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Assessing Design Thinking Mindset: Using Factor Analysis to Reexamine Instrument Validity

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Abstract

This method paper analyzes validity evidence of the Design Thinking Mindset Questionnaire and extends the capacity of researchers and practitioners to measure design thinking. Specifically, this project investigates the potential development of design thinking mindset among secondary students by appraising the validity of an existing design thinking mindset survey when used in the secondary-education context. Despite its importance, design thinking is invisible like other forms of cognition, presenting difficulty when monitoring students' development as design thinkers. 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 design thinking mindset and we had interest in the questionnaire. However, differences between the present administration and the original use of the questionnaire warrant further investigation of the validity of the measurement tool. To examine the instrument's validity, we applied exploratory and confirmatory factor analysis to compare the originally prescribed factor structure and an empirically obtained model. These procedures offer insight into the stability of the latent structure of design thinking mindset and the utility of the assessment tool in this context. By verifying the quality of the instrument in a secondary education context, researchers and practitioners may be better equipped to determine changes in this mindset among secondary students who are beginning their journey as designers.

Keywords: design thinking, secondary education, factor analysis, instrument validity

Introduction

Design is a central activity in engineering, as evidenced by its inclusion in Standards for Technological and Engineering Literacy (STEL) at the secondary-education level [1] and ABET standards at the higher education level [2]. Design is a problem-solving framework emphasizing empathy, creativity, and experimentation. Engineering designers use a non-linear, iterative process to understand users, challenge assumptions, redefine problems, and create innovative solutions [3]. At a specific level, design has been described as an evidence-based decision-making process [e.g., 4], however greater proficiency as a designers yields a perspective of design as freedom when problem-solving, given its open-ended nature [5].

What type of thinking is required to navigate the design process then? "Design thinking is an elusive and difficult construct to define" [6, p. 53]. However, a number of aspects of design thinking have been proposed including multi-disciplinary thinking, user-focused thinking, and solution-oriented thinking. Beyond attention to these types of outcomes, certain dispositions and mindsets have also been purported as necessary when addressing design problems: for example, creativity, critical thinking, and collaboration [1], [7], [8]. Yet, for all these aspects of design thinking, it is invisible like other forms of cognition.

Criticality of Measuring Design Thinking Mindset

As part of a larger research project, we are testing design pedagogy to influence students' critical thinking and awareness from the beginning of the design process using an approach we call Learning by Evaluating (LbE). Specifically, in the pedagogical strategy we have developed, students see example work in a series of comparisons and discern important features prior to beginning their own projects [9]. We argue that this discourse fosters a design thinking mindset, whereby students have a greater sense of what matters in design and why. Therefore, being able to monitor this mindset development process is an instrumental type of feedback in working towards our larger project claims about the efficacy of the LbE approach.

Historically, the assessment of design thinking skills has often relied on qualitative data, such as observations, interviews, and verbal protocol analysis (i.e., think-aloud studies). This can make it difficult to quantify and compare progress across students [10]. An original quantitative questionnaire by Dosi, et al. [7] assessed various aspects of design thinking mindset that appeared relevant to our project. The development of a research instrument requires rigorous development and testing in the first place, so identifying an existing instrument that is on target saves much effort in the research process.

However, reexamination is necessary whenever adaptations are made to the items or context [11] – [13]. Intrinsic characteristics of our ongoing research and intentional decisions by our research team warrant effort to understand how the instrument is operating. We are working in a secondary-education context that differs from the original audience of the questionnaire. Furthermore, the original questionnaire was developed with 71 items but we have identified subset of constructs with most salience for our project, described later.

Research Purpose

The purpose of this method paper is to appraise the validity of the existing design thinking mindset questionnaire for use in the secondary-education context. The development and extant uses of the survey are described (though we were unable to be informed by these applications of the questionnaire because they were contemporaneous with our own research development). Then construct validity of the questionnaire is examined in two steps: first, we summarize prior exploratory factor analysis (EFA) work to describe the construct organization of the instrument. Then, we apply confirmatory factor analysis (CFA) to compare the originally prescribed factor structure to the model obtained in our own EFA. Though this analysis offers insight about the utility of the assessment tool in our research context, this study's findings also hold potential significance for educators and researchers interested in design thinking mindset beyond our own project. Affirming the conceptual organization of the questionnaire can contribute to our understanding of the elements and development of design thinking mindset.

Instrument Background and Application

The original development process for the Design Thinking Mindset Questionnaire by Dosi, et al. [7] included a synthesis of literature, preliminary review, pilot testing, and revision of many items. The questionnaire uses a 5-point rating scale, from Strongly Agree to Strongly Disagree, for each of the included items. EFA in the initial research development produced a final instrument with 71 items based on 22 constructs informed by literature, theory, and empirical evidence [14].

Use of the Initial Questionnaire

Results held that the items had good internal consistency and construct validity—in the initial reporting evidence included the significance of the factor structure, variation explained, and the Kaiser-Meyer-Olkin test [7]. Furthermore, the questionnaire has been used in other studies to assess design thinking mindset [15] – [17] with varying results as to students' growth. Notably, among these studies, the internal consistency of factors on the questionnaire was fair to excellent (α = .62 – .91). Thi-Huyen, et al. [17] also used a subset of the questionnaire with wording on the items matching the original use, suggesting that portions of the questionnaire may operate reliably and in other design contexts.

Translation of the Questionnaire

Several studies have also been conducted with a translated version of the questionnaire [18], [19], [20]. This was first done by Ladachart, et al. [19] for use with ninth-grade students, a similar context to our study. The items were reinspected with EFA and CFA, resulting in a simplified instrument. The recommended questionnaire here only included 30 items and 6 constructs, which echoed main ideas of design thinking mindset in the original constructs. Although the structure has changed, the translated survey has also had high reliability on the factors (α = .86 – .93).

Follow-up Analysis of the Questionnaire

More recently, several members of the research team conducted follow-up analysis in multiple studies to verify the instrument's quality [21]. This work has further defined and developed the original scale. Like the translated instrument, their updated recommendation was for a simplified factor structure (from 22 to 10 factors). However, they argued that the model is consistent with previous interpretations because the items were consolidated on various subscales. The final 31 items had good reliability, between α = .78 and .88.

Implications for Ongoing Use of the Design Thinking Mindset Questionnaire

Taken together, the use of this questionnaire in several research directions indicates its promise for understanding design thinking mindset. The research studies have been conducted with a range of secondary and post-secondary participants now, with the items working as expected. As previously mentioned, these developments occurred simultaneous to our research, therefore we are as of yet uninformed by these findings. Surprisingly though, our team has moved in a similar direction by simplifying the instrument. Comparison among the reduced items and constructs remains harmonious with main aspects of design thinking mindset. Shifting recommendations for the items and factor structure, however, demonstrate that further attention is needed to accurately measure design thinking mindset.

Methods

Given the new context, our subset of the Design Thinking Mindset Questionnaire, as well as the newness of the psychometric evidence for the instrument, we applied several steps to ensure that the questionnaire is operating as expected. The verification details are described here as an extension of the instrument's original development.

Study Context

We have partnered with a large, urban school district to conduct this study of design thinking. Teachers selected for participation in the project led several sections each of an introductory course, *Foundations of Technology* (alternately called *Foundations of Engineering*). The class is largely organized around open-ended projects and cycles of the engineering design process, with successive complexity, as students develop familiarity with engineering thinking. As students develop greater proficiency with the design thinking process—in other words, a greater design thinking mindset—their understanding proceeds from a simplified process to one with greater detail.

Instrumentation

In connection with the theoretical framework of our larger project and the mechanisms whereby we hoped to impact design thinking mindset, our team selected 5 subscales at the beginning of the project for use with student participants. The selected subscales were for "holistic view" (3 items); "openness to different perspectives" (4 items); "critical questioning" (3 items); "envisioning new things" (3 items); and "creative confidence" (4 items). Side-by-side with later versions of the instrument, the items in "holistic view", "critical questioning" and "creative confidence" were almost wholly included. Yet, items from "openness to different perspectives" and "envisioning new things" were mainly reconceptualized to relate to collaboration and abductive reasoning.

At the beginning and end of the course, students responded to the 17 items from our subset of the Design Thinking Mindset Questionnaire. The electronic survey asked which class students were in, then provided the items. Once completed, the average value of each subscale was displayed to students as a personal benchmark. Instructors were also encouraged to conduct a class debriefing session related to the questionnaire content as either an orientation or reflection, at the beginning or end of the course, respectively. Because it was conducted as a class activity, it was permitted that all students would complete the items; however, student assent and parent consent were needed for student data to be included in our analysis.

Student Participants

Examining the construct validity of the questionnaire was conducted in two stages, first for EFA, then for CFA. The data for each stage were drawn from consenting student responses to the items at 6 high schools in consecutive years. In the first year, nearly 500 students were enrolled in the classes, but the number of fully consenting students (i.e., student and parents) was much lower. We were able to match 91 responses to participating students (18.3%). While the sample size was limited, the initial sample remained suitable for EFA given liberal heuristics of a 5:1 response-to-item ratio and an assumption of high factorability [14]. And, given prior evidence related to the instrument, we felt comfortable to proceed. The second year's data only included a potential 291 students enrolled in the courses, though the proportion of fully consenting students was higher (n = 133, 45.7%) and we matched 234 responses to students, taken at various times in the course.

Exploratory Factor Analysis

The efforts here give attention to the questionnaire's construct validity, which is the underlying structure of a measurement instrument and whether it measures the topics it purports to measure [22]. Factor analysis is the most common way to assess construct validity [14]. Despite the nomenclature, it is possible to apply either EFA or CFA for the purposes of exploration or confirmation of a measurement instrument [23]. We initiated our analysis with EFA to allow for greater flexibility with the model and to explore how a number of factors different from organization in the original instrument might influence the results and interpretation. Given the interrelated nature of constructs in design thinking mindset (for example they were even represented as a second-order model, with all factors related in [21]), we used oblimin rotation during factor analysis to allow for correlated factors.

Further data screening procedures followed Tabachnick and Fidell [24], including checking for missing data (from non-engagement), outliers, normality, and linearity applied to data for both EFA and CFA. Screening for engagement identified eight cases of completely missing data and five cases of straight-line responses, suggesting disengagement with the survey. Therefore, these responses 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 was n = 78. These responses were taken at various points in the course, hopefully reflecting variation in students' development of design thinking mindset, and preventing too homogeneous of responses. We also concluded that basic assumptions of linearity were met based on skewness and kurtosis statistics, as well as visual inspection of scatterplots [23].

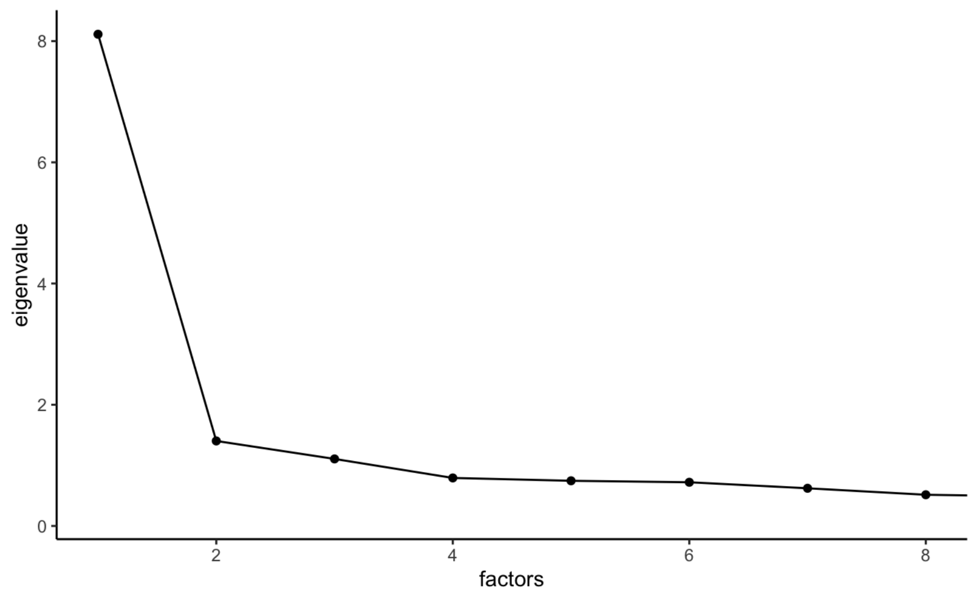
Prior to factor analysis, factorability of the data was appraised with the Kaiser-Meyer-Olkin (KMO) test and the Bartlett test. The results were in the excellent range (KMO = .91; Bartlet $p < .01$) [24], [25]. Considering various possible factor structures, inspection of a screen plot indicated as few as two factors could be retained (see Figure 1) and the original structure of subscales would have kept as many as 5 factors. Within this range we compared a variety of factor solutions on the balance of theory, empirical indicators, and interpretability [14].

Exploratory Model Results

The 5-factor model was difficult to interpret and did not have satisfactory results. Items from original subscales did not load together, nor did they load consistently. Factor loadings were more consistent on the 4-factor model, yet the conceptualization of each factor was not clear. Finally, the 3-factor model was conceptually interpretable and more parsimonious than the previous results. We iterated on the model by removing two items with cross-loadings, leaving 15 items in a 3-factor model. 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. The final factor loadings are reported in Table 1.

Figure 1

Scree Plot Showing Eigenvalues for Factor Extraction



Together, the three factors explain most approximately half (50.3%) of the variation in student responses related to design thinking mindset. We interpreted the first factor as critical questioning and curiosity. This subscale subsumed the original scale items for "critical questioning" (with the prefix N)—for example, "I look for something new in a new situation" (N_1). The added questions signal the importance of keeping an open mind in the design process, for example "I am comfortable to think something new, different from what already exists" (Q_2) and "I find value in other people's diversity (perspectives, abilities)" (J_3).

The next items related to confident envisioning, similar to the original creative confidence scale (prefix Q), though two items had loaded on the factor for curiosity instead. The remaining items were "I think I can use my creativity to efficiently solve even complicated problems" (Q_1) and "I believe in my abilities to creatively solve a problem" (Q_4). Coupled with two new items, "I am comfortable to insert into the final solution factors coming from a broader vision" (F_3) and "I can foresee different outcomes of a project" (P_2) we concluded there was satisfactory coverage of the factor. Together, these items exemplify the creative value 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 scale related to diversity (prefixed with J) all loaded here. Example items included "I am open to collaborate with people having different backgrounds" (J_2) and "I find value in other people's diversity (perspectives, abilities)" (J_3). One other item related to holding a broader perspective while designing, also shared conceptual similarities and loaded strongly on this factor (F_1).

Table 1

Factor Loadings for Refined Three-Factor Model

Item		Critical Questioning and Curiosity	Confident Envisioning	Diversity and Collaborative Perspectives
F_1		-.061	.295	.718
F_2		.495	.110	.213
F_3		.053	.653	.154
J_1		.225	.056	.511
J_2		.145	.190	.551
J_3		.452	-.196	.524
J_4		-.028	-.066	.783
N_1		.663	.099	.026
N_2		.752	-.112	.073
N_3		.898	.077	-.100
P_2		.096	.611	.044
Q_1		.239	.544	.166
Q_2		.605	.104	.064
Q_3		.564	.276	.099
Q_4		.022	.984	-.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 based on interpretation; loadings above .3 are shaded for emphasis.

In sum, though items were removed from original subscales, a refactored solution was conceptually cohesive. In the case of items from the "Holistic view" subscale (prefixed F), spread across other factors may indicate the holism required while designing—nurturing a holistic view while designing infuses other elements of design thinking—or that further item refinement is needed. This analysis of the instrument is part of a collection of evidence that has consolidated the number of constructs from the original count, down to 10 or fewer. In our case, the constructs of (a) critical questioning and curiosity, (b) confident envisioning, and (c) diversity and collaborative perspectives resonate with central tenets of design and correspond to factors identified in other research using derivatives of the questionnaire.

Confirmatory Factor Analysis

Once the model was conceptualized, we applied CFA and inspected fit indices to see the suitability of the model with new data. We used a robust maximum likelihood estimation with a mean adjusted test statistic (the "MLM" estimator), to address concerns of any non-normality due to the Likert-type responses or potential outliers [26]. This produces an adjusted chi-square estimate called the Satorra-Bentler chi-square, as well as robust estimates for fit indices [27]. A range of fit indices are provided for CFA models, and it is recommended to use several in tandem

[28], [29]. We determined to use root mean square error of approximation (RMSEA; recommended < .06 for suitable fit); standardized root mean square residual (SRMR; recommended < .08); and comparative fit index (CFI; recommended > .95) [14], [29] – [30].

Data screening steps were followed as reported in the earlier analysis. Among the responses, 16 were identified as insufficiently complete and excluded from the data. Mean imputation was applied to address missing data in six cases that were only missing one item. Five cases of straight-line response were also excluded from analysis. We also gave attention to response timing to ensure a delay in repeated measures—while the teachers administered the mindset survey at the beginning and end of the course, 14 responses were removed due to the repetition of the mindset survey within a short timeframe. We suspected that students mistakenly entered and completed the survey again in the short term. Again, assumptions of normality and linearity were also met among the variables, resulting in a final sample size of n = 199.

Confirmatory Model Results

We examined the CFA model based on specifications obtained from EFA, with three correlated factors, no co-varying items, and only one cross-loading item (J_3) from the original results. Unfortunately, the initial configuration produced problematic loadings based on item J_3, therefore we decided to relate the item only to the third factor, as this had a higher expected loading and maintained connection with the other diversity-related items from the Design Thinking Mindset Questionnaire. In this revised model, all of the factor loadings, factor covariance, and error estimates were significant. The standardized loadings ranged from .61 to .81 (see Table 2). Overall model fit was also satisfactory, meeting the standards for various fit indices (see Table 3).

The factors were highly correlated, suggesting a possibility of the items loading on a single factor or a second order factor, as in Vignoli, et al. [21]. A second-order model, where some combination of the factors and residual form a higher-order latent variable, is actually a special case of a model with several factors—only applying restrictions to the structure of relationships between the latent variables [31]. Yet, the model reported errors with variance and loading on the second-order factor and the second-order structure was only just-identified, meaning that additional fit indices were unavailable. An alternative, single-factor model was also compared, showing significant parameter estimates, but weaker fit (see Table 3).

Table 2

Confirmatory Factor Analysis Model Parameters

Item		Loading and Error Variance	
Critical Questioning and Curiosity			
F_2	I am able to understand which are the impacts on the external environment of the solution we are proposing.	0.662	0.562
N_1	I look for something new in a new situation.	0.652	0.575
N_2	I am curious about what I don't know.	0.666	0.556
N_3	I generally seek as much information as I can in new situations.	0.693	0.519
Q_2	I am comfortable to think something new, different from what already exists.	0.703	0.506
Q_3	I am sure I can deal with problems requiring creativity.	0.759	0.423
Confident Envisioning			
F_3	I am comfortable to insert into the final solution factors coming from a broader vision.	0.684	0.532
P_2	I can foresee different outcomes of a project.	0.611	0.626
Q_1	I think I can use my creativity to efficiently solve even complicated problems.	0.700	0.510
Q_4	I believe in my abilities to creatively solve a problem.	0.811	0.342
Diversity and Collaborative Perspectives			
F_1	I am able to consider what I am doing from a broader perspective.	0.759	0.424
J_1	I am comfortable to change my opinion.	0.637	0.594
J_2	I am open to collaborate with people having different backgrounds.	0.758	0.425
J_3	I find value in other people's diversity (perspectives, abilities).	0.781	0.391
J_4	I believe that teams with diverse perspectives result in superior outcomes.	0.724	0.475

Factor Covariances	Questioning	Envisioning	Diversity
Questioning	—		
Envisioning	0.999	—	
Diversity	0.908	0.842	—

Table 3

Confirmatory Factor Analysis Model Fit Indices

Model	Chi-Square (df)	RMSEA[a]	SRMR	CFI
Revised 3-Factor Model	146.8 (87)	0.066 [0.047 – 0.085]	0.051	0.946
Single-Factor Model	165.6 (77)	0.086 [0.068 – 0.104]	0.056	0.911

[a]Reported with 90% confidence interval

Conclusions

The challenge of verifying measurement validity is ongoing. Especially for a construct as elusive as design thinking mindset, this poses several challenges. The multiple, simultaneous approaches to revise the instrument demonstrate the relevance and need of this effort to ascertain students' design mindset. Yet, the development of the Design Thinking Mindset Questionnaire, originally introduced in [7] holds promise for better understanding design thinking and informing design education settings.

We have proposed and tested a subset of the question from the Design Thinking Mindset Questionnaire that, when restructured according to a three-factor model, demonstrated stability and good fit to student response data. Our review of the instrument affirms 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. Further verification of the models is warranted, hopefully to harmonize the findings around this measurement concept. And, building upon the steps we have taken to identify this model, we plan to examine patterns of students changing mindset, especially growth during design course experiences.

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