14. Factor structure, validity, and reliability of an instrument for assessing design thinking

Elena Novak and Ilker Soyturk

INTRODUCTION

A recent survey of business leaders from around the world lists creativity as one of the top skills for tomorrow's workforce and calls for schools to invest more time and education in this skill development (Dell, 2021). Many educators and policymakers consider creativity and innovation among critical 21st-century thinking skills. Nevertheless, practising these skills in a K-12 classroom remains a challenging task due to insufficient emphasis of these skills in today's curricula and lack of appropriate educator training and resources (Adobe, 2018). Several prominent researchers have argued that teacher preparation programmes should devote more attention to enhancing their graduates' creativity and design thinking (DT) skills, because DT can help teachers think more creatively about diverse, multifaceted, human-centred educational problems that require non-linear, complex solutions on a day-to-day basis (Henriksen et al., 2017; Mishra & Mehta, 2017).

DT originated in engineering and design professions as a framework for supporting an iterative and interactive process where designers "experiment, create and prototype models, gather feedback, and redesign" (Razzouk & Shute, 2012, p. 330). Research in this area focused primarily on the cognitive processes that novice designers apply to solve design challenges as compared with experienced designers (e.g., Nagai & Noguchi, 2003; Owen, 2007; Stempfle & Badke-Schaube, 2002). Recent research has extended the application of DT to non-design professions as an approach for developing an individual's confidence to think and act creatively (Wrigley & Straker, 2017). As a result, DT has been closely associated with innovation and creativity, as an increasingly practised approach for improving communication, innovativeness, and success (Cross, 2007; Royalty et al., 2014). It is considered a cognitive style (Kimbell, 2011) or a third way of thinking that is different from the humanities and sciences, due to "extensive experimentation and exploration resulting from an iterative process" (Hokanson & Nyboer, 2018, p. 1). More broadly, it is grounded in a philosophy of design that is different from other formulations of philosophy, such as a philosophy of science, for example, because a philosophy of design has different aims, e.g., use creativity to create something innovative, make an intentional change (Nelson & Stolterman, 2013).

A recent literature review on DT highlighted a lack of research that examines the impact of DT on organizational and individual performance as well as assessments of DT skills (Micheli et al., 2019). One of the reasons for the scarcity of research in this area is a lack of validated measures that assess DT skills. Moreover, a large body of research examined DT

in engineering, design, and business professions (Magistretti et al., 2021; Nakata & Hwang, 2020; Razzouk & Shute, 2012). Considerably less research examined DT in K-12 and teacher education. To address these research gaps, this study (1) examined DT in prospective teachers using Royalty et al.'s (2014) scale that measures the outcome of teaching DT, hence referred to as the *Design Thinking Scale* (DTS), and (2) explored the DTS's factor structure, validity, and reliability. The DTS is an 11 items five-point Likert scale that asks participants how confident they are that they can exhibit various behaviours related to DT. However, the scale has not been validated and its underlying factors are yet to be explored.

DESIGN THINKING MINDSET

DT is viewed as both a mindset and a process or a set of tools (Groeger et al., 2019; Wrigley & Straker, 2017). As a process and a set of tools, DT has been applied to solve "wicked problems" that require designers to solve ill-defined challenges (Buchanan, 1992). A typical DT process involves empathizing with end users, defining the problem, brainstorming radical ideas, prototyping, testing to refine the solution and collect data, and assessing project work (Stanford d.school, 2010). As a mindset, DT entails the underlying values, cognition, and behaviours that influence organizational culture and people's beliefs about innovativeness and creativity (Groeger et al., 2019). The "design state of mind" (Beverland et al., 2017) is rooted in the fixed and growth mindset dichotomy (Dweck, 2012) that explains how an individual's ability to innovate and think creatively connects to their mindset and not necessarily to the employed DT processes and tools, because it is the mindset that is critical for achieving desired innovation objectives (Liedtka, 2011).

A vast majority of DT literature has focused on the design thinking processes, tools, and methods as a way of making "the practices of designers accessible and meaningful to managers" (Johansson-Skoldberg et al., 2013, p. 128). However, equating DT with a skillset or toolset without understanding the DT mindsets (nuances of applying and practising DT) has resulted in DT often being misrepresented, demonstrating very little evidence of success (Collins, 2013; Howard et al. 2015; Nussbaum, 2011). Literature on DT as a mindset refers to attitudes, sensibilities, or stances that underpin a professional approach to design thinking. Although, DT researchers and professional designers agree that design mindset plays a critical role in DT, the literature on how design mindset is developed and applied is limited (Howard et al., 2015).

Several attempts have been made to conceptualize attributes of a DT mindset using a variety of research approaches. For instance, Carlgren et al. (2016) identified three major dimensions of DT (i.e., principles/mindsets, practices, and techniques) based on 61 interviews with companies that have extensive experience applying DT. Russo (2016) conducted a comprehensive analysis of 70 articles to investigate DT characteristics. The analysis revealed 17 commonly cited characteristics of DT that were broadly classified as a mindset, process, method, and attitude. Schweitzer et al. (2016) identified 11 characteristics of a DT mindset based on interviews with innovation managers: (1) empathetic towards people's needs and context; (2) collaboratively geared and embracing diversity; (3) inquisitive and open to new perspectives and learning; (4) mindful of process and thinking modes; (5) experiential intelligence; (6) taking action deliberately and overtly; (7) consciously creative; (8) accepting of uncertainty and open to risk; (9) modelling behaviour; (10) desire and determination to make a difference; and

Table 14.1 Principles of design thinking education

Human-centred	Design thinking is a human-centred process. The focus is on making people the source of inspiration and direction for solving design challenges.
Mindful of process	A critical mindset in design thinking is being "mindful of process" or having metacognitive awareness.
Empathy	Empathy is the intellectual identification with or vicarious experiencing of the feelings, thoughts or attitudes of others. Empathy develops through a process "needfinding" in which one focuses on discovering peoples' explicit and implicit needs.
Culture of prototyping	The mindset of creating and maintaining a "culture of prototyping" focuses on being highly experimental, building to think, and engaging people with artefacts.
Show don't tell	As a mindset, "show don't tell" takes traditional visualization one step further, as it includes sketching and traditional prototyping, digital communication and storytelling.
Bias toward action	"Bias toward action" is a focus on action-oriented behaviour rather than discussion-based work. A "bias toward action" mindset utilizes all modalities of learning.
Radical collaboration	This mindset is built upon the idea that radically diverse multidisciplinary teams will lead to greater innovations than teams that come from the same discipline. Examining and confronting team dynamics is an essential component.

Source: Rauth et al., 2010.

(11) critically questioning. Stanford University's Design School Bootcamp Bootleg (Stanford d.school, 2010) mentions the following seven mindsets: human-centred design, being mindful of the process, empathy, a culture of prototyping, show don't tell, bias toward action, and radical collaboration. These mindsets were adapted from Rauth et al.'s (2010) seven basic principles of design thinking education (Table 14.1). However, there is no information about how these principles were developed.

Overall, despite the variety of different research approaches, settings, and target audiences used to study DT characteristics, the literature provides quite consistent findings regarding the commonly cited characteristics of a DT mindset. These characteristics reveal DT scholars' efforts to translate cognitive processes involved in DT into observable behaviours.

MODELS FOR TEACHING DESIGN THINKING

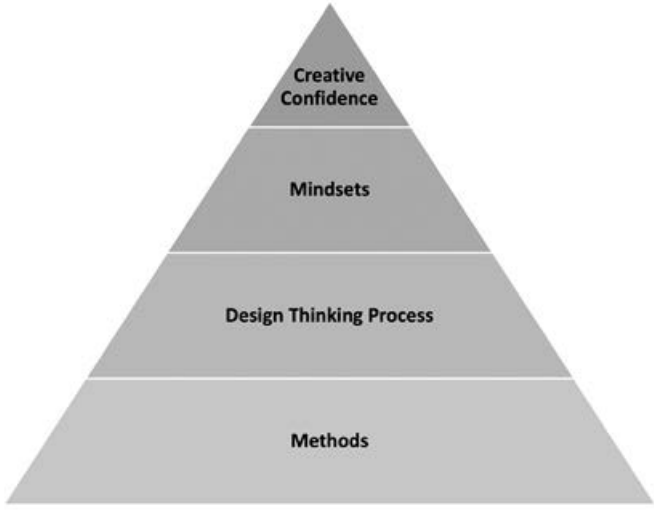
The recent increased interest in DT as an approach for supporting innovation and success in business and industry has drawn attention to DT from non-design communities. For instance, the d.school at Stanford University and the d.school at the Hasso Plattner Institute of Germany are among the leading institutions in the field that work with students from all disciplines to enhance their creativity and innovation through a design process (Royalty et al., 2014). They use a design thinking framework to increase students' *creative confidence* (Kelley & Kelley, 2013), which is believed can support students' ability to act and think creatively. The concept of creative confidence is rooted in Bandura's (1994) work on *self-efficacy*. Self-efficacy reflects an individual's belief in their ability to succeed in a particular domain (Bandura, 1994). In DT education, the domain can be viewed as creative problem-solving. According to Bandura (1982), self-efficacy is part of a broader construct, *agency* – a means by which "people can effect change in themselves and their situations through their own efforts" (p. 1175). Agency involves beliefs about the world, cognitive, behavioural and social states, physical settings, context and other factors. Royalty et al. (2014) view creative agency as

"individuals' capacity to effect change in themselves and their situations to support successful creative problem-solving" (p. 82).

Several models and frameworks were proposed for teaching DT. For instance, Rauth et al.'s (2010) model for teaching creative confidence (Figure 14.1) postulates that repeated practice of DT fosters the development of design mindsets and processes. Students become more confident in their creative problem-solving and ability to act with creative confidence:

> Different competencies are developed, such as prototyping skills, emotional skills, capability of adopting perspectives, empathy and a certain mindset. The development of these creative competencies culminates in the acquisition of creative confidence, which assures the students of their own ability of acting and thinking creatively. (Rauth et al., 2010, p. 7)

The model suggests a hierarchy of skills and competencies as a series of steps that lead to the development of creative confidence, which is the goal of DT education.



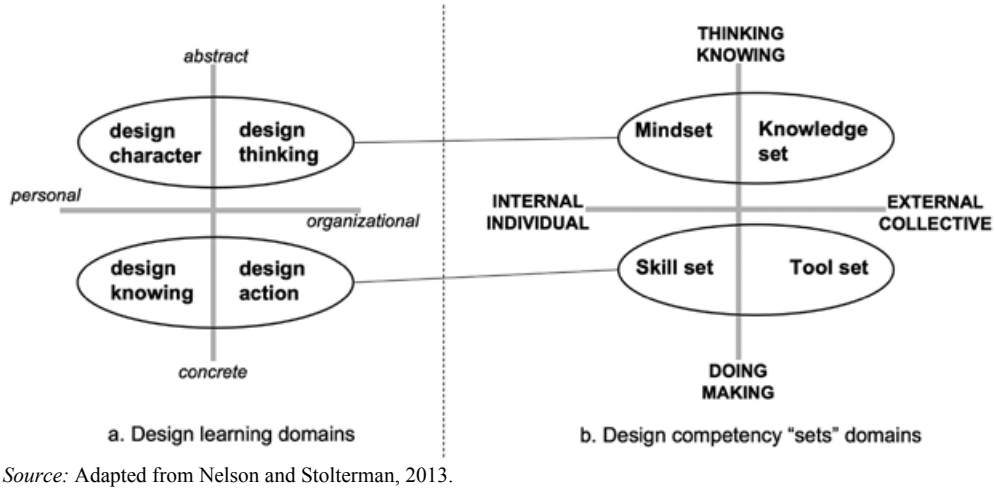
Source: Adapted from Rauth et al., 2010.

Figure 14.1 Model of creative confidence

In contrast to Rauth et al.'s (2010) hierarchical approach, Nelson and Stolterman (2013) used a quadrant with dichotomies to represent skills and competencies that are foundational to design learning. They view design learning across four domains: (a) design character, (b) design thinking, (c) design knowing, and (d) design action or praxis (Figure 14.2a). These four domains correspond to the four design competency sets that are essential in the process of becoming a designer: (i) mindset, (ii) knowledge set, (iii) skillset, and (iv) toolset (Figure 14.2b). Figure 14.2 demonstrates the connections between the competency sets and design domains. Design character and design thinking are manifested through mindsets and

knowledge sets, while design knowing and design action are manifested through skillsets and toolsets.

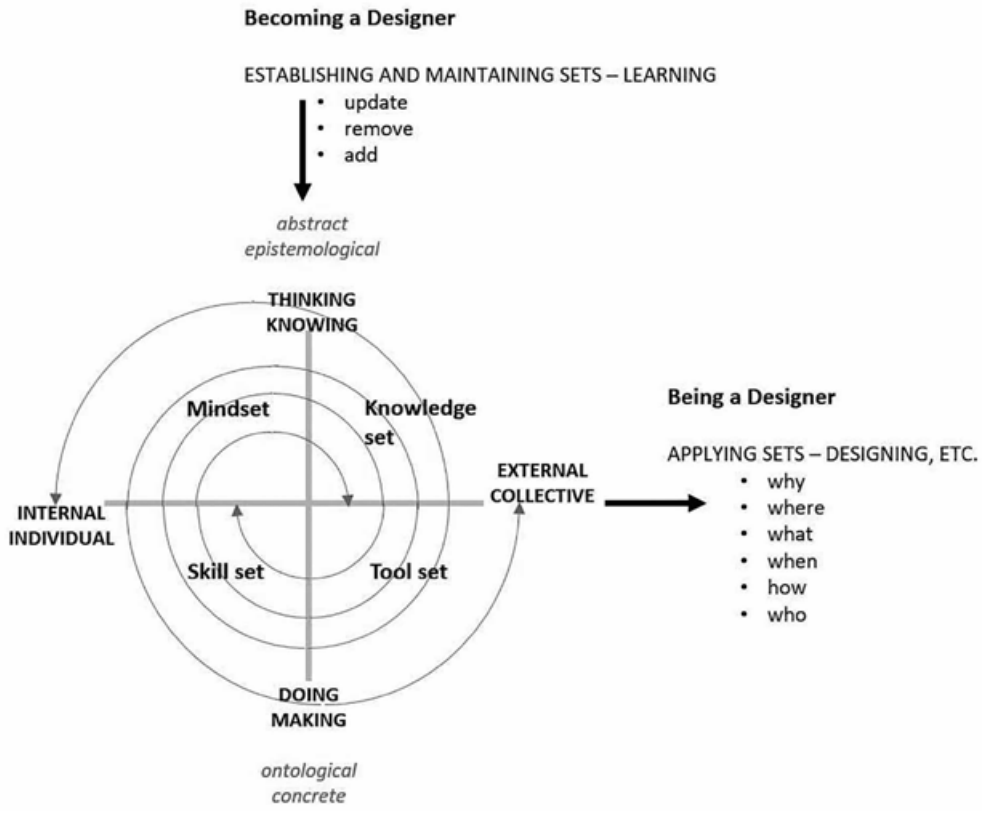
Nelson and Stolterman (2013) argued that design knowledge and design knowing cannot be captured using typical knowledge hierarchies that represent knowledge as an outcome of training or learning (e.g., Bloom's (1956) taxonomy of learning, Russell Ackoff's (1989) knowledge hierarchy), because "wise action and not just evaluated understanding is a demonstration of design wisdom" (Nelson & Stolterman, 2013, p. 229). They view the outcome of design education as being "a process of managing competency sets that are interrelated among the quadrants formed by the crossing axis of familiar dichotomies such as concrete reality and abstract thinking, and the individual contrasted to social collectives" (Nelson & Stolterman, 2013, pp. 229–230; Figure 14.3). Nelson and Stolterman's (2013) hierarchy of design-learning outcomes presents the following progression: design capacity (facts, skills, understandings), confidence (do/act – create change), capability (make/produce – excellence), competence (to learn – to not know, to know), courage (creative and innovative), connection (interrelated and interrelating), and character (personal wholeness). Thus, for instance, design capacity is valuable only if a designer has the confidence to act. The competence to learn in designing matters only if the designer has the courage to be innovative and creative. This hierarchy suggests that DT mindset is foundational for learning design skills, facts, and tools.



Source: Adapted from Nelson and Stolterman, 2013.

Figure 14.2 Interconnections of DT domains and sets

Despite these differences, Rauth et al.'s (2010) and Nelson and Stolterman's (2013) models share many similarities. For instance, both models identify mindset, DT skills, and methods/tools among the essential design competency sets. In addition, both models view mindset as a more complex competency set than the skillset in terms of knowledge acquisition, as mindset is inherently more abstract than a concrete skillset. At the same time, Nelson and Stolterman (2013) cautioned that their schemas (Figures 14.2 and 14.3) are not enough for explaining

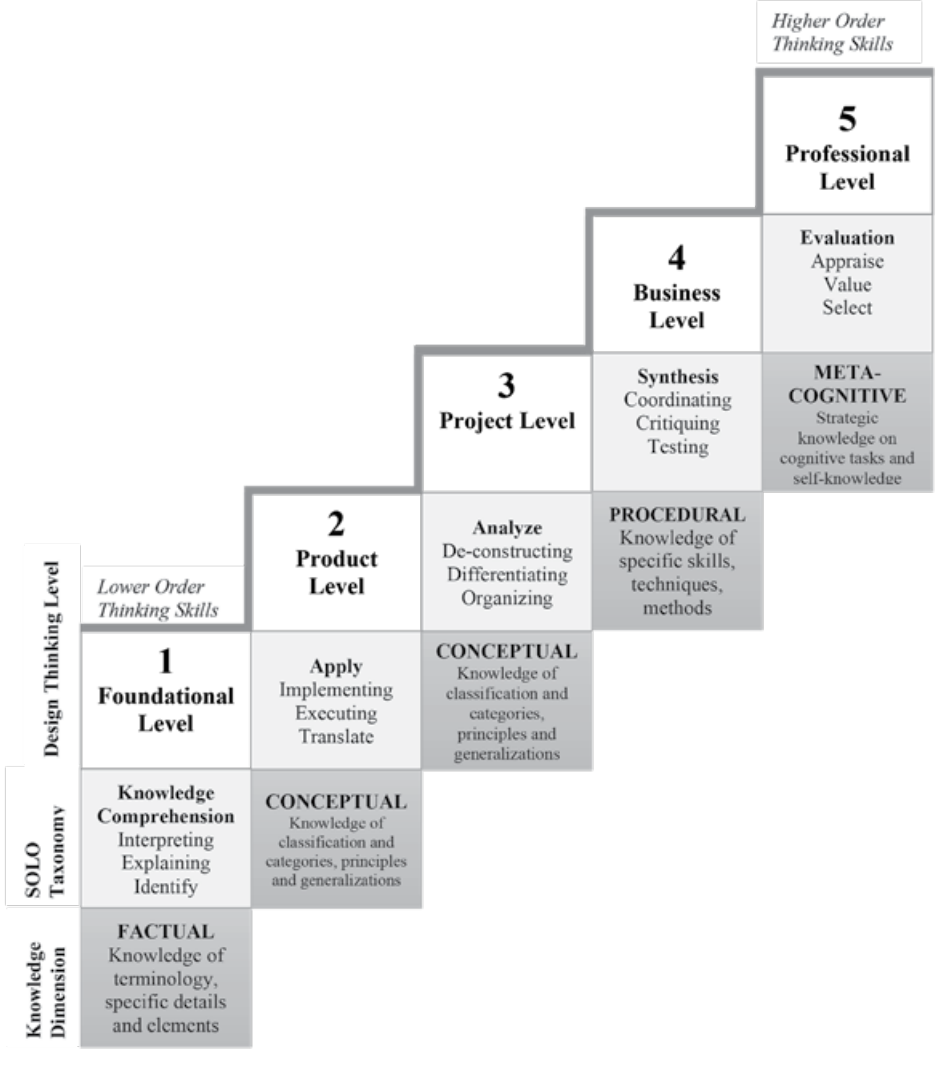


Source: Adapted from Nelson and Stolterman, 2013.

Figure 14.3 Mediation of DT sets and the process of establishing and maintaining design competency sets

design expertise because a designer's knowledge is influenced by numerous external factors such as predispositions, aptitude, environment, societal norms, laws, clients, and stakeholders. More recently, Wrigley and Straker (2017) proposed the Educational Design Ladder to guide the learning process of Design Thinking in Design and Business fields. The Educational Design Ladder (Figure 14.4) was developed based on a review of 51 courses on Design Thinking as well as various academic programmes centred on creativity and innovation from 28 universities around the world. The analysis of the content being taught in these courses as well as how it was taught in terms of assessments and instructional approaches revealed the following five themes: "(i) theories, methods and philosophies, (ii) product focus, (iii) design management, (iv) business management, and (v) professional development" (p. 377). These themes represent a progression in Design Thinking knowledge and therefore can be viewed as "pedagogical stages in the development of Design Thinking" (p. 379). Wrigley and Straker (2017) combined the identified themes with Biggs' SOLO taxonomy (the Structure of the Observed Learning Outcome; Biggs, 1996) to provide a hierarchical framework for designing

a curriculum that integrates Design Thinking and Business across the five stages of DT. The Educational Design Ladder model offers an approach for developing a multi-disciplinary curriculum in DT. However, it is unclear to which extent the model can be applied in non-business fields such as education, for example.



Source: Adapted from Wrigley and Straker, 2017.

Figure 14.4 Educational design ladder pedagogy

MEASURING OUTCOMES OF TEACHING DESIGN THINKING

Despite the growing popularity of integrating DT in non-design fields, little is known about how the acquisition of DT skills can be assessed (Micheli et al., 2019). Most of the research in this area is primarily qualitative.

An initial quantitative attempt to measure the outcomes of teaching DT was undertaken by Royalty et al. (2014) who conducted a series of surveys and interviews to identify key DT competencies in successful d.school alumni (The Hasso Plattner Institute of Design at Stanford University). These studies led to the development of the *Design Thinking Scale* (DTS), validation of which is the focus of the present study. The DTS includes 11 DT competencies in the area of creative problem-solving such as creative idea sourcing, comfort with ambiguity, openness, building creating environments, anti-perfectionism, prototyping, perseverance after failure, creativity facilitation in others, mastery and knowledge of creative process, and successful problem-solving. Our examination of the literature on a DT mindset suggests that these DT competencies are reminiscent of those identified in the extant literature (Carlgren et al., 2016; Russo, 2016; Schweitzer et al., 2016), thus suggesting the DTS's DT competencies can be found in various settings, audiences, and domains of practice.

RESEARCH GOALS

We collected responses of prospective teachers to a battery of assessments of DT, creativity, and innovation to examine the factor structure, validity, and reliability of the DTS. Specifically, two studies were conducted to pursue the following research goals:

1. Examine the DTS' factor structure using Exploratory Factor Analysis (EFA; Study I).
2. Examine the DTS' internal consistency and reliability (Study I&II).
3. Confirm the EFA results using Confirmatory Factor Analyses (CFA; Study II).
4. Examine aspects of the DTS' validity:
    i. Convergent validity was examined by correlating DT with Creative Achievement (Carson et al., 2005) and Innovation scores (Chen et al., 2017). Positive associations of DT with Creative Achievement and Innovation scores were hypothesized (Study II).
    ii. Discriminant validity: One of the common variables that may threaten to confound self-reporting measures such as DT is social desirability bias, i.e., participants' socially desirable responses to questions. To examine the extent to which participants are likely to provide socially desirable responses to the DTS items, Marlowe–Crowne Social Desirability scores (Crowne & Marlowe, 1960) were correlated with DT scores (Study II).

STUDY I: EXPLORATORY FACTOR ANALYSIS AND INTERNAL CONSISTENCY OF THE DTS

The goal of the first study was to examine the DTS's factor structure using EFA. In addition, it examined the DTS's internal consistency.

Method

Participants and procedures

Undergraduate students majoring in education (N = 191; 185 females, six males; M age = 21.75, SD = 2.26) from a large mid-western university in the United States participated in the study. Participants were recruited from undergraduate Science Methods and Educational Technology courses. They completed a background questionnaire (age, gender, educational background, etc.) and the DTS online for research credit participation in their course.

Design thinking scale (Royalty et al., 2014)

The original DTS includes 11 five-point Likert-type items that gauge respondents' beliefs about their ability to act with creative confidence. The response categories include: "Not at all confident" (1), "A little confident" (2), "Moderately confident" (3), "Very confident" (4), and "Completely confident" (5). Before administering the instrument to the study participants, we conducted several informal interviews with prospective teachers and their course instructors to get a better understanding of how they interpret the items and the scale relevancy to teacher education. Based on the interviews, Item 3 wording ("Change the definition of a problem you are working on") was changed to "Consider a problem from different perspectives". DT scores were calculated by averaging the 11 items of the scale. The minimum possible score was 1 and the maximum possible score was 5. Table 14.2 presents descriptive statistics of the 11 DTS items.

Data analysis

The factor structure of the DTS was investigated using EFA, which helps determine how items are related to constructs if a theory model is not provided (Brown, 2006; Thompson, 2004). Principal Axis Factoring (PAF; Schumacker & Lomax, 2010) along with Direct Oblimin (DO) rotation was used in EFA. Internal Consistency of the factors was measured using Coefficient Alphas for each factor and the total scale.

Results

Factor structure

After screening the data and verifying relevant assumptions, the potential factor structure of the DTS was examined using EFA with PAF extraction with DO rotation. The Kaiser's criterion for the eigenvalue greater-than-one rule and the scree plot (Figure 14.5) suggested a two-factor solution for the DTS (Table 14.3). The first factor included five items (#4, #8, #9, #10, #11) that can be viewed as *Creative Agency* – an "individual's capacity to effect change in themselves and their situations to support successful creative problem-solving" (Royalty et al., 2014, p. 82). The second factor included five items (#2, #3, #5, #6, #7) that describe *Design Dispositions* such as being mindful of the design process, a culture of prototyping, action-oriented behaviours, and collaboration (Rauth et al., 2010). Item #1 was excluded because it did not fit the meaning of Factor 2. These factor loadings are consistent with the theoretical perspectives underlying the DT construct (Rauth et al., 2010; Royalty et al., 2019).

Table 14.2 Descriptive statistics for the design thinking scale items (N = 186)

How confident are you that you could…	M	SD
1. Find sources of creative inspiration not obviously related to a given problem.	2.89	0.935
2. Effectively work on a problem that does not have an obvious solution.	2.89	0.908
3. Consider a problem from different perspectives.	3.68	0.826
4. Shape or change your external environment to help you be more creative.	3.43	0.899
5. Share your work with others before it is finished.	3.66	1.024
6. Try an approach to a problem that may not be the final or best solution.	3.32	0.942
7. Continue to work on a problem after experiencing a significant failure.	3.30	1.052
8. Help others be more creative.	3.86	0.945
9. Identify and implement ways to enhance your own creativity.	3.60	0.966
10. Explicitly define or describe your creative process.	3.23	1.025
11. Solve problems in ways that others would consider creative.	3.33	1.022

Note: *SD* = Standard deviation.

Table 14.3 Final exploratory factor analysis for the DTS with factor loadings (10 items)

	Items	Factors	
		1	2
9.	Identify and implement ways to enhance your own creativity.	0.948	
11.	Solve problems in ways that others would consider creative.	0.820	
8.	Help others be more creative.	0.780	
10.	Explicitly define or describe your creative process.	0.726	
4.	Shape or change your external environment to help you be more creative.	0.581	
6.	Try an approach to a problem that may not be the final or best solution.		0.878
5.	Share your work with others before it is finished.		0.690
7.	Continue to work on a problem after experiencing a significant failure.		0.559
2.	Effectively work on a problem that does not have an obvious solution.		0.402
3.	Consider a problem from different perspectives.	0.355	0.357

Note. Factor 1 = Creative Agency; Factor 2 = Design Dispositions

Internal consistency

The DTS and its two sub-scales had a high level of internal consistency (Cronbach's $\alpha_{\text{CreativeAgency}} = 0.884$; Cronbach's $\alpha_{\text{DesignDispositions}} = 0.807$, Cronbach's $\alpha_{\text{DTS}} = 0.882$).

Discussion

The DTS factor structure suggests that DT skills as assessed by the DTS can be viewed along two dimensions: Design Dispositions and Creativity Agency. Using an EFA, five DTS items

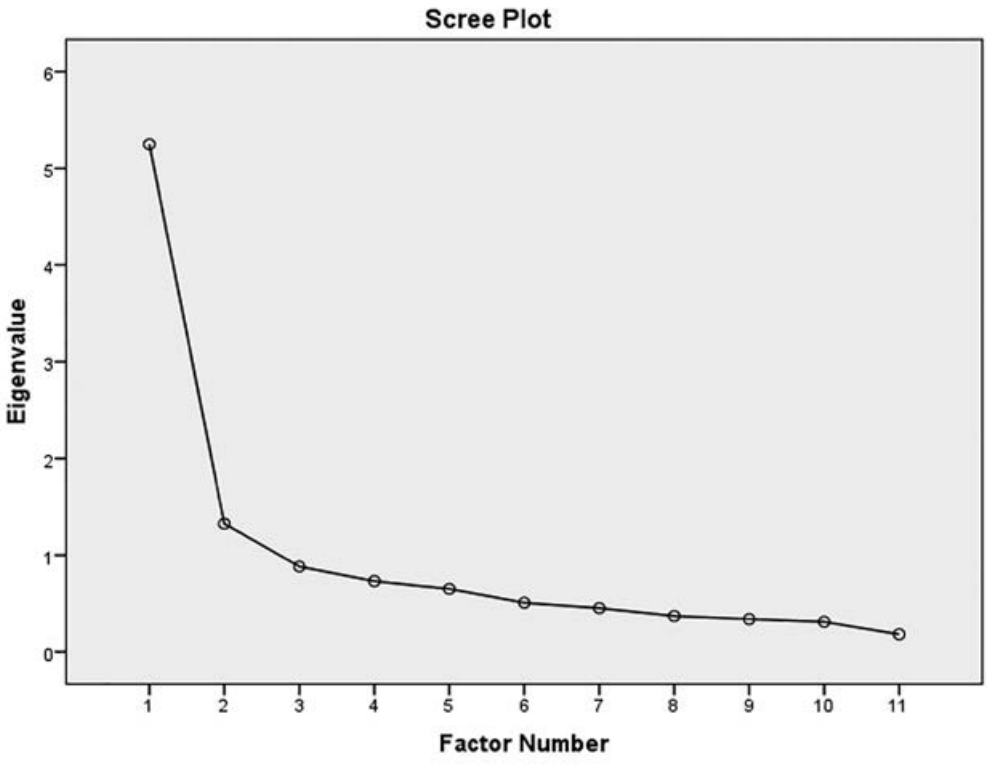


Figure 14.5 Scree plot for the DTS

are loaded on the Creative Agency factor and the other five DTS items loaded on the Design Dispositions factor.

The Design Dispositions subscale includes items that describe how people approach work on design-led innovations. These design dispositions reflect the basic principles of DT education (Rauth et al., 2010) and are similar to Schweitzer et al.'s (2016) attributes of a DT mindset. For example, Item 10 (Share your work with others before it is finished) implies working with others and gathering feedback, which is similar to Schweitzer et al.'s (2016) DT mindsets of empathy, collaboration, and openness to new perspectives. Item 6 (Try an approach to a problem that may not be the final or best solution) describes what Schweitzer et al. (2016) define as an experiential intelligence mindset – a preference for experimenting with different ideas and transforming "tangible ideas into tangible outcomes" (Schweitzer et al., 2016, p. 79). Item 7 (Continue to work on a problem after experiencing a significant failure) and Item 2 (Effectively work on a problem that does not have an obvious solution) reflect a mindset of accepting uncertainty and being open to risk (Schweitzer et al., 2016) as well as a mindset of a culture of prototyping and action-oriented behaviour (Rauth et al., 2010). Designers often need to create solutions for a future that is different from the present. Tasks like these require an ability to embrace ambiguity and the risk of failure.

The DTS's Creative Agency dimension focuses on the conscious creative mindset that highlights an understanding of a creative process and the work one does to produce innovative ideas and solutions (Schweitzer et al., 2016). In order for people to have a creative agency, they need to understand what it takes to be creative, as well as conditions and processes that enable creativity in themselves and others (Kelley & Kelley, 2013; Royalty et al., 2014; Schweitzer et al., 2016). Sample items in this subscale include "Identify and implement ways to enhance your own creativity", "Help others be more creative", "Explicitly define or describe your creative process," and "Shape or change your external environment to help you be more creative".

STUDY II: CONFIRMATORY FACTOR ANALYSIS, VALIDITY, AND TEST–RETEST RELIABILITY OF THE DTS

The goal of Study II was threefold. First, we investigated whether a confirmatory factor analysis (CFA) supported the two-factor solution identified in Study I. Second, we examined the DTS's convergent validity by correlating DT with Creative Achievement (Carson et al., 2005) and Innovation scores (Chen et al., 2017), and the DTS's discriminant validity by correlating DT with Marlowe–Crowne Social Desirability scores (Crowne & Marlowe, 1960). Third, we explored the DTS's test–retest reliability.

Method

Participants and procedures

Education majors (N = 179; 154 females, 25 males; M age = 20.94, SD = 3.30) enrolled in an undergraduate Educational Technology course in the same mid-western university in the United States participated in Study II that took place in the following semester after Study I. Participants completed a series of online questionnaires: (1) background questionnaire, (2) DTS (Royalty et al., 2014), (3) Creative Achievement (Carson et al., 2005), (4) Innovation Stance (Chen et al., 2017), and (5) Marlowe–Crowne Social Desirability Scale (MCSD; Crowne & Marlowe, 1960). Students received course credit for participating in the study.

Two weeks later, a sub-sample of 27 students (one male; 26 females) completed the DTS again (post-test) for additional course credit. The pre- and post-test took place before and after one of the course projects that required students to create a Scratch story – a web-based tool for teaching coding and computational skills in K-12 education.

Instruments

Design Thinking Scale (Royalty et al., 2014): Ten DTS items that were retained after conducting the EFA in Study I were used to assess participants' DT. DT scores were calculated by averaging the 10 items of the scale. The minimum possible score was 1 and the maximum possible score was 5.

Creative Achievement questionnaire (Carson et al., 2005) is a self-report measure that assesses creative personality across 10 artistic and scientific domains. The participants were asked to mark all items describing their accomplishments. The items in each domain are weighted from 0 to 7. A total creative achievement score was calculated by summing all items (minimum score = 0, maximum score = 47).

Innovation Stance (Chen et al., 2017) includes 12 four-point Likert-style items that ask participants to rate their comfort taking risks, appreciation of new ideas, entrepreneurial spirit, and desire to do something different or unique. Innovation scores were calculated by averaging the 12 items (minimum score = 0, maximum score = 4).

Marlowe–Crowne Social Desirability Scale (MCSD; Crowne & Marlowe, 1960). A short version of the MCSD (Reynolds, 1982) was used in the present study. It included 13 items that assessed participants' tendency to tailor their responses to appear socially acceptable. The items are keyed True (Coded 1) or False (Coded 2) to describe either very socially desirable but untrue for most people or very socially undesirable but very common behaviours. The scale includes five reversely coded items (i.e., Items 5, 7, 9, 10, and 13); the range of total scores is between 13 and 26.

Data analysis

CFA was conducted to examine whether the hypothesized model of factors in EFA was related to the set of items, and whether the sample confirms the model (Schumacker & Lomax, 2010). Chi-square, root mean square error of approximation (RMSEA) of 0.06 or less, standardized root mean residual (SRMR) of 0.08 or less, and comparative fit index (CFI) and Tucker–Lewis index (TLI) greater than 0.90 and 0.95, respectively, were used for model testing (Bentler, 1990; Hu & Bentler, 1999). A chi-square difference test was used for comparison across models. Mplus 7.0 was used for CFA.

The associations between the two DTS sub-scales (i.e., Creative Agency and Design Dispositions), creative achievement, innovation, and Marlowe–Crowne Social Desirability scores were examined using a Pearson's correlation coefficient.

Results

Confirmatory Factor Analysis (CFA)

The two-factor structure of the DTS was confirmed using CFA with the Study II data. CFA was performed using a diagonally weighted least square estimator. The results (see Table 14.4 for more detail) indicated that the two-factor solution had a close fit. All standardized factor loadings were statistically significant ($p < 0.01$) ranging from 0.446 to 0.830. Additionally, the correlation between the factors was 0.71. Standardized factor loadings for the two DTS factors (i.e., Creative Agency and Design Dispositions) ranged from 0.446 to 0.633 and from 0.587 to 0.83, respectively.

The results suggested adding error covariances between Item 5 and Item 6, which resulted in the greatest decrease in χ^2. A further examination of these two items in wording and context showed that these items belong to the same latent factor and share some commonality. After adding error covariances between Item 5 and Item 6, the model significantly improved ($\Delta\chi^2 = 7.93$, $\Delta df = 1$, $p < 0.01$). Fit indices were also satisfactory. For more details regarding the factor loadings in the modified model see Table 14.4.

Convergent validity

The Creative Agency DTS sub-scale had a moderate to large correlation with Innovation ($r = 0.449$, $p < 0.001$) and a low correlation with Creative Achievement ($r = 0.189$, $p = 0.011$).

Table 14.4 Confirmatory factor analysis standardized factor loadings for the DTS (N = 178)

#	Items		Models	
			Initial	Modified
2	Effectively work on a problem that does not have an obvious solution.		0.633	0.638
3	Consider a problem from different perspectives.		0.605	0.612
5	Share your work with others before it is finished.		0.497	0.438
6	Try an approach to a problem that may not be the final or best solution.		0.559	0.504
7	Continue to work on a problem after experiencing a significant failure.		0.446	0.440
4	Shape or change your external environment to help you be more creative.		0.587	0.586
8	Help others be more creative.		0.756	0.756
9	Identify and implement ways to enhance your own creativity.		0.830	0.827
10	Explicitly define or describe your creative process.		0.568	0.660
11	Solve problems in ways that others would consider creative.		0.594	0.596
		$\chi^2(df)$	59.033 (34)*	48.758 (33)**
		RMSEA	0.064	0.052
		CFI	0.929	0.955
		TLI	0.906	0.939
		SRMR	0.063	0.054

Note: *$p < 0.05$, **$p < 0.01$

Similarly, the Design Dispositions DTS sub-scale had a moderate to large correlation with Innovation ($r = 0.512$, $p < 0.001$) and a low correlation with Creative Achievement ($r = 0.231$, $p = 0.002$). These results indicate that the DTS theoretically relates to the Creative Achievement and Innovation constructs, though the relationship is much stronger for Innovation than for Creative Achievement (Table 14.5).

Discriminant validity

There was a low but statistically significant correlation between the Social Desirability and Creative Agency scores and between the Social Desirability and Design Dispositions scores ($r = 0.300$, $p < 0.001$, and $r = 0.304$, $p < 0.001$, respectively). These results suggest that the DTS is related to the Social Desirability construct, but the relationship is weak (Table 14.5).

Test–retest reliability

The test–retest reliability for the Creative Agency and Design Dispositions subscales were 0.790 and 0.696, respectively. These results indicate that the DTS has a good test–retest reliability of the DTS.

Table 14.5 Descriptive statistics and correlations of the DTS subscales with other constructs

Constructs	Descriptive statistics	Correlation coefficients				
	Mean (SD)	1	2	3	4	5
1. Creative agency[a] (DTS subscale)	3.77 (0.62)	–				
2. Design dispositions[a] (DTS subscale)	3.77 (0.70)	0.511**	–			
3. Creative achievement[b]	10.34 (9.59)	0.189*	0.231**	–		
4. Innovation[c]	2.95 (0.4)	0.499**	0.512**	0.271**	–	
5. Social desirability[d]	20.55 (2.59)	0.300**	0.304**	0.073	0.274**	–

Note: *$p < 0.05$, **$p < 0.01$
[a] Scores were calculated by averaging the total number of items; possible score range: 1–5.
[b] Scores were calculated by summing all items; possible score range: 0–47.
[c] Scores were calculated by averaging the total number of items; possible score range: 1–4.
[d] Items were scored dichotomously; possible score range: 13–25.

Discussion

Study II confirmed the EFA results using CFA and examined the DTS' convergent and discriminant validity, and its test–retest reliability. The CFA confirmed the two-factor structure of the DTS that was identified in Study I. On average, prospective teachers reported moderately high levels of Design Dispositions ($M = 3.77$, $SD = 0.70$) and Creative Agency ($M = 3.77$, $SD = 0.62$). The internal consistency results revealed good internal consistency for the DTS as a whole and its two subscales with scores well above the 0.70 threshold for research instruments (Hocevar & Bachelor, 1989).

Consistent with the study hypothesis, prospective teachers' DTS scores were positively correlated with their Creative Achievement and Innovation scores, thus suggesting that the DTS theoretically relates to the constructs of creative achievement and innovation. Interestingly, the correlation coefficient of DT and Innovation was much higher than the one of DT and Creative Achievement. These findings indicate that while the DTS theoretically relates to both Innovation and Creativity, its association with the concept of innovation is more pronounced than with creativity. The correlation indices of DT, Innovation, and Creative Achievement ranged between 0.19 and 0.51, suggesting that DT as measured by the DTS can be viewed as a unique construct. Overall, the results revealed good convergent validity of the DTS.

Regarding the DTS' discriminant validity, the correlation between the DTS and Marlowe–Crowne Social Desirability scores was statistically significant, but the association was weak ($r = 0.30$, $p < 0.01$). These results suggest that the phrasing of the DTS items encourages socially desirable responses to some extent. However, caution is advised when interpreting the correlations between the DTS and MCSDS, because the dimensionality of the MCSDS is not fully understood (Leite & Beretvas, 2005).

LIMITATIONS

Although Likert scale instruments offer many advantages such as allowing participants to rate their level of agreement, simplicity of responding to questions, and ease of data capturing, there are several limitations associated with using them. First, Likert scale instruments employed in the current study are self-reporting, which is subject to bias. Second, they may cause respondents to select answers from the same range of response categories such as "strongly agree" or "strongly disagree". Last, the study used several questionnaires. The length of the questionnaires and boredom might impact participants' motivation to answer questions and result in a random selection of a response category (Glas & Dagohoy, 2007).

CONCLUSION

Developing high-quality instruments in social and behavioural sciences is crucial for advancing research (Boateng et al., 2018), particularly in fields such as DT that have a limited array of tools for measuring quantitative variables. This study provided empirical evidence regarding the DTS factor structure and its internal consistency and validity. Overall, the findings suggest that the DTS has a promising validity and reliability and can be used for assessing DT skills in education-majors. Specifically, the DTS can be used for assessing the outcomes of DT education and investigating the impacts of various interventions that aim to enhance DT skills.

The need to think creatively and collaborate across knowledge boundaries to create innovative solutions has been long acknowledged in the field of education (Henriksen et al., 2017). Teachers need to be able to collaborate with educators from various subject areas as well as professionals from other fields such as counselling, psychology, information technology, and business, to develop a shared understanding of problems and solutions. Collaborative design practices and participatory approaches such as co-design – which represent the evolution and diversification of DT – can help address these challenges. DT is already making its way into teacher preparation programmes integrating DT into teacher preparation curricula (Novak & Mulvey, 2020; Novak & Wisdom, 2020; Chin et al., 2019; Conlin et al., 2015; Koh et al., 2015). However, currently there is no framework that guides the integration of DT skills, practices, and mindsets in teacher preparation programmes. Future research should attempt to conceptualize a framework/model that will introduce prospective teachers to DT practices and competencies the way they are being practised in the field of education. Such a framework will result in a better understanding of how DT should be evaluated and assessed in teacher education, thereby leading to the development of context-relevant DT measurement instruments, i.e., instruments that are designed for a specific context (e.g., teacher education) and audience (e.g., teachers). Research in this area can help teacher preparation programmes develop the much-needed learning experiences and curricula to support teachers' ability to develop and use DT in their teaching practice.

Although the DTS instrument was developed to assess outcomes of DT education in Stanford's d.school's alumni, the DTS framework can be potentially applied to other settings and audiences, as our literature review revealed that the DT competencies of the DTS are reminiscent of those identified in the extant literature that explored DT competencies in a variety of contexts and audiences (Carlgren et al., 2016; Russo, 2016; Schweitzer et al., 2016). This research hypothesis, however, remains untested as the instrument was validated with prospec-

tive teachers only. As such, future research should examine how well the DTS performs in different contexts with various audiences. In addition, the current study's sample size included primarily females, thus limiting our ability to test the measurement invariance of the DTS for male and female participants. Future research should examine the suitability of applying the DTS to different genders of students in different contexts.

In conclusion, the field of DT needs more research tools to assess various aspects of DT. Future attempts to develop such tools should capitalize on prior research that conceptualized DT mindset attributes using various research methods, including literature reviews (Russo, 2016) and interviews (Carlgren et al., 2016; Schweitzer et al., 2016). A mixed-methods framework can be particularly useful for developing Likert-type instruments for assessing DT skills and competencies (Onwuegbuzie et al., 2010). Mixing qualitative and quantitative approaches can increase the sample size, instrument fidelity, as well as researchers' ability to interpret data and assess the fidelity of interventions and programs (Collins et al., 2006). For instance, in addition to administering the quantitative instrument, researchers can collect qualitative data using interviews and reflections to better understand respondents' interpretations of the DT competencies and situations that are likely to result in elevated levels of DT. Qualitative data can also be useful in providing valuable insight into participants' perceptions of the instrument's cultural relevance, which is critical in the study of DT.

REFERENCES

Ackoff, R.L. (1989). From data to wisdom. *Journal of Applied Systems Analysis*, *16*(1), 3–9.

Adobe Systems Incorporated (2018). Creative problem solving in schools: Essential skills today's students need for jobs in tomorrow's age of automation. http://cps.adobeeducate.com/GlobalStudy

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist*, *37*(2), 122–147.

Bandura, A. (1994). *Self-efficacy.* John Wiley & Sons, Inc.

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin*, 107(2), 238–246. https://doi.org/10.1037/0033-2909.107.2.238

Beverland, M. B., Gemser, G., & Karpen, I. O. (2017). Design, consumption and marketing: outcomes, process, philosophy and future directions. *Journal of Marketing Management*, *33*(3–4), 159–172. https://doi.org/10.1080/0267257X.2017.1283908

Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher Education*, *32*, 347–364.

Bloom, B. S. (1956). *Taxonomy of educational objectives. Vol. 1: Cognitive domain*. New York: McKay, 20, 24.

Boateng, G. O., Neilands, T. B., Frongillo, E. A., Melgar-Quiñonez, H. R., & Young, S. L. (2018). Best practices for developing and validating scales for health, social, and behavioral research: A primer [Review]. *Frontiers in Public Health*, *6*(149). https://doi.org/10.3389/fpubh.2018.00149

Brown, T. A. (2006). *Confirmatory factor analysis for applied research* (1st ed.). Guilford.

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues*, *8*, 5–21.

Carlgren, L., Rauth, I., & Elmquist, M. (2016). Framing design thinking: The concept in idea and enactment. *Creativity and Innovation Management*, *25*(1), 38–57.

Carson, S. H., Peterson, J. B., & Higgins, D. M. (2005). Reliability, validity, and factor structure of the creative achievement questionnaire. *Creativity Research Journal*, *17*(1), 37–50. doi:10.1207/s15326934crj1701_4

Chen, Y.-F., Cannady, M. A., Schunn, C., & Dorph, R. (2017). *Measures technical brief: Innovation stance in STEM*. Retrieved from http://activationlab.org/tools/

Chin, D. B., Blair, K. P., Wolf, R. C., Conlin, L. D., Cutumisu, M., Pfaffman, J., & Schwartz, D. L. (2019). Educating and measuring choice: A test of the transfer of design thinking in problem solving and learning. *Journal of the Learning Sciences*, *28*(3), 337–380.

Collins, H., 2013. Can design thinking still add value? *Design Management Review*, *24*(2), 35–39.

Collins, K. M. T., Onwuegbuzie, A. J., & Sutton, I. L. (2006). A model incorporating the rationale and purpose for conducting mixed methods research in special education and beyond. *Learning Disabilities: A Contemporary Journal*, *4*, 67–100.

Conlin, L. D., Blair, K. P., Cutumisu, M., & Schwartz, D. L. (2015). Guardian angels of our better nature: Finding evidence of the benefits of design thinking. *Proceedings of 122nd ASEE Annual Conference and Exposition*. 1–12.

Cross, N. (2007). *Designerly ways of knowing*. Boston: Birkhauser Verlag AG.

Crowne, D. P., & Marlowe, D. (1960). A new scale of social desirability independent of psychopathology. *Journal of Consulting Psychology*, *24*(4), 349–354. doi:10.1037/h0047358.

Dell Corporation (2021). The top five skills for tomorrow's workforce. https://www.delltechnologies.com/en-us/perspectives/the-top-5-skills-for-tomorrows-workforce/

Dweck, C. (2012). *Mindset: How you can fulfil your potential*. Hachette UK.

Henriksen, D., Richardson, C., & Mehta, R. (2017). Design thinking: A creative approach to educational problems of practice. *Thinking Skills and Creativity*, *26*, 140–153. doi:https://doi.org/10.1016/j.tsc.2017.10.001

Hocevar, D. & Bachelor, P. (1989). A taxonomy and critique of measurements used in the study of creativity. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds), *Handbook of creativity*. New York: Plenum.

Hokanson, B., & Nyboer, J. (2018). Design thinking: Towards the construction of knowledge. In M. J. Spector, B. B. Lockee, & M. D. Childress (Eds.), *Learning, design, and technology: An international compendium of theory, research, practice, and policy* (pp. 1–19). Cham: Springer International Publishing.

Howard, Z., Senova, M., & Melles, G. (2015). Exploring the role of mindset in design thinking: Implications for capability development and practice. *Journal of Design, Business & Society*, *1*(2), 183–202.

Hu, L.-T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*, *6*(1), 1–55. https://doi.org/10.1080/10705519909540118

Glas, C. A. W., & Dagohoy, A. V. T. (2007). A person fit test for IRT models for polytomous items. *Psychometrika*, *72*(2), 159–180.

Groeger, L., Schweitzer, J., Sobel, L., & Malcom, B. (2019). Design thinking mindset: Developing creative confidence. Conference Proceedings of Academy of Design Innovation.

Johansson-Skoldberg, U., Woodilla, J. & Cetinkaya, M. (2013). Design thinking: Past, present and possible futures. *Creativity and Innovation Management*, *22*(2), 121–146.

Kelley, T., & Kelley, D. (2013). *Creative confidence: Unleashing the creative potential within us all*. Random House LLC.

Kimbell, L. (2011). Rethinking design thinking: Part I. *Design and Culture*, *3*(3), 285–306.

Koh, J. H. L., Chai, C. S., Wong, B., & Hong, H. Y. (2015). *Design thinking for education*. Springer, Singapore.

Leite, W. L., & Beretvas, S. N. (2005). Validation of scores on the Marlowe–Crowne social desirability scale and the balanced inventory of desirable responding. *Educational and Psychological Measurement*, *65*(1), 140–154. https://doi.org/10.1177/0013164404267285

Liedtka, J. (2011). Learning to use design thinking tools for successful innovation. *Strategy & Leadership*, *39*(5), 13–19.

Magistretti, S., Pham, C. T. A., & Dell'Era, C. (2021). Enlightening the dynamic capabilities of design thinking in fostering digital transformation. *Industrial Marketing Management*, *97*, 59–70. https://doi.org/https://doi.org/10.1016/j.indmarman.2021.06.014

Micheli, P., Wilner, S. J. S., Bhatti, S. H., Mura, M., & Beverland, M. B. (2019). Doing design thinking: Conceptual review, synthesis, and research agenda. *Journal of Product Innovation Management*, *36*(2), 124–148. https://doi.org/https://doi.org/10.1111/jpim.12466

Mishra, P., & Mehta, R. (2017). What we educators get wrong about 21st-century learning: Results of a survey. *Journal of Digital Learning in Teacher Education*, *33*(1), 6–19.

Nagai, Y., & Noguchi, H. (2003). An experimental study on the design thinking process started from difficult keywords: Modeling the thinking process of creative design. *Journal of Engineering Design*, *14*, 429–437. https://doi.org/10.1080/0954482031000160691l.

Nakata, C., & Hwang, J. (2020). Design thinking for innovation: Composition, consequence, and contingency. *Journal of Business Research*, *118*, 117–128. https://doi.org/https://doi.org/10.1016/j.jbusres.2020.06.038

Nelson, H. G. & Stolterman, E. (2013). *The design way: Intentional change in an unpredictable world*, 2nd ed. Cambridge, MA: MIT Press.

Novak, E., & Mulvey, B. (2020). Enhancing design thinking in instructional technology students. *Journal of Computer-Assisted Learning*, *37*(1), 80–90. http://dx.doi.org/10.1111/jcal.12470

Novak, E., & Wisdom, S. (2020). Using 3D printing in science for elementary teachers. In J. J. Mintzes and E. M. Walter (Eds), *Active learning in college science: The case for evidence-based practice*. Berlin: Springer Nature.

Nussbaum, B., 2011. Design thinking is a failed experiment. So what's next? [online]. Available at: https://www.fastcompany.com/1663558/design-thinking-is-a-failed-experiment-so-whats-next (accessed 4 February 2022).

Onwuegbuzie, A. J., Bustamante, R. M., & Nelson, J. A. (2010). Mixed research as a tool for developing quantitative instruments. *Journal of Mixed Methods Research*, *4*(1), 56–78. doi:10.1177/1558689809355805

Owen, C (2007). Design thinking: Notes on its nature and use. *Design Research Quarterly*, *2*, 16–27.

Rauth, I., Köppen, E., Jobst, B., & Meinel, C. (2010). *Design thinking: An educational model towards creative confidence.* Paper presented at the DS 66-2: Proceedings of the 1st international conference on design creativity (ICDC 2010).

Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research*, *82*(3), 330–348. https://doi.org/10.3102/0034654312457429

Reynolds, W. M. (1982). Development of reliable and valid short forms of the Marlowe–Crowne social desirability scale. *Journal of Clinical Psychology*, *38*, 119–125.

Royalty, A., Chen, H., Roth, B., & Sheppard, S. (2019). Measuring design thinking practice in context. In C. Meinel & L. Leifer (Eds), *Design thinking research: Understanding innovation.* Cham: Springer.

Royalty, A., Oishi, L. N., & Roth, B. (2014). Acting with creative confidence: Developing a creative agency assessment tool. In L. Leifer, H. Plattner, & C. Meinel (Eds), *Design thinking research*, 79–96. Springer International Publishing.

Russo, S. (2016). Understanding the behaviour of design thinking in complex environments. PhD dissertation. Swinburne University of Technology. Melbourne, Australia.

Schumacker, R. E., & Lomax, R. G. (2010). *A beginners guide to structural equation modeling*. Routledge, New York.

Schweitzer, J., Groeger, L., & Sobel, L. (2016). The design thinking mindset: An assessment of what we know and what we see in practice. *Journal of Design, Business & Society*, *2*, 1–23.

Stanford d.school. (2010) bootcamp bootleg [www.document]. Available at: https://dschool.stanford.edu/resources/the-bootcamp-bootleg (accessed 29 September 2021).

Stempfle, J., & Badke-Schaube, P. (2002). Thinking in design teams—an analysis of team communication. *Design Studies*, *23*, 473–496.

Thompson, B. (2004). *Exploratory and confirmatory factor analysis: Understanding concepts and applications*. American Psychological Association. doi:10.1037/10694-000

Wrigley, C., & Straker, K. (2017). Design thinking pedagogy: The educational design ladder. *Innovations in Education and Teaching International*, *54*(4), 374–385. https://doi.org/10.1080/14703297.2015.1108214