Assessing the Development of Design Thinking Mindset in Secondary Students

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Author Note

Presented November 16-17, 2023 in "Session VI: Design Thinking and Practice" at the 109th Meeting of the 1909 Conference and the 60th Southeastern Technology Education Conference, Nashville, TN

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Abstract

Design thinking is a problem-solving framework emphasizing empathy, creativity, and experimentation. Designers use a non-linear, iterative process to understand users, challenge assumptions, redefine problems, and create innovative solutions. Despite its importance, design thinking is invisible, like other forms of cognition, presenting difficulty when monitoring students' development as design thinkers. This research project investigates the potential development of design thinking mindset among secondary students in an introductory technology and engineering course. Specifically, it seeks to appraise the validity of an existing design thinking mindset survey when used in the secondary-education context and report descriptive statistics related to students' design thinking mindset. Dosi et al. (2018) worked on measuring design thinking mindset resulting in a 71-item instrument to assess design thinking mindset based on 22 constructs. Our ongoing research involves a design thinking mindset and we had interest in the questionnaire. However, the original questionnaire developed was lengthy and a shorter one may be appropriate for the study. Furthermore, we are working in a secondary education context that differs from the original audience of the questionnaire. Both of these changes warrant further investigation of the validity of the measurement tool. As part of a larger research study, the quantitative data used here were collected by administering a subset of the design thinking mindset survey to students at the beginning and end of the introductory technology and engineering course. To examine the instrument's validity, we apply exploratory factor analysis to evaluate the construct validity of the assessment tool, providing valuable insights into its structure and relevance, and calculate other psychometric and reliability indicators. This study's findings hold potential significance for educators and researchers interested in promoting design thinking as a valuable skill among secondary students. Affirming the utility of the assessment tool in this context can contribute to our understanding of the development of design thinking mindset. Furthermore, these insights into design thinking can inform the development of more effective educational interventions and strategies, fostering a generation of creative problem solvers among secondary students.

Keywords: design thinking, secondary education, research evaluation, factor analysis

Assessing the Development of Design Thinking Mindset in Secondary Students

Design is a central activity in engineering. Accordingly, design is a central aspect of K-12 technology and engineering education, as evidenced by its inclusion in the Standards for Technological and Engineering Literacy (STEL) core disciplinary standards (ITEEA, 2020). The design process is a problem-solving framework emphasizing empathy, creativity and experimentation. Designers use a non-linear, iterative process to understand users, challenge assumptions, redefine problems, and create innovative solutions (Crismond and Adams, 2012). At a specific level, design has been described as an evidence-based decision-making process, however greater awareness of the design process has likened it to freedom in problem solving, given its open-ended nature (Daly, 2015).

What type of thinking is required to navigate the design process then? “Design thinking is an elusive and difficult construct to define” (Mentzer, 2014 p. 53). However, a number of aspects of design thinking have been proposed (Dosi et al., 2018; Patel and Mehta, 2017), including thinking across disciplines, with users in mind, or with prototypes. Design process is a problem-solving framework emphasizing empathy, creativity, and experimentation. Other types of thinking required to design are illustrated by the STEL technology and engineering practices; among the dispositions and mindsets students need when addressing problems in our field are creativity, critical thinking, and collaboration. Yet, despite its importance, and the variety of activities which are arguably part of design, design thinking is invisible like other forms of cognition.

Monitoring students' development as design thinkers is essential to furthering their development as designers. Design thinking promotes the acquisition of critical skills such as empathy, creativity, collaboration, and problem-solving, and tracking students' progress enables educators to assess their growth in these essential areas (Kimbell, 2011). Furthermore, design thinking hinges on practical problem-solving, and ongoing monitoring facilitates evaluating a student's ability to identify, define, and tackle complex issues (Brown, 2008). Regular monitoring provides valuable feedback and iteration opportunities and encourages students to learn from their experiences, enhance their design-thinking skills, and refine their problem-solving approaches (Kavousi, 2020). Early experiences with design-and feedback on design-are instrumental in preparing students for the challenges of various professional fields where design thinking is increasingly valued as a powerful approach to addressing real-world problems. Finally, by monitoring and acknowledging students' progress in design thinking, educators foster a growth mindset, instilling in students the belief in their capacity for continuous learning and improvement (Brock, 2016).

Research Objectives

As part of a larger research project related to design, we sought a measure of design thinking mindset and had interest in a questionnaire from Dosi et al. (2018). The development of a research instrument requires rigorous development and testing in the first place, and reexamination when the instrument or context of use is adapted (Jackson, 2018). Therefore, in response to our changing contextual application of the questionnaire, as well as using a subset of the measurement tool, examination of the validity of the instrument was warranted.

Herein, we work to appraise the validity of an existing design thinking mindset survey for use in the secondary-education context. First, we provide an overview of the questionnaire and extant evidence for its validity. Next, we describe the new context and sampling procedures used to administer the survey. Then we apply exploratory factor analysis to evaluate content validity of the questionnaire.

Challenges in Monitoring Development as Design Thinkers

Monitoring students' development as design thinkers comes with several challenges, due to the nature of design. Firstly, design thinking involves creative and subjective problem-solving, making assessment subjective and reliant on varying interpretations (Oliveira et al., 2021). Design thinking also draws from various disciplines, making it challenging to assess students' development comprehensively. Monitoring may require input from educators with different expertise (Altman et al., 2018). The effectiveness and appropriateness of design thinking approaches may also vary across different cultural and contextual settings, making it necessary to consider these factors in the assessment (Lee et al., 2020). Historically, the assessment of design thinking skills often relies on qualitative data, such as observations, interviews, and open-ended responses. This can make it difficult to quantify and compare progress across students (Oliveira et al. 2021). Finally, aligning the assessment of design thinking with broader educational goals and curricular standards can be complex, particularly if these goals are not well-defined (Bartoloni et al., 2021). Due to these challenges, many existing tools have not been able to capture the complexity and nuances of the design thinking process (Dosi et al., 2018; Oliveira, 2021).

The Design Thinking Mindset Questionnaire

Initial Questionnaire Development

One effort to evaluate design thinking was by Dosi et al. (2018). Their research describes developing and validating a questionnaire designed to measure the design thinking mindset. Measuring design thinking mindset is relevant for research and practice, i.e., measuring the impact of different pedagogies and designing more balanced and complete design teams. To develop the instrument, the authors comprehensively reviewed the relevant literature and identified 19 constructs, or main aspects of design thinking, and developed example questions related to each which were reviewed by other scholars in design thinking. The pilot questions were administered to two samples with design thinking experience (n = 307)—one group of professionals and one group of students—and an exploratory factor analysis was conducted on their responses. The exploratory factor analysis of the responses resulted in a 71-item instrument to assess design thinking mindset based on 22 constructs (because three additional constructs were separated based on statistical results). The results showed that the questionnaire had good internal consistency and construct validity (Dosi et al., 2018), though they recommended follow-up with confirmatory factor analysis. The authors concluded that measuring the impact of different variables and designing more balanced and complete design teams is possible with a measure of design thinking mindset (Dosi et al., 2018).

The final Design Thinking Mindset Questionnaire from Dosi et al. (2018) used a 5-point rating scale, from Strongly Agree to Strongly Disagree. Each of the constructs included in the final scale held between 3 and 5 questions—for example, among the constructs were "embracing risk," "holistic view," and "open to different perspectives." While our use of the scale maintained many of these characteristics, the shorter questionnaire that we have adopted will be used to collect data for the secondary students.

Application of the Questionnaire in Other Studies

The Dosi et al. (2018) questionnaire has been used in several research studies to evaluate the impact of research projects on various aspects of society, including other engineering education settings and innovation. Chen and Chou (2019, 2021) used the questionnaire to assess design thinking mindset in a healthcare innovation course and found that several constructs of design thinking mindset were improved, such as "tolerance for uncertainty," "embracing risk," and “mindfulness and awareness of process.” Avsec (2021) used the Design Thinking Mindset Questionnaire with 76 pre-service teachers studying instruction in a Creative Technical Workshops course. Each subscale of the instrument showed good internal consistency, with Cronbach’s alpha ranging from 0.70 – 0.91, and there were significant increases in many of the constructs of design thinking. Similarly, Thi-Huyen et al. (2021) used a subset of the questionnaire from Dosi et al. (2018) in their research about design education in a flipped learning format. They reported high internal consistency on each of the subscales used, which is promising for the quality of the overall instrument. Here, several areas of design thinking mindset were improved following the education experience (“empathy,” “holistic view,” “problem reframing,” and “team working”).

Several studies have been conducted using a translated version of the survey from Dosi et al. (2018). Ladachart, Cholsin, et al. (2022) translated the survey for use with ninth-grade students and reinspected the items with exploratory factor analysis (n = 297) and confirmatory factor analysis (n = 593), resulting in a simplified instrument. The recommended questionnaire format included only 30 questions and six constructs, which were similar to main ideas from the original questionnaire. In their study, student design thinking mindset improved in several aspects (human-centered thinking and confidence to use creativity) following an engineering activity, compared to reports beforehand. In another study, Ladachart, Radchanet, and Phothong (2022) conducted research on design thinking mindsets facilitating students learning of scientific concepts and design-based activities. The study aimed to explore 37 eighth-grade students’ conceptual learning and design-thinking mindsets in the context of design-based learning on pulleys. An abstract test on pulleys and the Likert scale questionnaire measuring design thinking mindset were administered to the students before and after the design-based learning treatment.

Based on the results of this study, the authors determined that an orientation to learning through the process of making and testing had a slight influence on design thinking mindset, and thereby had an influential role in facilitating conceptual learning (Ladachart, Radchanet, and Phothong, 2022). Furthermore, the translated survey was also used by Phothong et al. (2023) with eighth-grade students, who reported high reliability among the survey items (ranging from 0.860 to 0.925). However, they reported mixed results related to improved design thinking mindset of students.

More recently, several members of the research team conducted follow-up analysis in several studies to further verify the instrument quality (Vignoli et al., 2023). Their aim was to further define, develop, and validate the original scale to assess design thinking. Repeating the factor analysis, the team recommended a 10 factor solution in their follow-up research, which would be more parsimonious than the previous model and included fewer items. They argue, however, that the model is consistent with the previous interpretation, by consolidating items on each subscale. Yet, when interpreting the results of a confirmatory factor analysis, the team removed even more items, resulting in a final 31-item scale on the 10 design thinking dimensions. The scale's reliability was reported between 0.78 – 0.88, strong, and the structure could also be explained in a second-order model, where each construct predicted an overall level of design thinking mindset, when tested with several samples. Although the structural consistency of this model was demonstrated with two samples, the ongoing research related to the questionnaire (and shifting indicators) demonstrates that further attention is needed to accurately measure design thinking mindset. The latest format of the scale dropped several of the items we had administered, though (as the authors mention) similar questions remained on the instrument. It is possible that in the new context of our research, the specific indicators to measure design mindset would require modification and adaptation, or would be best fit by a slightly different factor structure.

Subsetting the Questionnaire for the Present Study

Simultaneously to much of this research, our larger research project developed with an interest in studying design thinking mindset as part of the theoretical framework (Jackson et al., 2023). In the larger project, we are testing design pedagogy to influence students' critical thinking and awareness from the beginning of the design process. Specifically, we are employing an approach we call Learning by Evaluating (LbE) where students see example work and must discern important features, prior to the beginning of their own design work. We see that design mindset as an early element of this theory of change, so by cultivating a design thinking mindset, students might have greater awareness of what matters in design and why (Mentzer et al., 2023). Moreover, the project focussed on tracking changes in the design thinking mindset among students as they engaged with the LbE approach. The original questionnaire by Dosi et al. (2018) assesses various aspects of design thinking that appeared relevant to the project. Therefore, in connection with the study's theoretical framework and the research setting of our project, described next, we chose to select a subset of constructs identified in the original questionnaire that would have the most salience. We selected five subscales which were "holistic view" (3 items); "openness to different perspectives" (4 items); "critical questioning" (3 items); "envisioning new things" (3 items); and "creative confidence" (4 items).

Past research has delved into these subscales in a broader perspective. For example, the holistic view" and "openness to different perspectives" are related to the idea of empathy (Abramson, 2021), while "critical questioning" and "envisioning new things "are related to the concept of critical thinking (Colley et al, 2012). "Creative confidence" is related to the idea of cultivating positive behaviors such as kindness and cooperation (Indriyana & Kuswandono, 2019). As mentioned, in prior research using the design thinking questionnaire, these subscales have at various times increased among the students sampled. The latest version of the instrument, recommended by Vignoli et al. (2023) completely incorporated questions from “holistic view” and “critical questioning.” Nearly all of the “creative confidence” questions remained, though few questions about being “open to different perspectives” and “envisioning new things” remained. And where they did, these questions were reconceptualized as relating to collaboration and abductive reasoning.

Methods

Given the new context where we attempted to use (part of) the Design Thinking Mindset Questionnaire, as well as the newness of psychometric evidence supporting the instrument, we applied several steps to ensure that the questionnaire was operating as expected. The details of our study and analysis are described here as an extension of the questionnaire’s original development.

Study Context

Partner District and Teacher Classrooms

We partnered with a large, urban school district in Georgia. Previously, this district established partnerships with several members of the NSF team. This prior collaboration served to highlight our successful relationship, thereby bolstering our reputation for fostering a mutually beneficial alliance between teachers, researchers, and curriculum developers. Teachers selected for participation in this study were responsible for instructing sections of the Foundations of Technology Course and had undergone prior training and professional development emphasizing project-based pedagogy in addition to their certification in Engineering by Design. In these instructional settings, we have relied on teachers' professional judgment while they maintain their role in introducing design projects, guiding class discussions to orient students, facilitating research and skill development in design, and overseeing student progress as part of their regular teaching responsibilities.

Foundations of Technology Course

The Foundations of Technology Course which represents the introductory level of technology and engineering education is an integral component of the Engineering by Design core program (Gensemer & Caron, 2010). Notably, Foundations of Technology is the most widely embraced course within the Engineering by Design curriculum, being taught in more than 270 school districts spanning 23 states (Burke, 2012). The curriculum experience introduces students to the design thinking process through repeated scaffolded projects throughout the year, each applying the design process. As students develop greater proficiency with the design thinking process, their understanding can move from a simplified process to one with greater detail, and this learning is tangibly represented by changes in the depictions of the design process throughout the course.

Student Participants

The study's population comprises 497 ninth grade students that were enrolled in technology and engineering design courses and drawn from six high schools. The participant selection criteria were meticulously established to ensure a representative sample for the investigation. First, participants should be 9th-grade students, as the study evaluates learning as a beginning designer. Participants are selected from schools that offer engineering courses at the 9th grade to ensure that the study includes students at the appropriate grade level. Informed consent from participants signed by their parents was obtained to ensure their availability to participate in the study and that participants are willing and able to contribute to the research.

Procedures

At the beginning and end of the course, all students completed the previously described subset of the Design Thinking Mindset Questionnaire. Because it was linked to the class content, it was permitted by the IRB that all students complete the items, regardless of whether they agreed to have their data analyzed. However, in order for student data to be included in our analysis, student assent forms and parent consent forms were completed, and teachers provided several reminders to encourage student participation.

The questionnaire was administered electronically to students. The electronic survey asked which class students were in, and then provided 17 selected items (as described in Subsetting the Questionnaire for the Present Study). Once completed, the average value for each subscale was displayed to students as a personal benchmark. Instructors were also encouraged to conduct a class debriefing session related to the questionnaire's content as either an orientation or reflection, at the beginning or end of the course, respectively. For example, a suggested prompt was to begin conversation with the question, “Why do you think it is important to think broadly (or consider different perspectives) in the design thinking process?” which relates to the aims of the overall research project and integrates aspects of design thinking mindset which the students just reported.

Analysis

Our analysis and reinspection of the Design Thinking Mindset Questionnaire began with a review for content validity. Then, we conducted factor analysis to examine the construct validity of the items. Finally, we report reliability indicators based on the resultant factor structure.

Content Validity

There are several definitions of content validity, however most of them describe it as the degree to which a measure, such as a test or a survey, represents all aspects of a given construct, concept, or theme that it intends to measure (Delgado-Rico et al., 2012). Polit and Beck (2006) define content validity as the measurement instrument's ability to encompass a representative array of items pertinent to the assessed construct. In a similar thought, Wynd, Schmidt, and Schafer (2003) also describe content validity to include whether the instrument items comprehensively cover the research domain under scrutiny. As a result, content validity is commonly interpreted as the extent to which a selection of items effectively encapsulates a well-rounded working definition of the focal construct (Polit & Beck, 2006).

Bums and Grove (1993) have outlined a multifaceted approach to establishing content validity, which draws from three distinct sources: existing literature, input from representatives of the relevant population, and insights from experts. They also emphasize that the process can be divided into two key stages: the development stage and the judgment stage. The initial step in instrument development involves identifying the specific domain of the construct to be measured. This can be achieved through meticulous literature reviews, as well as through the collection of insights from interviews and focus groups. By precisely defining the desired traits of interest, understanding comprehensively the limitations, dimensions, and components of the subject can be attained. Qualitative methods, such as interviews and focus groups, can prove invaluable in uncovering the domain and conceptual aspects of the construct under investigation.

During the judgment stage, it is imperative to involve professionals with relevant expertise to subjectively assess the extent to which the scale has been designed to measure the desired trait (Kerlinger, 1986). However, Ghiselli has underscored that content validity hinges on subjective or professional judgment (Ghiselli, 1964). In essence, content validity is contingent on experts' subjective evaluations of the extent to which the construct in question is adequately represented in the assessment instrument. To ensure robust content validity, involving a panel of at least five experts in the field (Bums & Grove, 1983) or a range of five to ten experts (Wilson, 1989) is recommended, using rating scales to gauge the content domains of the scale effectively. However, it is important to note that there is no one-size-fits-all, purely objective method for ascertaining the content validity of an instrument, nor is there a universally applicable statistical approach (Polit & Hungler, 1991; Dempsey, 1986).

Overall, the content validity of the Design Thinking Mindset Questionnaire is robust and well-supported. It was meticulously developed through an extensive literature review, drawing from a wealth of information found in over 100 articles related to design thinking. This strong foundation suggests that the questionnaire's items are grounded in existing knowledge and research within the field of design thinking. These pilot questions were then reviewed by other experts for feedback. Furthermore, the questionnaire demonstrates an impressive breadth, across 22 design-related constructs, which suggests a comprehensive coverage of different facets of design thinking. In addition, the fact that the questionnaire has been employed in previous research to assess educational interventions for design thinking adds further credibility to its content validity, indicating that it has been successfully applied and validated in real-world contexts.

While some of the recent applications of the survey have been in middle-school contexts, there is a need for additional work to verify the questionnaire's validity and reliability within new contexts of use. While this demonstrates a responsible approach to questionnaire development, it also highlights an ongoing commitment to ensure that the content remains valid and reliable in the research context. Even focusing on certain constructs of the questionnaire, as we do here, each construct includes several items to probe the underlying aspect of design thinking. Our research team includes expertise in design thinking research, as well as years of experience in secondary-level Technology and Engineering Education contexts.

Our initial review of the items and discussions with teachers who have implemented a portion of the questionnaire indicate that the content is suitable for this context of use. Next, the planned assessments of response validity using exploratory factor analysis and reliability indicate a proactive approach to confirm the questionnaire's content validity within the study's framework.

Construct Validity

Another important type of validity, construct validity, relates to the underlying structure of measurement instruments and whether they measure the topics they purport to measure (Hoyt et al., 2006). Construct validity is most commonly determined by applying factor analysis to examine the underlying structure of a measurement tool (Kahn, 2006). That is, by applying factor analysis, researchers are able to determine whether questionnaire items which purport to measure the same construct do in fact move together based on an underlying explanation of variance.

“One challenge is that factor analysis has many decision points” (Kline, 2013, p. 171). Despite the nomenclature, it is possible to apply either exploratory factor analysis or confirmatory factor analysis for the purposes of exploration or confirmation of a measurement instrument (Flora et al., 2012). However, we applied exploratory factor analysis so that there would be fewer constraints on the model and so that we could explore how a different number of factors affected the model results and interpretation. Ultimately, when determining the number of factors to retain, several criteria should be considered including a balance between statistics, parsimony, and theory (Kahn, 2006). Because of the close relationship between each construct of design thinking mindset—they may even be represented as a second-order factor (Vignoli, 2023)—we allowed correlation of the factors using oblimin rotation. Following data screening and the assurance of factorability, explored various factor models beginning with five factors (aligned with the original subscale) and informed by visual inspection of a scree plot and interpretability of the statistical structure.

Reliability Coefficients

Finally, reliability coefficients were calculated for each of the identified subscales. Reliability is the consistency of a measure or method. It indicates how trustworthy and stable the results are when the research is repeated under similar conditions or over time. Reliability shows that external factors or random errors do not influence the results (Eckel, 2023). Although coefficient alpha (also called Cronbach's alpha) is often reported to purport the consistency of a set of questions, this reliability coefficient is based on several assumptions that are not always upheld. These assumptions include that there are neither error correlations, nor that there is variation in the factor loading of the items in the questionnaire (Raykov & Marcoulides, 2011; Zinbarg et al., 2005). To accommodate a less restrictive model, we report the coefficient omega, which only holds that the items must be congeneric—that is that the questions are unidimensional (Dunn et al., 2014).

Results

Nearly 500 students were enrolled in participating classes, yet the number of fully consented students was much lower (n = 153, 30.8%). Furthermore, sporadic participation in the mindset survey led us to be able to match 91 responses (18.3% of the total students) to those that had granted permission. Though the sample size was limited, the initial sample remained suitable given liberal heuristics of a 5:1 response-to-indicator ratio and an assumption of high communalities (Kahn, 2006).

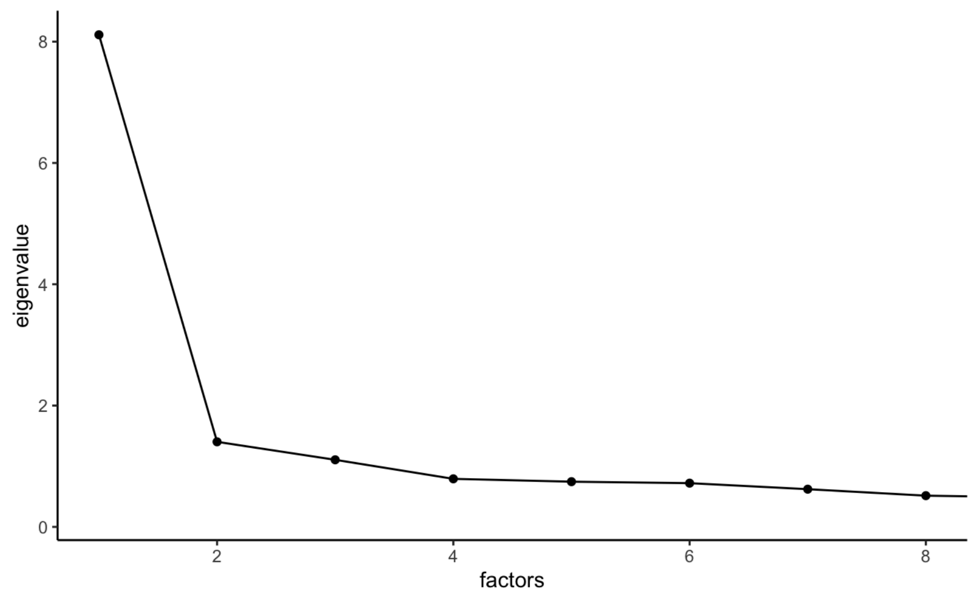
Further data screening followed procedures from Tabachnick and Fidell (2007), including checking for missing data (e.g., participant non-engagement), outliers, and normality and linearity. Screening for engagement identified eight cases of completely missing data and five cases of straight-line response, suggesting disengagement with the survey, which were removed. Three cases contained only one missing response and were imputed using mean imputation based on other items on the Design Thinking Mindset Questionnaire. Following these data cleaning steps, the remaining number of responses for analysis was n = 78. These responses were taken throughout the course, hopefully reflecting variation in students' design thinking mindset and preventing attenuation based on responses being too homogeneous. Based skewness and kurtosis, as well as visual inspection of variable scatterplots, we concluded the basic assumptions of linearity to be met (Flora et al., 2012).

Factor Analysis

Prior to factor analysis, the factorability of the data was appraised with the Kaiser-Meyer-Olkin (KMO) test and the Bartlett test. The results were in the excellent range (KMO = 0.91; Bartlett $p < 0.01$) showing strong factorability (Capobianco, 2012; Tabachnick and Fidell, 2007). Five factors would be retained based on the original subscales, although a scree plot indicated two changes in slope to suggest as few as two factors be retained (see Figure 1). Using this range, we compared a variety of potential factor solutions to see whether the subscale items loaded on consistent factors and whether any deviations were interpretable.

Figure 1

Scree Plot Showing Eigenvalues for Factor Extraction



Exploration of the factor models was conducted with the maximum likelihood method based on polychoric correlations (appropriate for a 5-point scale) and oblimin rotation. Although theoretically compatible with the selection of five subscales, the five-factor model did not have satisfactory results. Items from the same original subscales did not load together, nor did they load consistently to a single derived factor. The factor loadings were more consistent in the four-factor model, yet the conceptualization of the fourth factor was not clear or meaningful. Finally, the three-factor model was conceptually interpretable and more parsimonious than the previous results. We iterated on the model by removing two items with cross-loading and successively re-running the factor analysis. With the removal of these two items, interpretability was successively improved. Although the items do not wholly align with the original subscales, they are cohesive and similar to subscales on the reduced models proposed in later development of the instrument (e.g., Ladachart, 2021; Vignoli, 2023). The final factor loadings are reported in Table 1.

Table 1

Factor Loadings for Refined Three-Factor Model

Item		Critical Questioning and Curiosity	Creative Confidence	Diversity and Collaborative Perspectives
F_1		-0.061	0.295	0.718
F_2		0.495	0.110	0.213
F_3		0.053	0.653	0.154
J_1		0.225	0.056	0.511
J_2		0.145	0.190	0.551
J_3		0.452	-0.196	0.524
J_4		-0.028	-0.066	0.783
N_1		0.663	0.099	0.026
N_2		0.752	-0.112	0.073
N_3		0.898	0.077	-0.100
P_2		0.096	0.611	0.044
Q_1		0.239	0.544	0.166
Q_2		0.605	0.104	0.064
Q_3		0.564	0.276	0.099
Q_4		0.022	0.984	-0.019
Variance Explained		20.6%	15.7%	14.0%
Reliability Coefficient	ω_h	.80	.81	.77
	Cronbach's α	.87	.83	.83

Note. Factor labels are applied based on interpretation; factor loadings above 0.3 are shaded for emphasis.

Together, the three factors explain 50.3% of the variance in student responses related to design thinking mindset. Items that load strongly on the first factor all relate to curiosity and holding a beginner's mind. For example, the original scale items for "critical questioning" (with the prefix N) all remained consistent on this factor—"I look for something new in a new situation" (N_1); "I am curious about what I don't know" (N_2); and "I generally seek as much information as I can in new situations" (N_3). Two items related to novel thinking aligned with this item as well, Q_2 "I am comfortable to think something new, different from what already exists" and Q_3 "I am sure I can deal with problems requiring creativity." These attributes signal the importance of keeping an open mind in the design process.

The next items related to creative confidence, which was one of the original scales included. Although two items loaded on the factor for curiosity instead, others were aggregated to provide satisfactory coverage of the creative confidence factor. The most indicative item for this factor was Q_4, "I believe in my abilities to creatively solve a problem." The two items joining the scale were F_3, "I am comfortable to insert into the final solution factors coming from a broader vision," and P_2, "I can foresee different outcomes of a project." These two items exemplify the creative values of holding and refining mental solutions during the design process.

The final factor was about diversity and collaboration in design thinking. Items from the original Design Thinking Mindset Questionnaire related to diversity all loaded strongly here (prefixed with J). One other item, F_1, relates to holding a broader perspective while designing, and shares conceptual similarities with these items. Unfortunately in model exploration, two items from the concept of "envisioning new things" were removed, leaving only P_2. However, this is a good fit with the concept of creativity in design. The items for "holistic views" (prefixed with F) were spread across concepts. This may indicate the holism required while designing—that nurturing a holistic perspective infuses other elements of design thinking—and also indicates that further item refinement is needed. The original subscale included three items, though later versions of the questionnaire included new items that may be a better fit. One item, J_3, was also left in the model with cross-loadings because it seemed connected to both thinking curiously and collaboratively ("I find value in other people's diversity").

Reliability Analysis

The reliability of the given factor solution was calculated following satisfactory interpretation of the model (Zinbarg et al., 2005). The overall reliability, ω_h, for the items was 0.73 a substantial portion of the variation of items is related to a single common factor. Taking each factor separately, the ω_h reliabilities were .80, .81, and .78, in order. The level of reliability shown suggests that response variation was consistently associated with the underlying factors. These values are also included in Table 1, along with the more common Cronbach's alpha values which were excellent.

Conclusion

The challenge of verifying measurement validity is ongoing. As part of a larger project we administered a truncated version of the Design Thinking Mindset Questionnaire originally produced by Dosi et al. (2018). With the changes made to the instrument (not delivering all of it) and use in a new educational context, it is necessary to reinspect the validity and reliability evidence of the scale to ensure it is functioning as expected. Our review of the instrument confirms that the questions are appropriate for secondary design education settings, and structural evidence of the instrument similarly indicates that the instrument is suitable for use in understanding how design thinking mindset is developing.

Our use and analysis of the instrument is part of a collection of evidence, which has consolidated the number of constructs from the original count of 22, down to 10 or fewer. In our case, we identified three constructs related to design thinking mindset, which influence student activity. These constructs are (a) critical questioning and curiosity, (b) creative confidence, and (c) diversity and collaborative perspectives. These elements correspond to factors identified in other research using the design thinking questionnaire.

Some limits to this study are opportunities to bolster the validity evidence related to design thinking mindset. First, the sample of participating students here was limited. Due to the previously supported theoretical structure, and high correlation among items on the survey, it was acceptable for us to proceed with exploratory factor analysis. However, attaining a greater sample size would increase the statistical power of our analysis and enable confirmatory designs. Furthermore, with this supportive evidence, analysis may be undertaken to appraise student design thinking mindset and growth over time. Given the hypothesis that our design pedagogies are working, the benefit of such findings would be twofold—comparison of design thinking mindset over time may inform our pedagogical strategies, and may offer further predictive validity evidence that reinforces the utility of this design thinking mindset questionnaire.

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