a creative process primarily intended for developing solutions to 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). However, the intention is not to use the DTAIL model in the development of all instructional lessons. Learning objectives that can be effectively met through well-known strategies may not require a creative development approach.

Mostly resonating

Two teacher-participants (Ben and Leslie) provided descriptions that were interpreted as resonating with the DTAIL model, but they also described a few aspects of the model as not completely in alignment with their experiences. Ben felt his approach resonated, but that as he continued to iterate, he did not necessarily go through each of the five stages as depicted each time. Instead, he sometimes engaged in additional reflection and revision without gaining added perspective or running another test of his ideas. "*I think the reflective aspect of the Design Thinking process was the most valuable part of creating my instructional lesson plan. As I reflected on my plans, I gained a better understanding of the variables related to my problem and developed new strategies to navigate around them"* (Ben, P7).

Leslie felt her instructional design experience was like "controlled chaos," which made her view the DTAIL representation as too uniform. She felt the DTAIL model graphic still suggested a forward-moving direction, which she did not always feel as she was developing her instruction. *"Although I can see the movement in your model, it appears more uniform than I would say my mental processes were—perhaps more specifically, an image of controlled chaos is more what I experienced. [My design was] sometimes two steps forward only to take three steps back"* (Leslie, P9).

Note that while both teacher-participants felt the model did not fully visualize these aspects of their experience, Design Thinking assumptions are actually supported by their descriptions, and they both saw value in the approach: *"Understanding the fluidity and strength of [Design Thinking] is critical to shifting ways of engaging with the teaching/learning process"* (Leslie, P9). However, it also suggests that the DTAIL model did not yet fully capture Design Thinking in context to these teacher-participants' approach to developing instructional lessons.

Completely resonating

Four of ten teacher-participants provided descriptions that were interpreted as completely resonating with the DTAIL model (Colin, Claire, Angelica, and Lou). The descriptions of their instructional lesson design process coincided with the Design Thinking elements as depicted on the DTAIL model graphic, and they supported its potential, e.g., *"For teachers who are new to the process of Design Thinking this would add a lot of value to our work"* (Colin, P1); *"I like the thinking that there are simple problems and that there are problems that are wicked. I really need everyone to know, this was very motivating for me"* (Angelica, P4).

Lou (P10) provided one of the strongest examples of complete resonation with the model. Before his participation in the RET summer programs, Lou had no knowledge of or experience with using a Design Thinking approach. He described the choices teachers make about the instruction they teach as a "curricular story." He saw lessons as resources and felt that each teacher had his or her own way of "weaving those resources" together.

For the RET program instructional lesson implementation, Lou developed a new unit that 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 and redesigning. Afterwards, students reflected on aspects that worked and challenges for the next design iteration.

In his post-implementation interview, Lou shared his thoughts on the ways in which the DTAIL model aligned with the process he went through to develop this STEM instructional lesson.

> [The development process is] like your picture [i.e., the DTAIL model] and that's the rehearsal. Rehearsals are sloppy and they're all over the place. They're not linear and you want it to be linear; it just doesn't always go that way. But the end product is nice and pretty and everything. Where I'm at in the [development] process now [is the nice and pretty stage]. Where I was in the process this summer was definitely all over the place… [In the DTAIL model] all those little curves and crevices and colors are all those little variables that we have to figure out to get to that pinpoint. It's not a linear graph. It doesn't go straight. It's got a direction, but it doesn't have a defined direction… When I looked at that picture this morning I was like, oh my gosh. I know exactly where I am in that picture. I'm in the second little cave. There's three little caves, but I'm in the second one. I wouldn't say I'm in the third one yet, but I'm definitely out of the first… That's what's cool about that picture... I can push it around a little bit. It can gel a little bit differently and maybe that was the artist's intention or maybe that's just my interpretation. I thought I was in that third little opening on the picture and I just realized that it opened up a brand new whole picture, so—right now I thought I was at the end and now I'm really at the beginning of this part. I'm not going to end [development] for the sake of ending it; I have to do it right. (Lou, P10)

Lou saw himself in the model, often moving backward in order to move forward, but with definite direction. He had originally thought that the implementation of his newly created instructional lesson would signify the end of its development, but as he reviewed the DTAIL model, it made him think of new things he wanted to try in its next iteration. This suggests that the model was able to provide him with an aligned visualization of the process he actually experienced, which seemed to motivate him towards continued iteration and revision.

> There were different things that resonated with me in the teacher part of what we did in our RET program. A big one… was that [DTAIL] 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)

Not only did Lou use the DTAIL model to develop his instructional lesson during the five-week RET program, but he continued to use it as a guide for developing units throughout the subsequent school year.

> 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)

The teacher-participants who were identified as mostly and completely resonating with the model indicated that they found the lessons they created and implemented to be valuable. Moreover, the DTAIL model continued to be useful to them as they reflected on learning gaps and methods for redesigning their lesson for the next implementation.

Phase III design decisions

The analysis of Design Study B teacher-participant responses was used to determine aspects of the model that needed further revision. For instance, Ben and Leslie's descriptions of their lesson designing experiences suggested that two aspects of the model needed to be clarified. First, a description needed to be added to make it more explicit that the stages were to be used *as needed* to navigate the problem space. While the DTAIL model does provide a circular five-stage process, in practice the Design Thinking stages might overlap or be conducted simultaneously. Additionally, the iterative Design Thinking approach suggests that stages are repeated; however, this does not mean all the stages are repeated with the same level of depth and/or in the same order. Instead, some stages, such as reflecting or testing, might be implemented repeatedly, perhaps without utilizing the other stages.

Also, the model needed to more strongly visualize how the five-stage wheel fosters the reframing of the problem space. Leslie mentioned that she often felt she was moving backwards. Yet to her, the visualization of the model implied a consistently forward-moving direction. A stronger visual connection of the wheel to the chaotic problem space might allow users to be better prepared for navigating this diverging-converging space. In addition, it was determined that the model should depict backwards momentum in some instances to demonstrate a potential need to return to earlier possible solutions—further dig into them to better determine if they now align or should be removed—before moving forward again.

For this Phase III version of the model, several polishing revisions were made. The rotating wheel was moved so that it was more clearly connected to the rectangular frames. Arrows were also added to the frames. These arrows incorporate a dashed line to indicate an optional direction and can be seen to move backward within the frame as needed to demonstrate an active reframing of the problem several times throughout the problem space. The rectangular frames were more concretely labeled as *Problem Reframing* and the fluctuating area as the *Problem Space*. The *Wicked Problem* label was changed to *Instructional Lesson Problem* to align with the purpose of the model more explicitly. Also, during this study, we were increasingly being asked to clarify how an instructional lesson is a prototype. The teachers often thought of prototypes as cars, buildings, or bridges, but not instructional lessons. We therefore decided to change the *Prototype Testing* stage label to *Design Testing* to better foster teachers' view of themselves as designers (Kalantzis & Cope, 2010; Kali et al., 2015; McKenney et al., 2015; Svihla et al., 2015). Also, the *Reframing* stage was renamed *Reflective Reframing* to indicate its reliance on a designer thoughtfully drawing from previous stages. Lastly, text was added to the center of the stage wheel to provide explicit direction that the stages are to be repeated within each reframing *as needed*. The final version of the model can be viewed in Fig. 4.

The findings from these three design phases have demonstrated that the potential value of the DTAIL model as a tool for teachers originates from its visualization of Design Thinking assumptions that are not apparent in other popular models.

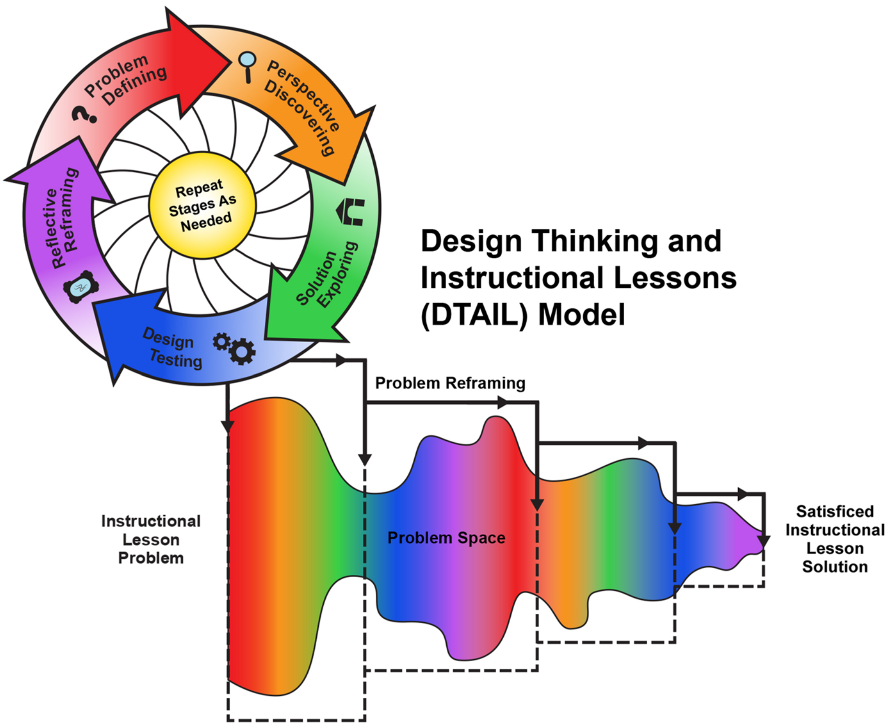

Fig. 4 The Design Thinking and Instructional Lessons (DTAIL) model depicts a creative approach for developing instructional lessons in which teachers iteratively use five stages to frame and reframe the fluctuating problem space until it is narrowed to a satisficed instructional lesson solution

Conclusion

This article described the design process used to develop the DTAIL model. The process began with a review of the literature supporting the need for creative approaches to instructional lesson development, a description of existing popular Design Thinking models, and the limitations of those models for fully visualizing the process of instructional lesson development. We argued that these popular models have overly simplified what is essentially a complex process. We further contend that Design Thinking should not be used for every instructional lesson design situation but is most effective for those with a complex instructional problem or in which a creative approach is desired. Various representations of the DTAIL model were tested across three phases, which resulted in increasingly detailed depictions of the model.

In the first phase of model development, findings suggest that a Design Thinking model used to develop instructional lessons should include an explicit representation of iteration. This was depicted through a rotating circle and active verbs for the stage labels. In the second phase, the rotating stages did not fully visualize the process on their own. Subsequently, the stages were coupled with a fluctuating problem space inspired by a rhizomatic root system (Teal, 2010). The third design phase provided more nuanced revisions. The problem space and reframing aspect of the model were labeled and two of the stage labels were changed. Also, the rotating stages were tied more firmly to the act of reframing. Lastly, the narrowing frames were depicted with dashed lines and arrows pointing backward to demonstrate the recursive nature of the approach more explicitly.

The scholarly literature and findings from two design studies suggest that Design Thinking models that facilitate teacher-driven design of instructional lessons should include the five design stages with an explicit depiction of rotation and recursiveness. In addition, Design Thinking models should also depict (1) iteration, reflection, and revision; (2) a chaotic fluctuating problem–solution space, and (3) circling backward to eventually narrow the problem space toward a satisficed solution. We contend that the DTAIL model embodies these elements and that further empirical testing is warranted.

The design studies utilized a mixed methods approach and were exploratory in nature, and as such our main intention was to embody a strong sense of trustworthiness (Creswell, 2013) and sincerity (Tracy, 2013). Towards this end, we incorporated several qualitative validation strategies (Creswell, 2013), working for a prolonged time with teacher-participants, developing formal researcher memos after field observations and informal memos as we analyzed data, and meeting regularly during debriefing sessions to discuss progress. We also conducted multiple design iterations, worked alongside our participants to co-create meaning, and provided a rich, thick description of teacher-participant perceptions through key reference examples for themes (Anderson & Shattuck, 2012). In addition, we shared the instructional lesson observation summaries with each of the ten teacher-participants whose implementation was observed as part of member checking (Creswell, 2013).

Nonetheless, the small sample size of the studies, as well as the type of data collected limit the generalizability of the study findings. Due to the exploratory nature of this initial work, we recommend continued empirical research be conducted within teacher education programs, during professional development sessions, and across a variety of subject areas beyond STEM. Future studies should attend to teachers' implementation and evaluation of lessons they create using the DTAIL model. Research that determines (1) to what extent the DTAIL model stages align with the process teachers use to design instructional lessons, (2) what types of activities effectively foster framing and reframing, and (3) the impact of instructional lessons designed through the DTAIL approach on student learning is also of great interest. To demonstrate the effectiveness of the model, studies are needed that richly describe teachers' use of the DTAIL model in contrast with other methods of developing lesson plans.

There is still much to uncover concerning the use of Design Thinking in education. However, evidence from the three design phases indicate that the DTAIL model resonated with the teacher-participants. Furthermore, the teacher-participants viewed the DTAIL model as a promising approach for developing K-12 public school and community college instructional lessons.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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Kristin Elwood is the Director of Digital Initiatives and Instructional Design and a Clinical Assistant Professor for the School of International Letters and Cultures at Arizona State University, where she supports faculty in and conducts research on digital learning innovations.

Michelle E. Jordan is an Associate Professor of Educational Psychology and the Learning Sciences in the Mary Lou Fulton Teachers College at Arizona State University. She currently conducts research on how teachers and students engage in collaborative learning during design projects.