Journal of Research and Curriculum Development, Vol.12, Issue.1, January – June, 2022
ISSN: 2730-387X (Online) https://so03.tci-thaijo.org/index.php/jrcd/index

Validating a Design-Thinking Mindset Questionnaire with Thai Secondary School Students

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Received: February 11, 2022
Revised: June 29, 2022
Accepted: June 30, 2022

Abstract: *Science, Technology, Engineering, and Mathematics (STEM) education, as an educational policy, provides opportunities for students to learn science and mathematics in more integrated ways than the use of traditional methods. This can be pedagogically accomplished via a design-based approach, in which students engage in collaboratively solving engineering problems using various domains of knowledge and skills. In this pedagogical process, design thinking is vital. However, given that design thinking is a complex construct, a way in which it can be practically measured in an effective way has yet to be sufficiently developed. This may become a limitation, because teachers need to assess whether or not students are in the process of developing design thinking while engaged in design-based activities. In an attempt to support teachers in measuring the design thinking of students in a practical way, the current study aims to develop and validate a five-point Likert-scale questionnaire, based on 892 Thai secondary students subsequently using exploratory and confirmatory factor analyses. The results revealed that the six components of design thinking can be measured by 28 items on the questionnaire. It may be recommended that, in addition to other methods, such as a think-aloud protocol, the questionnaire can be used to measure the design thinking of the students.*

Keywords: *Design thinking, Factor analysis, Measurement, STEM education*

Introduction

Science, technology, engineering, and mathematics (STEM) education has been recognized as a reform movement in education by countries in the Asia-Pacific region, where a key aim is to achieve STEM literacy among citizens and to increase a workforce in STEM-related careers (Promboon, Finley & Kaweekijmanee, 2018; Wahono, Lin & Chang, 2020). In this regard, the engineering design process is pedagogically recommended as a key approach to integrated STEM education (Kelly & Knowles, 2016) by which students learn to collaboratively solve real-life problems using knowledge, skills, and dispositions in STEM. In this process, design thinking is deemed vital for students, as it is applied when individuals engage in engineering design-based activities (Dym, Agogino, Eris, Frey & Leifer, 2005). Thus, it seems important, if not necessary, that students are enabled to develop design thinking, in order for them to learn STEM meaningfully and successfully through the engineering design process (Li et al., 2019).

One of challenges inherent in facilitating students' design thinking is the issue of how design thinking can be defined and measured in an effective yet practical way. Being defined, for example, as a process of (1) empathizing with users, (2) defining the problem, (3) ideating ideas, (4) creating prototypes, and (5) testing the prototypes (Institute of Design at Stanford, 2019), it appears that design thinking is a complex construct, comprising a number of dimensions; thus, measuring it can be challenging. While in research, design thinking can be measured using various methods, such as observations, open-ended questions and document analysis (Aflatoony, Wakkary & Neustaedter, 2018), as well as a think-aloud protocol when students are engaged in a design-based activity (Mentzer, Becker & Sutton, 2015), this might not be appropriate for teachers working with a large number of students. Thus, it is crucial that an effective and practical way of measuring design thinking is developed for the sake of teachers.

Previous attempts have been devoted to measuring individuals' design thinking using Likert-scale questionnaires (Blizzard, Klotz, Potvin, Hazari, Cribbs & Godwin, 2015; Dosi, Rosati & Vignoli, 2018), which are more practical and effective for use by teachers than the other methods used in research. However, as these questionnaires were originally developed in English at university or college level, they might not be fully applicable in Asian contexts at school level. At least, processes of translating and validating these questionnaires are required before they can be made available to teachers. Thus, the current study aims to develop and validate a questionnaire measuring design thinking for use in the context of Thailand's schools. Its results will not only provide a validated questionnaire for Thai teachers to measure design thinking, but also offer a theoretical basis for educators who wish to develop a questionnaire measuring design thinking in other Asian contexts.

Design thinking is a mode of thinking individuals use in the process of designing (Li et al., 2019). It can be defined as "an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and redesign" (Razzouk & Shute, 2012, p. 330). It may also refer to individuals' ability to combine empathy, creativity, and rationality to analyze and match solutions to particular problems (Wrigley & Straker, 2015). Arguably, it is this empathy that makes design thinking different from other modes of thinking (Dym et al., 2005) when individuals design products to solve the problems of others, not their own. As a consequence, design thinking can be described as a five-stage process of (1) empathizing with users, (2) defining the problem, (3) ideating ideas, (4) creating prototypes, and (5) testing the prototypes (Institute of Design at Stanford, 2019). Inherent in this process is collaboration, as designing often involves teamwork among individuals with diverse backgrounds (Gracio & Rijo, 2017).

Given the complexity of design thinking, there have been attempts to identify the characteristics of those who have and exhibit design thinking. Such characteristics can be labeled using different terms, such as "traits" (Blizzard et al., 2015), "attributes" (Schweitzer et al., 2016), and "mindset" (Dosi et al., 2018). However, the term "mindset" seems to be the most appropriate (Brenner, Uebernickel & Abrell, 2016), as it refers to "the set of opinions, beliefs and behaviors that characterize an individual" (Paparo, Dosi & Vignoli, 2017, p. 369) when individuals engage in design-based activities. Regardless of the terms used, it appears that design thinking is a multi-faceted concept. As indicated in Table 1, a design-thinking mindset can be described by different yet similar sets of characteristics. These differences are understandable given the fact that a design-thinking mindset can be applied to various contexts (e.g., engineering and business) and scopes (e.g., individual and organization).

Table 1 Characteristics of a design-thinking mindset

Bilzzard et al. (2015)	Schweitzer et al. (2016)	Dosi et al. (2018)	Cook & Bush (2018)
1. Collaboration	1. Empathetic towards people's needs and contexts	1.Tolerance for ambiguity	1. Human-centeredness
2. Experimentation	2. Collaboratively geared and embracing diversity	2. Embracing risks	2. Bias toward action
3. Optimism	3. Inquisitive and open to new perspectives and learning	3. Human centeredness	3. Radical collaboration
4. Feedback-seeking	4. Mindful of process and thinking modes	4. Empathy	4. Culture of prototyping
5. Integrative thinking	5. Experiential intelligence	5. Mindfulness of process	5. Mindfulness of processes
	6. Taking actions deliberately and overtly	6. Holistic view	
	7. Consciously creative	7. Problem framing	
	8. Accepting of uncertainty and open to risks	8. Team working	
	9. Modelling behaviour	9. Team members' interactions	

Table 1 (continue)

Bilzzard et al. (2015)	Schweitzer et al. (2016)	Dosi et al. (2018)	Cook & Bush (2018)
	10. Desire and determination to make a difference	10. multi-disciplinary collaboration	
	11. Critically questioning	11. Open to different perspectives	
		12. Learning oriented	
		13. Experimentation	
		14. Learning from mistakes	
		15. Bias toward action	
		16. Tangible transformation	
		17. Critical questioning	
		18. Abductive thinking	
		19. Envisioning new things	
		20. Creative confidence	
		21. Desire to make a difference	
		22. Optimism to have an impact	

Based on these lists, design thinking can be summarized as generally entailing empathy with people's problems, a desire to take action, and learning in the process of problem solving in order to have an impact on people's lives and societies. While designing, those involved in design thinking wish to communicate ideas and collaborate with others, be open to diverse perspectives, be mindful of the process of problem solving, be aware of their own thinking modes, be comfortable with ambiguity and uncertainty, be confident about creativity, embrace risks when trying different approaches or testing new ideas, and be resilient not to back down from challenging problems. Research has indicated that a design-thinking mindset can facilitate students' learning of STEM. For example, by introducing some tenets of design thinking (e.g., fail-forward mindset) within design-based activities, Marks and Chase (2019) found that students reacted positively to failure and produced successful designs.

Li et al. (2019) argues that "everyone designs and can design" (p. 94) and that design thinking "is important for every student" (p. 94); thus, it should be an educational goal in the 21st century. However, that everyone can design does not mean that everyone is born with the sophisticated ability of design thinking. Several studies have demonstrated the differences between novice and expert designers. Crismond (2013) has summarized "misconceptions" of design practices commonly found among novice designers, as compared to expert designers. Specifically, Mentzer et al. (2015) have noted that novice designers engage in design thinking with little understanding of the problem from clients' perspectives and that they tend to become fixed on a single solution rather than comparing alternatives. Nonetheless, what is implied by such comparisons between novice and expert designers is that design thinking is something teachable and learnable (Cook & Bush, 2018).

If design thinking is to be an educational goal, teachers must have a way to measure and assess students' design thinking, as measuring and assessing are common practices in education. Without measurement and assessment, how can teachers know, for example, which characteristics of design thinking their students already have before the instruction, which characteristics they must emphasize during the instruction, and whether the students have acquired such characteristics after the instruction? While research provides some methods to measure and assess design thinking such as a think-aloud protocol (Mentzer et al., 2015) and a Likert-scale questionnaire (Blizzard et al., 2015), they may not be appropriate and practical for teachers working in different contexts. For them, the think-aloud protocol may be time-consuming and laborious, while the Likert-scale questionnaire may not be contextually sensitive. Therefore, it is useful to develop an instrument that is appropriate and practical for teachers in particular circumstances.

Research methodology

In order to develop an instrument for teachers in Thailand measuring students' design thinking in an appropriate and practical way, a Likert-scale questionnaire is deemed appropriate, as this format of measurement is commonly used in education. Moreover, when compared to the think-aloud protocol (Mentzer et al., 2015), it does not require special skills on the part of teachers. Nonetheless, what is challenging is that such a questionnaire must be reliable, comprehensive, and contextually sensitive enough when it is written in Thai. Thus, based on our literature review, the most extensive list of design-thinking characteristics (Dosi et al., 2018) was used as the starting point. The list covers about 71 items representing 22 characteristics of expert design thinkers, as presented in Table 1. However, as noted in the original questionnaire, two pairs of these characteristics (i.e., Experimentation and Learning from mistakes, and Bias toward action and Tangible transformation) can be merged, resulting in a total of 19 characteristics.

Then, all items of Dosi et al.'s (2018) questionnaire were translated into Thai. During this process, it was recognized that two items (i.e., I am comfortable to learn from experiences and I am comfortable to learn from observations) are similar in terms of structure and meaning. Thus, these two items were combined into one item (i.e., I am comfortable to learn from experiences and observations). The translated questionnaire was sent to a group of teachers to test its readability. After rewording according to the teachers' comments, the translated questionnaire was converted to an online format. Later, invitations were sent to teachers in secondary schools across Thailand for their students to complete the translated questionnaire. This resulted in 953 responses from students. These students included 261 males and 692 females who are in the seventh grade (N = 51), eighth grade (N = 137), ninth grade (N = 90), tenth grade (N = 345), eleventh grade (N = 102), and twelfth grade (N = 228).

Given that the questionnaire has a large number of items, it was likely that some students might feel overwhelmed by it and thus might automatically choose the same answer for all items. The reaction of being overwhelmed was confirmed by some teachers. Thus, it was necessary to screen the data. During this process, it was apparent that 61 students (6.4%) used automation to complete the questionnaire. As a result, these students were excluded from the data set, resulting in 890 students. These students included 238 males and 652 females who are in the seventh grade (N = 50), eighth grade (N = 124), ninth grade (N = 84), tenth grade (N = 321), eleventh grade (N = 100), and twelfth grade (N = 211). Then, these students were divided into two groups for the exploratory and confirmatory factor analyses. In so doing, data from one third of them (N = 297) were randomly selected for exploratory factor analysis (EFA), and data from two thirds of them (N = 593) were then used for confirmatory factor analysis (CFA).

In order to examine whether the first set of data was suitable for EFA, the basic requirements were examined. According to Howard (2016), the two most popular data inspection techniques for EFA are Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy. In the current study, it was found that Bartlett's test is significant ($\chi 2$ (2415) = 14168.08, $p < .05$) and that the KMO score is .95, indicating this set of data is appropriate for EFA. Then, the principal axis factoring (PAF) approach and the varimax method were used to conduct EFA. As a criterion to reduce the number of items in the questionnaire for the current study, only items with factor loading equal to or higher than 0.3 on one factor were included for further analysis. In other words, any items with factor loading higher than 0.3 on more than one factor or with factor loading less than 0.3 on one factor were excluded. As a result, 28 items representing six factors remained for CFA (see Table 2).

Table 2 Factor loadings based on an exploratory factor analysis

Items	Factor					
	1	2	3	4	5	6
D33: I am comfortable to share my knowledge with my teammates.	.713					
D37: I am comfortable to work with people having diverse perspectives from mine.	.677					
D40: I am open to collaborating with people having different backgrounds.	.640					
D36: I think in a team it is preferable to have different competences.	.637					
D39: I am comfortable to change my opinions.	.456					
D76: I am sure I can deal with problems requiring creativity.		.802				
D74: I think I can use my creativity to efficiently solve even complicated problems.		.749				
D77: I believe in my ability to creatively solve a problem.		.688				
D73: I am comfortable to use prototypes to represent new ideas.		.630				
D72: I can foresee different outcomes of a project.		.517				
D83: I am comfortable to positively think and act.		.508				
D80: I desire to create value with the final solution.		.501				
D82: I think I can overcome difficulties.		.490				
D61: I am comfortable transforming ideas into something tangible.			.606			
D64: I am curious about what I do not know.			.602			
D65: I generally seek as much information as I can in new situations.			.564			
D62: I am comfortable transforming a hypothesis in something to be tested.			.489			
D23: I am able to recognize when we are in a divergent or convergent phase of the process.				.601		
D20: I easily empathize with the concerns of other people.				.493		
D25: I am able to understand what are the impacts of the external environment of the solution we are proposing.				.480		
D7: I am comfortable dealing with problems that I cannot predict whether they will be successfully solved.					.675	
D4: I am comfortable dealing with unsolved problems.					.659	
D6: I enjoy the fact that a solution can result from unexpected directions.					.654	
D1: I feel comfortable with what is unknown.					.559	
D11: I like taking many chances, also if it leads me to make mistakes.					.525	
D2: I prefer new contexts to familiar ones.					.395	
D14: People are a source of inspiration while identifying the direction of the design solution.						.517
D17: I can tune into how users feel rapidly and intuitively.						.437

Then, the items belonging to each factor were interpreted using Dosi et al.'s (2018) framework of design-thinking characteristics in order to name the factors of design-thinking characteristics resulting from the EFA in the current study. For Factor 1, there were five items from three original factors, namely Team members' interactions, multi-disciplinary collaboration, and Open to different perspectives. As these three factors reflect collaboration among designers with different backgrounds, Factor 1 was named Collaboratively working with diversity.

Regarding Factor 2, there were eight items from four original factors, namely Envisioning new things, Creative confidence, Desire to make a difference, and Optimism to have an impact. In a broad sense, these five factors reflect characteristics that designers believe in creativity and are optimistic to make a new product that makes an impact or difference. Thus, they were named Being confident and optimistic to use creativity.

For Factor 3, there were four items from two original factors, namely Tangible transformation, and Critical questioning. These two original factors seem to differ, as the former reflects a characteristic of designers who prefer to make their ideas concrete and testable, and the latter reflects a characteristic of designers who want to be informed before solving a new problem. However, they share a characteristic that designers are oriented to learning in a new situation by making and testing their ideas. Thus, they were named Orientation to learning by making and testing in the current study.

Regarding Factor 4, there were three items from three original factors, namely Empathy, Mindfulness of process, and Holistic view. These three items were grouped under the new factor of Mindfulness to process and impacts on others, because they all reflect a characteristic that designers are not only mindful of the process by which they are doing, but also its products that will affect other people and the environment.

For Factor 5, there were six items from two original factors, namely Tolerance for ambiguity, and Embracing risks. These original factors are closely related, given that designers must work on solving uncertain problems for a period of time, so that they must often take risks to solve those problems successfully. Therefore, these six items were named Comfortable with uncertainty and risks.

Regarding Factor 6, there were only two items from two original factors, namely Human centeredness, and Empathy. As these two items reflect a characteristic that designers take human users' experiences and feelings into consideration when they are designing a product, these two items were then named Human centeredness.

Given the six factors of design-thinking characteristics as a result of EFA in the current study, it was necessary to test this factor structure with CFA using the second set of data. The results of CFA would enhance the validity of the questionnaire to be used in Thai contexts.

Research results

After 59 adjustments to achieve adequate goodness of fit, CFA indicated that the factor structure gained from EFA correlates with the second set of data and has construct validity (Chi-squire = 332.602, df = 285, p-value = 0.0274, RMSEA = 0.017, CFI = 0.995, and SRMR = 0.028). As can be seen in Table 3 and Figure 1, the factor loading values of all six factors are positive and significant at .01, ranging from 0.784 to 0.979. Also, the factor loading values of all 28 items are positive and significant at .01, ranging from 0.546 to 0.836. Moreover, Cronbach's alpha values of reliability for Collaboratively working with diversity, Being confident and optimistic to use creativity, Orientation to learning by making and testing, Mindfulness to process and impacts on others, Comfortable with uncertainty and risks, and Human centeredness are 0.884, 0.915, 0.861, 0.767, 0.803, and 0.598, respectively. Thus, with a caution regarding the last factor, the questionnaire is acceptable to measure Thai students' design-thinking mindsets.

Table 3 Factor loadings based on a confirmatory factor analysis

Design-Thinking Mindset Factor	Indicator	Factor Loading	SE	t	R^2
Collaboratively working with diversity (CW)		0.852	0.019	43.902**	0.726
	X1	0.787	0.018	43.594**	0.619
	X2	0.823	0.015	54.248**	0.677
	X3	0.780	0.018	43.500**	0.608
	X4	0.836	0.015	55.223**	0.698
	X5	0.797	0.018	43.368**	0.636
Confident and optimistic to use creativity (CO)		0.822	0.021	38.623**	0.676
	X6	0.791	0.018	43.819**	0.625
	X7	0.747	0.021	35.097**	0.558
	X8	0.776	0.019	41.242**	0.602
	X9	0.730	0.022	33.896**	0.533
	X10	0.732	0.021	34.449**	0.536
	X11	0.759	0.020	38.502**	0.576
	X12	0.777	0.018	42.992**	0.604
	X13	0.762	0.020	38.804**	0.580
Orientation to learning by making and testing (OL)		0.879	0.019	46.012**	0.772
	X14	0.793	0.018	44.205**	0.629
	X15	0.761	0.020	35.654**	0.579
	X16	0.793	0.018	44.343**	0.629
	X17	0.764	0.020	38.607**	0.584
Mindfulness to process and impacts on others (MP)		0.974	0.018	54.663**	0.948
	X18	0.776	0.020	39.217**	0.603
	X19	0.700	0.026	27.337**	0.490
	X20	0.789	0.021	37.664**	0.617
Comfortable with uncertainty and risks (CR)		0.784	0.030	25.943**	0.615
	X21	0.597	0.031	19.368**	0.356
	X22	0.639	0.033	19.222**	0.408
	X23	0.546	0.034	15.875**	0.298
	X24	0.665	0.031	21.553**	0.442
	X25	0.696	0.033	21.051**	0.484
	X26	0.678	0.030	22.769**	0.460
Human centeredness (HC)		0.979	0.029	33.445**	0.959
	X27	0.660	0.030	22.014**	0.435
	X28	0.662	0.030	22.040**	0.438
Chi-square = 332.602, df = 285, *p*-value = 0.0274 RMSEA = 0.017, CFI = 0.995, SRMR = 0.028					

Discussion

By conducting EFA and CFA successively, the current study demonstrated that Dosi et al.'s (2018) comprehensive list of design-thinking characteristics can be reduced to a smaller number of factors. However, these factors are able to reflect key aspects of design thinking as shared in previous studies. For example, the collaborative, creative, and optimistic nature of design thinking (Bilzzard et al., 2015; Schweitzer et al., 2016) is reflected in the first and second factors. Moreover, bias toward action, the culture of prototyping, and mindfulness of process (Cook & Bush, 2018) are represented in the third and fourth factors. In addition, accepting uncertainty and being open to risks (Schweitzer et al., 2016) is apparent in the fifth factor. While not clearly manifested as a reliable factor, human centeredness could be represented in the sixth factor. Thus, it is reasonable to recommend that the questionnaire validated in the current study be used to measure and monitor Thai students' design-thinking mindsets.

However, given that "empathy [is the] most important piece of the design-thinking process" (Cook & Bush, 2018, p. 99), the items originally belonging to the factor, namely

Empathy, in Dosi et al.'s (2018) list of design-thinking characteristics did not appear to constitute a single factor in the current study. Rather, some of the items were distributed together with other factors (i.e., human centeredness, mindfulness to process, and holistic view). In a sense, this is understandable, given that human centeredness can refer to "developing empathy for the people for whom you are designing" (Cook & Bush, 2018, p. 95). In another sense, this might mean that, at least for students participating in the current study, empathy does not operate only in the first stage of the design-thinking process, as graphically illustrated by the Institute of Design at Stanford (2019), but also in the whole process of design thinking. This hypothesis supports what Hess and Fila (2016) noted, namely that "empathy […] functions from the beginning to the end of a design project" (p. 108).

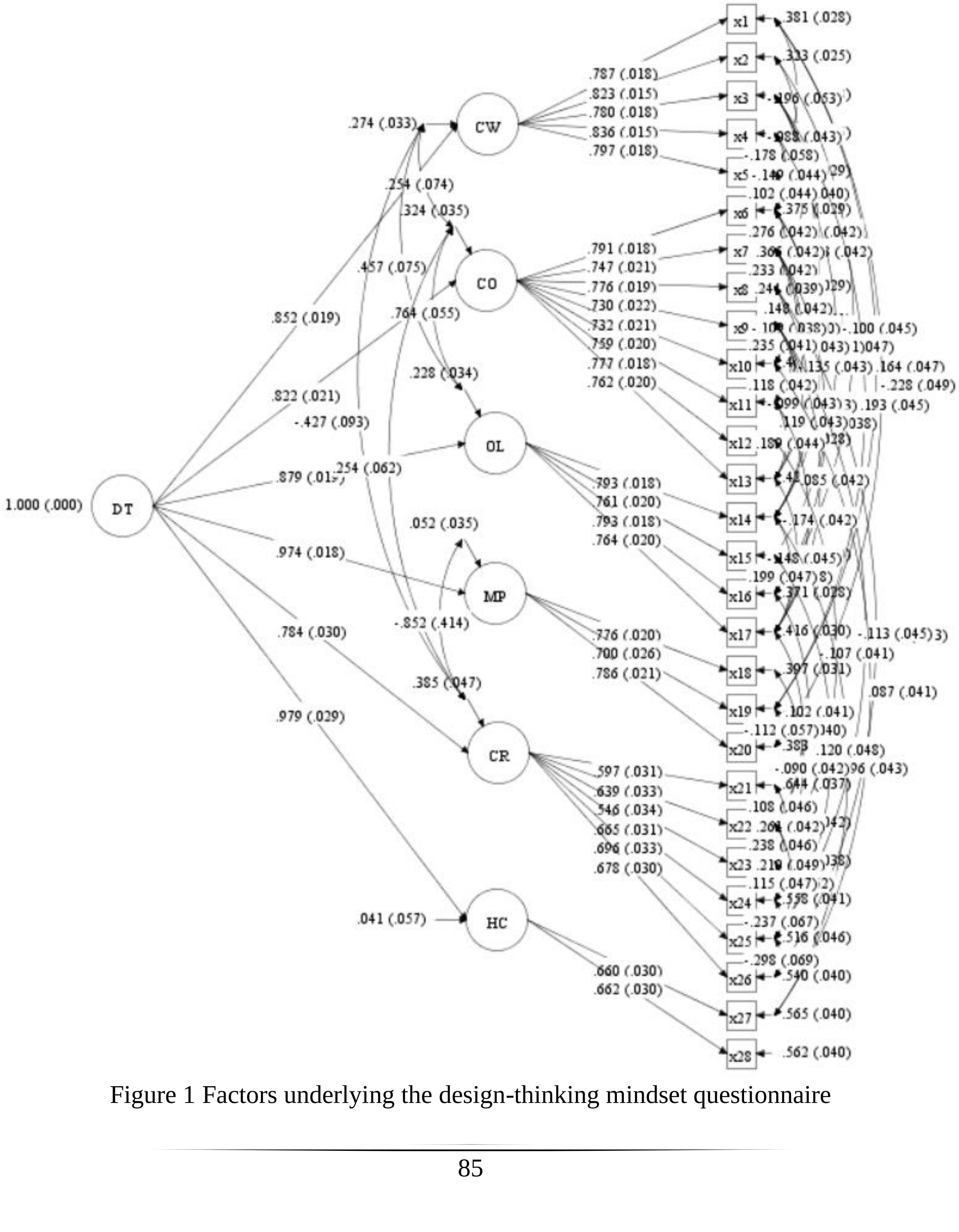

Figure 1 Factors underlying the design-thinking mindset questionnaire

Conclusion

In the modern world, STEM education has recently become an educational policy in many countries. This policy encourages teachers to use design-based learning as a pedagogical approach to facilitate STEM literacy among citizens as well as to increase the workforce in STEM-related careers. Implicitly or explicitly, this requires teachers to cultivate students' design thinking as a mindset of those who are capable of creating new technologies. While various models of design-based learning have been developed, an effective yet practical way to measure and monitor students' design thinking is not sufficiently developed, especially in Asian circumstances. Based on a previous instrument, the current study demonstrated the process of validating a prudent version of a Likert-scale questionnaire to be used in Thai contexts. With acceptable results, the questionnaire is ready and available to be used on request to the authors. Moreover, it might be useful and interesting if the questionnaire were translated and used in other contexts.

Acknowledgement

This study was financially supported by Thailand Science Research and Innovation (previously known as the Thailand Research Fund) under the code RSA6180010. It was carried in accordance with the ethical principles approved by the University of Phayao's Human Ethics Committee under the number 2/048/62.

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