J. Korean Earth Sci. Soc., v. 44, no. 4, p. 318−330, August 2023
https://doi.org/10.5467/JKESS.2023.44.4.318

ISSN 1225-6692 (printed edition)
ISSN 2287-4518 (electronic edition)

The Validation of the Systems Thinking Assessment Tool for Measuring the Higher-order Thinking Ability of Vietnamese High School Students

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Abstract: This study aimed to verify the validity of a measurement tool for Vietnamese high school students' systems thinking abilities. Two quantitative assessment tools, the Systems Thinking Measuring Instrument (Lee et al., 2013) and the Systems Thinking Scale (Dolansky et al., 2020), were used to measure students' systems thinking after translation into Vietnamese. As a result, it was revealed that Cronbach-α for each tool (i.e., STMI and STS) was .917 and .950, respectively, indicating high reliability for both. To validate the construct validity of the translated questionnaire, exploratory factor analysis was performed using SPSS 26.0, and confirmatory factor analysis was performed using AMOS 21.0. For concurrent validity, correlation analysis using structural equation modeling was performed to validate the translated questionnaire. Exploratory factor analysis revealed that 10 items from the STMI and 12 items from the STS loaded on the intended factors and appropriate factor loading values were obtained. For confirmatory factor analysis, a structural equation model organized with 10 items from the STMI and 12 items from the STS was used. The result of this showed that the convergent validity values of the model were all appropriate, and the model fit indices were analyzed to be χ^2/df of 1.892, CFI of .928, TLI of .919, SRMR of .047, and RMSEA of .063, indicating that the model consisting of the 22 items of the two questionnaires was appropriate. Analysis of the concurrent validity of the two tools indicated a high correlation coefficient (.903) and high correlation (.571-.846) among the subfactors. In conclusion, both the STMI and STS are valid quantitative measures of systems thinking, and it can be inferred that the systems thinking of Vietnamese high-school students can be quantitatively measured using the 22 items identified in our analysis. Using the tool validated in this study with other tools (e.g., qualitative assessment) can help accurately measure Vietnamese high school students' systems thinking abilities. Furthermore, these tools can be used to collect evidence and support effective education in ODA projects and volunteer programs.

Keywords: concurrent validity, construct validity, STMI (Systems Thinking Measuring Instrument), STS (Systems Thinking Scale)

I. Introduction

The need for the focus on STEM education in Vietnam was raised as a result of the recognition that 'urgent educational actions are needed to increase international competitiveness and labor productivity in Vietnam, as one of the poorest countries.' To prepare Vietnamese students for the Fourth Industrial Revolution, the Ministry of Education and Training introduced STEM education, and after a trial implementation, the full-scale introduction of STEM education was initiated (Tharayil et al., 2018). Consequently, the emphasis on adopting STEM education has been in place since 2013, and developing STEM education curricula, programs, and training for teachers to implement them became necessary (Duc et al., 2019). However, it took a

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significant time and resources to train teachers for professional competencies in STEM education and other interdisciplinary education in Vietnam, and there was still a lack of research on program development, implementation, and teacher training, particularly in STEM area (Nguyen et al., 2020). Given this, Vietnam requires support from international organizations or advanced countries to address these limitations, and South Korea is one of the countries supporting promoting STEM education in Vietnam through education ODA (Official Development Assistance) projects or short-term abroad education volunteer programs (Chae, 2015).

Over the past decade, South Korea put continuous efforts to establish a convergence education in education fields through announcing a comprehensive plan for convergence education (2020-2024) as well as focusing on STEM and STEAM education. As a result, it has equipped itself with structural and human resources and capabilities to implement convergence education throughout the country (Ministry of Education, 2020). In addition, KoFAC (Korea Foundation for the Advancement of Science and Creativity) has been operating programs such as ‘STEM Think Classroom’ and ‘STEM+I Think Classroom’ since 2020, mainly through university-affiliated gifted education centers in national universities to promote continuous development and extension of convergence education. There were additional efforts to make such programs to be aligned to core technologies of the Fourth Industrial Revolution, such as AI (Artificial Intelligence) and big data, as well as to be connected to career education in relation to the fields (Lee et al., 2022).

A current plan for the development of convergence education in South Korea is based on the STEM education which is an integrated curriculum with two or more subjects, including science, technology, engineering, and mathematics, that is the conception provided by NSF (National Science Foundation) (Ministry of Education, 2020; Sanders, 2009). In such convergence education and STEM education, designing outcomes and developing solutions are important, as they are emphasized in technology or engineering courses. This technological or engineering approach requires such abilities of problem-solving, conducting research, interpreting and optimizing data that are core competencies considered as important in the era of the Fourth Industrial Revolution, while also highlighting the importance of abilities to integrate knowledge and content from interdisciplinary areas (Jeon et al., 2022; Lee et al., 2022). To integrate knowledge across various subjects and think systematically, higher-order thinking abilities are required. “Systems Thinking” is one of the advanced thinking abilities emphasized in science education or convergence education research, which can support students’ systemic convergence of related knowledge and skills.

Systems thinking can be defined as “the ability to see things as a whole and consider interactions between related elements for problem-solving through inquiry” (O'Connor and McDermott, 1997; Lee, 2020). Many studies reported the effectiveness of systems thinking-based learning in cultivating students’ competence and higher-order thinking abilities. For example, Ben-Zvi Assaraf and Orion (2005a, 2009) reported that the integrated learning activities focusing on natural environments knowledge centered around the Earth system with the theme of water circulation helped students to engage in integrated thinking about water circulation and to understand the hidden aspects of the cycle. Additionally, various studies, such as Lee et al. (2011), Jeon and Lee (2015), and Park et al. (2018), reported that systems thinking improvement programs had positive effects on students’ competence and comprehensive thinking.

Systems thinking that requires problem-solving and comprehensive thinking through the integration or convergence of knowledge or skills from different fields has been widely used to analyze educational effects of interdisciplinary education or STEM education. Research results reporting the educational outcomes of interdisciplinary education or STEM education also demonstrate the improvement in systems thinking (Im and Lee, 2014; Jeon and Lee, 2015; Lee and Lee, 2017; Lee et al., 2011; Park and Lee, 2014). Systems thinking is one of the important skills highlighted in the Next Generation Science Standards (NGSS) focusing on how students should engage in three-dimensional learning around STEM disciplines (NGSS Lead States, 2013). For example, systems thinking plays an important role in students' engagement in sense-making experiences in relation to the crosscutting concept 4 (i.e., Systems and System Models) and 5 (i.e., Energy and Matter in Systems). In addition, many researchers have been highlighting the importance of systems thinking as a set of analytic skills for identifying and understanding systems, and predicting their behaviors and effects (Anderson and Johnson, 1997; Arnold and Wade, 2015; Cabrera et al., 2008; Richmond and Peterson, 2001). Likewise, in Korea, the 2015 revised science curriculum, especially an integrated science discipline, includes 'Earth System' as a separate unit and highlights systems thinking skills to foster students' understanding of natural phenomena in earth system and how it works. Given the importance of systems thinking in supporting students' learning, there is a need for developing and providing appropriate assessment tools that researchers and educators can effectively use.

Prior to 2013, researchers examined students' systems thinking ability through qualitative analysis of the questionnaires that Ben-Zvi Assaraf and Orion (2005a) used, such as GDN (Groundwater Dynamic Nature), CTQ (Cyclic Thinking Questionnaire), and GMQ (Global Magnitude Questionnaire). Later, Lee et al. (2013) developed a quantitative assessment tool for systems thinking and it became possible to statistically analyze students' improvement of system thinking in both qualitative and quantitative ways. In addition, Jeon et al. (2022) presented an evaluation rubric that can be used to define and analyze students' system thinking levels. With the use of this rubric, evaluation tools for systems thinking have been diversified and meaningful results have been reported statistically. There is continuous research trend in developing qualitative or quantitative assessment tools for systems thinking. For example, Dolansky et al. (2020) developed a systems thinking assessment scale, reporting on a questionnaire that measures the same constructs as the systems thinking assessment tool developed by Lee et al. (2013). With these assessment tools, it is possible to statistically measure systems thinking more accurately and meaningfully.

The current education ODA projects and abroad education volunteer programs conducted by South Korea in Vietnam provide Vietnam teachers a professional learning opportunities (e.g., training or workshop) on integrated or STEM/STEAM education. The developed integrated education programs are taught to local high school students. In this context, there are efforts to identify educational effects of implemented programs. For this, we focused on students' systems thinking ability that can be used to examine the educational effects of integrated or STEM/STEAM education programs provided to Vietnamese high school students. In this purpose, a validated assessment tool for Vietnamese high school students was needed.

Given this context with what has been found around students' systems thinking based learning and the needs for educational supports in Vietnam, the main purpose of this study was to verify the validity of a measurement tool for Vietnamese high school students' systems thinking ability, for later analysis of the effects of continuous education ODA projects and abroad education volunteer programs. With the context of how systems thinking is important in science education in Vietnam as it is in both Korea and the US, we see possibilities of using systems thinking assessment tools for students in Vietnam. For this, we choose two systems thinking assessment tools validated. Systems Thinking Measuring Instrument (STMI) and Systems Thinking Scale (STS) were used to measure Vietnamese high school students' systems thinking after translation into Vietnamese. Throughout this study, the construct validity was used with exploratory factor analysis and confirmatory factor analysis which are standardized methods for verifying the construct validity (Seong, 2011; Song, 2011). And concurrent validity using correlation analysis of the tools was examined since the validity is verified when a high static correlation is drawn between the two assessment tools.

The research question guided the present study is:

RQ: Do the construct validity and concurrent validity of the Systems Thinking Measuring Instrument (STMI) and Systems Thinking Scale (STS) support the application of the systems thinking assessment tools for STEM education in Vietnam?

II. Method

1. Context of the Study

The context of this study can be seen in Fig. 1. Two assessment tools were selected to measure Vietnamese students' systems thinking. The first tool used was the Systems Thinking Measuring Instrument (STMI) including 20 items with a five-factor structure developed in Korean (Lee et al., 2013). Since its development, STMI has been continuously validated by researchers and has been used as a tool to measure students' systems thinking ability (Lee and Lee, 2016; Lee, 2020). The second tool used was the Systems Thinking Scale (STS) including 20 items with a single-factor structure developed in English by Dolansky et al. (2020), but there is no research reported the validity. Therefore, this study aimed to analyze the validity of the tool for use in South Korea or other countries.

Both tools (i.e., STMI and STS) were translated into Vietnamese and content validity was verified to apply to 226 Vietnamese high school students. STMI was translated from Korean to Vietnamese, while STS was first translated from English to Korean, and then re-translated to Vietnamese. We followed this process because Vietnamese student participated in translation preferred translating Korean to Vietnamese and to prevent mistranslating. Three experts (i.e., two professors and one Ph. D.) in systems thinking education or related area participated in translating English to Korean, and a bilingual Vietnamese student who is studying in Korea translated tools to Vietnamese. There were more than three times of expert group meetings for translating tools to minimize any possible misunderstanding of the meaning of translated items between the two languages as well as ensure that the translated tools are culturally appropriate and easily understandable by Vietnamese high school students. To protect research ethics, the objective and process of the study were explained to the participants and related stakeholders (i.e., students, parents, teachers, and schools), and their consent was obtained before conducting the tests.

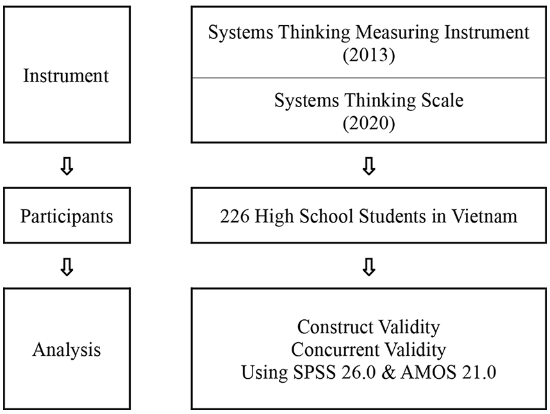

Fig. 1. Process of study

2. Participants and Data Collection

This study was to verify the validity of a systems thinking measuring tool for Vietnamese high school students. The participants were recruited through quota sampling according to the age-based quota within the high school students population. The targeted 226 Vietnamese high school students consisted of 109 (48.2%) male and 117 (51.8%) female, and 45 (19.9%) were 15 years old, 126 (55.8%) were 16 years old, and 55 (24.3%) were 17 years old. Their academic achievement levels were classified into five levels (i.e., excellent, good, average, below average, poor), and it was confirmed that they followed a normal distribution with 12 (5.3%) in excellent, 43 (19.0%) in good, 133 (58.8%) in average, 27 (11.9%) in below average, and 11 (4.9%) in poor (Table 1). To collect data, the purpose of data collection and utilization of data were explained to Vietnamese students, parents, and teachers. After obtaining consent, data was collected through Google Survey Forms, and the validity and reliability of the tests were analyzed using SPSS 26.0 and AMOS 21.0 programs.

Table 1. Information of participants

Information		Frequency(%)	Information		Frequency(%)	Information		Frequency(%)
Gender	Male	109(48.2)	Age	15	45(19.9)	Academic Achievement	excellent	12(5.3)
							good	43(19.0)
				16	126(55.8)		average	133(58.8)
	Female	117(51.8)					below average	27(11.9)
				17	55(24.3)		poor	11(4.9)
Total		226(100)	Total		226(100)	Total		226(100)

3. Measuring Tools

1) STMI (Systems Thinking Measuring Instrument)

STMI was developed by Lee et al. (2013) to measure high school students' systems thinking ability. It consists of five sub-factors of systems thinking (i.e., systems analysis, mental model, personal mastery, shared vision, and team learning), with 4 items for each sub-factor (Lee et al., 2013; Senge, 2012). A 5-point Likert scale was applied to each item, and the validity was verified through exploratory and confirmatory factor analysis conducted on high school students two or more times (Lee and Lee, 2013, 2016). In addition, further reliability verification was conducted in other research focusing on systems thinking targeting university students or adults (Cho and Hwang, 2016; Lee, 2020). In this study, the overall reliability of STMI was .917, with sub-factor reliability ranging from .662 to .920, and the examples of items for sub-factors are in Table 2. In this study, after translating the tool into Vietnamese, exploratory factor analysis was conducted to select 10 items from four sub-factors with high factor loading values, and then a structural equation model was verified, and the concurrent validity of STS was finally confirmed.

2) STS (Systems Thinking Scale)

STS was developed by Dolansky et al. (2020) to measure nursing students' systems thinking in higher education. This tool was developed based on Senge's (2012) Fifth Discipline, and consists of 20 single-factor items. The items were constructed with a 5-point Likert scale like STMI, and the reliability analysis for all 20 items in this study resulted in .950. In this study, to apply STS to Vietnamese high school

Table 2. Example of STMI items

STMI		Items
Sub Factors	Systems Analysis	When given a problem situation to be resolved, I take into account a variety of solutions.
	Mental Model	I consider whether my behavior will affect results.
	Personal Mastery	I make plans, taking into account the current situation.
	Shared Vision	I tend to be good at listening to the opinions of other people.
	Team Learning	When I contribute to team learning, I actively participate in the activities of the team.

Table 3. Example of STS items

STS	Items
When I want to make an improvement ~~	
Item 1	I seek everyone's view of the situation.
Item 2	I look beyond a specific event to determine the cause of the problem.
Item 3	I think understanding how the chain of events occurs is crucial.
Item 4	I include people in my work unit to find a solution.
Item 5	I think recurring patterns are more important than any one specific event.
…	…

students, exploratory factor analysis was conducted to select 12 items with high factor loading values and a single factor. 12 items selected were used to validate the structural equation model with STMI and to verify the concurrent validity of STMI assessment tool. Example items from this tool are shared in Table 3.

4. Data Analysis

The process of data analysis can be described in three phases. First, to verify the construct validity of the Vietnamese-translated STMI and STS, exploratory factor analysis was conducted using SPSS 26.0. Exploratory factor analysis involved calculating the Cronbach - α coefficient for each tool to determine reliability, followed by principal component analysis with Promax rotation for the results. Based on the results of exploratory factor analysis, items with low factor loading values or those that did not load onto the primary factors were deleted, and items that were suitable for measuring systems thinking among Vietnamese high school students were selected.

Second, for the selected items from exploratory factor analysis, a structural equation model was set up between STMI and STS, and confirmatory factor analysis and validity verification were conducted using AMOS 21.0. To verify the confirmatory factor analysis, the convergent validity of the model was analyzed through the average variance extraction (AVE), and model fit indices (χ^2/df, CFI, TLI, SRMR, RMSEA) were calculated.

Finally, the correlation coefficient derived from the structural equation modeling was analyzed to see the concurrent validity between STMI and STS. As both tools were developed to measure the systems thinking, significant correlation coefficients in the correlation analysis would indicate that the concurrent validity was verified. Particularly, there is no other tool developed for assessing systems thinking after STMI, the validity of STMI has been reported through studies examining the mediating effects with tools for assessing science motivation or science self-efficacy (Lee and Lee, 2016; Lee, 2020). In this study, given that there are two different tools for measuring systems thinking, we aimed to verify the concurrent validity between the two tools by conducting a correlation analysis with Vietnamese high school students.

III. Results

Result 1. Exploratory Factor Analysis

Exploratory factor analysis was conducted to examine the validity of the STMI and STS for measuring high school students' systems thinking ability in Vietnam. The outcomes of the exploratory factor analysis and reliability analysis for the two tools can be seen in Table 4.

STMI includes 20 items with a five-factor structure, while STS contains 20 items with a single-factor structure. The responses may reflect environmental, cultural, and linguistic differences because both tools were developed in different languages (i.e., English and Korean) and cultural contexts from Vietnam (Chung and Choi, 2018; Lee et al., 2019). Therefore, it was necessary to examine whether each item in STMI and STS loaded onto the intended factors with appropriate factor loading values and reliability in the results of Vietnamese high school students' responses. For this, a principal component factor analysis with Promax rotation was performed using SPSS 26.0, and factors were set when the initial eigen-values were above 1. Items with factor loading values below .3 or those that not loaded onto the intended factors were deleted to ensure item validity. As a result of the exploratory factor analysis performed through the above process, there were no items loaded onto the Personal Mastery factor in STMI. In addition, two items loaded onto the Team Learning factor, three items onto the Mental Model factor, three items onto the Systems Analysis factor, and two items onto the Shared Vision factor, resulting in a total of 10 items being identified as valid. The reliability of each factor was between .666 and .800, and the reliability for all 10 items was .872. In the case of STS, 20 items were analyzed into two factors instead of a single factor, with 12 items loaded onto the higher eigen-value

Table 4. Outcomes of exploratory factor analysis and reliability

STMI	Item (Factor #)	Result of EFA			STS	Result of EFA		
		Factor loading	Cronbach's-α			Item #	Factor loading	Cronbach's-α
Systems Analysis	Systems Analysis 1	.824	.780	.872		Item 1	.787	.917
	Systems Analysis 2	.768				Item 2	.785	
	Systems Analysis 3	.509				Item 3	.772	
Mental Model	Mental Model 1	.781	.733			Item 4	.765	
	Mental Model 2	.601				Item 5	.761	
						Item 6	.738	
	Mental Model 3	.357				Item 7	.715	
Shared Vision	Shared Vision 1	.605	.666			Item 8	.661	
	Shared Vision 2	.466				Item 9	.642	
Team Learning	Team Learning 1	.859	.800			Item 10	.642	
	Team Learning 2	.759				Item 11	.600	
						Item 12	.489	
Unweighted Least Square: Factor 1 – 2.603, Factor 2 – 2.269, Factor 3 – 1.939					Unweighted Least Square: Factor 1 – 2.603			

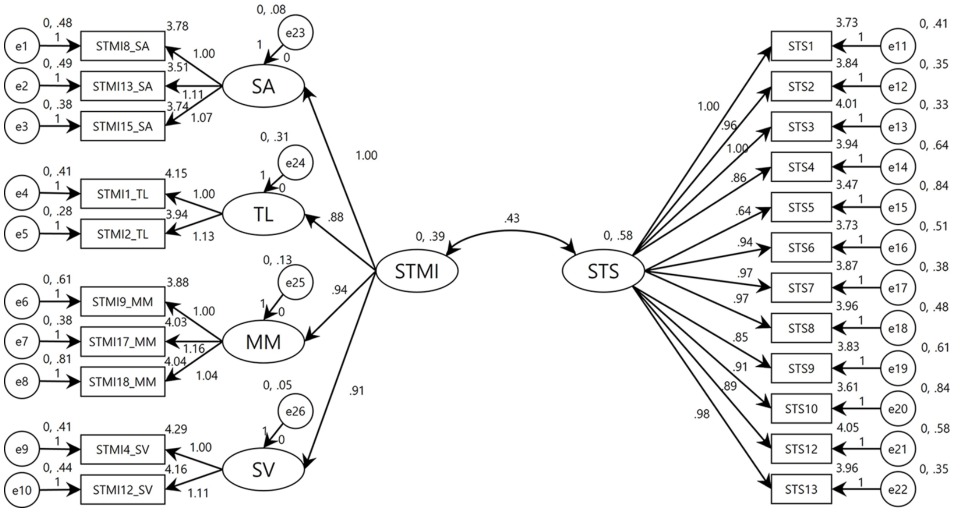

Fig. 2. Structural equation models for confirmatory factor analysis

factor and 8 items loaded onto the lower eigen-value another factor. After considering the eigen-values and factor loading values of each item, 12 items corresponding to the one factor were identified as valid. The reliability of these 12 items was .917.

Result 2. Confirmatory Factor Analysis

Confirmatory factor analysis was also conducted to further validate the validity of the extracted 10 items from STMI and 12 items from STS , which were validated in exploratory factor analysis. The structural equation model constructed for confirmatory factor analysis is shown in Fig. 2.

A structural equation model was constructed to establish the correlation between them because of that these two tools are independent. In addition, four sub-factors were included for STMI. The validity of the structural equation model was assessed through convergent validity and model fit indices, and the outcomes are as shared in Tables 5 and 6.

Table 5. Outcomes of convergent validity of the model

	Estimate	S.E.	C.R.	S.R.W.	AVE	Concept Reliability
STMI → SA	1.000			.911	.835	.952
STMI → TL	.877	.121	7.237	.700		
STMI → MM	.936	.123	7.637	.855		
STMI → SV	.914	.109	8.368	.928		
MM → STMI 18	1.042	.134	7.774	.622	.544	.703
MM → STMI 17	1.156	.126	9.190	.789		
MM → STMI 9	1.000			.660		
TL → STMI 2	1.132	.116	9.798	.858	.660	.794
TL → STMI 1	1.000			.777		
SA → STMI 8	1.000			.704	.546	.782
SA → STMI 13	1.108	.113	9.838	.737		
SA → STMI 15	1.074	.105	10.183	.768		
SV → STMI 4	1.000			.696	.542	.703
SV → STMI 12	1.112	.121	9.214	.720		
STS → STS1	1.000			.764	.582	.916
STS → STS2	.964	.078	12.378	.780		
STS → STS3	1.000	.079	12.706	.797		
STS → STS4	.858	.088	9.758	.634		
STS → STS5	.639	.091	7.020	.469		
STS → STS6	.940	.085	11.045	.708		
STS → STS7	.971	.080	12.159	.768		
STS → STS8	.970	.085	11.461	.730		
STS → STS9	.847	.086	9.807	.637		
STS → STS10	.912	.099	9.235	.604		
STS → STS12	.888	.086	10.280	.664		
STS → STS13	.978	.078	12.481	.785		

Table 6. Outcomes of model fit

	χ^2	df	χ^2/df (1~3)	CFI (>.9)	TLI (>.9)	SRMR (<.08)	RMSEA (less .08)
Model	385.97	204	1.892	.928	.919	.047	.063

In the confirmatory factor analysis of the structural equation model, estimates, standardized regression weights (S.R.W.), average variance extraction (AVE), and concept reliability were examined. If the standardized regression weight and AVE are above .5 and the concept reliability is above .7, the convergent validity can be considered to be verified. According to Table 5, although one item showed a standardized regression weight lower than the criterion, as all other fit indices were above the criterion value, it can be concluded that the measurement model is appropriate based on various results.

The model fit indices for the confirmatory factor analysis of the structural equation model are presented in Table 6. A model is considered as acceptable if the χ^2/df is between 1 and 3, CFI and TLI are above .9, and SRMR and RMSEA are below .08. In this study, the model presented has a χ^2/df of 1.892, CFI of .928, TLI of .919, SRMR of .047, and RMSEA of .063, all of which indicate good model fit. Therefore, it can be concluded that 10 items from STMI and 12 items from STS are valid tools for measuring systems

Table 7. Outcomes of correlation analysis between STMI and STS

	Estimate				
STMI ↔ STS	.903				
	STS	TL	SA	MM	SV
STS	1				
TL	.635***	1			
SA	.827***	.596***	1		
MM	.782***	.571***	.795***	1	
SV	.825***	.756***	.846***	.754***	1

***$p < .001$

thinking to Vietnamese high school students.

Result 3. Analysis of Concurrent Validity

The correlation analysis was conducted to verify the concurrent validity of the two tools used in this study. STMI and STS were developed based on the same theory of system thinking grounded in Senge's Fifth Discipline (2012). Given this, a high level of correlation between these tools can provide evidence for concurrent validity. Correlations between STS and STMI, as well as all sub-factors of STMI and STS were analyzed by setting correlations in the structural equation model, and the outcomes are presented in Table 7.

It was revealed that there is a significant positive correlation (+) between STMI and STS with a correlation coefficient of .903 at a significance level of 95% which is a very high positive correlation (+) with a correlation coefficient of over .9. The sub-factors of STMI and STS also showed that they have a high positive correlation coefficient (+) from .571 to .846, all of which are significant at a significance level of 95%. Therefore, it can be confirmed that these two tools are valid measurements for high school students' systems thinking based on the results of the concurrent validity analysis as well as the results of the construct validity analysis.

IV. Discussion and Conclusion

In this study, STMI (Lee et al., 2013) and STS (Dolansky et al., 2020) were used to examine the validity, and the results of the study provide implications for future education projects in Vietnam. STMI was originally developed in Korean and was translated into Vietnamese, while STS was originally developed in English and was translated into Vietnamese through Korean. The content validity of the translated tools was examined by experts, and the final systems thinking measuring tool for Vietnamese high school students was determined. For translated tools' reliability, Cronbach's alpha was used to assess the internal consistency of the tools. To validate the construct validity and concurrent validity, exploratory and confirmatory factor analysis and correlation analysis were conducted. The main results of the study are as follows.

First, the Cronbach-α for the responses of Vietnamese high school students to STMI and STS tests were .917 and .950, respectively, indicating very high reliability. The reliability and validity of STMI have been verified through various studies (Cho and Hwang, 2016; Chung and Choi, 2018; Han and Jo, 2015; Kim and Mun, 2017; Kim et al., 2017) that reported reliability analysis values of .8 or higher. In contrast, reliability and validity values for STS have not been reported since its development in 2020. The reliability coefficients identified in this study can provide evidence for the use of TST as a reliable tool for measuring systems thinking ability, along with the STMI.

Second, for the construct validity analysis, exploratory factor analysis was performed and, as a result, 10 items from STMI and 12 items from STS were found as appropriate to measure Vietnamese students' systems thinking. Principal component analysis (with Promax rotation) was used in the exploratory factor analysis and it was found that 2 items in Team Learning, 3 items in Systems Analysis, 3 items in Mental Model, 2 items in Shared Vision from STMI, and 12 items from STS loaded appropriately.

Third, the confirmatory factor analysis was conducted for 12 items from STMI and 10 items from STS that demonstrated validity through the exploratory factor analysis. The result of the analysis revealed that both the convergent validity and model fit indices were appropriately derived. The structural equation model was set up between 10 items from STMI and 12 items from STS, which showed a correlation. The standardized regression weight (S.R.W.) and AVE were both .5 or higher, and the concept reliability was .7 or higher, indicating that the convergent validity of the model was verified. Regarding the model fit indices, χ^2/df was 1.892, CFI was .928, TLI was .919, SRMR was .047, and RMSEA was .063, indicating that the tool including 22 items from STMI and STS can be considered as a valid measurement tool to assess Vietnamese high school students' systems thinking ability.

Finally, in this study, the correlation analysis using the structural equation model showed that the correlation between STMI and STS was .903, which was a significant result at a 95% level of significance. Furthermore, the correlation between the sub-factors of STMI and STS ranged from .571 to .846, indicating a very high correlation, and all correlations were significant at a 95% level of significance. A high level of correlation between the two tools is closely connected to the validity of the tools in measuring systems thinking because both STMI and STS were developed based on the same theoretical bases. Given this, it was revealed that both tools measure the same construct.

Based on the results of the construct validity assessment, it can be concluded that the tool including 22 items consisting of 10 items from STMI and 12 items from STS is a valid measuring tool to assess the systems thinking ability of Vietnamese high school students. With the recent moves highlighting STEM/ STEAM and convergence education in various countries, as one of the teaching and learning programs providing a new direction, the systems thinking measuring tool translated into three different languages can contribute to future studies, especially focusing on international comparison on the effectiveness of related education programs.

The conclusion of this study leads to the following implications and recommendations for future research in connection to measuring the systems thinking of Vietnamese high school students. First, there is still a need for research on measuring systems thinking. Systems thinking requires comprehensive and integrated thinking abilities as students consider a system and related factors as a whole during their learning or problem-solving (Ben-Zvi Assaraf and Orion, 2005b, 2009; Senge, 2012). Many researchers in education have been focusing on developing or verifying tools to evaluate students' systems thinking ability (e.g., STMI and STS). More recently with the emphasis on STEM/ STEAM or integrated education, various subjects or fields are being integrated in learning activities, and this move also can be seen in Vietnamese education (Linh et al., 2019; Nguyen et al., 2020; Vuong et al., 2020; Tinh et al., 2021). Given this, appropriate measuring tools are needed that can support educational research on Vietnamese students' systems thinking ability and learning process. If it is possible to accurately measure the effectiveness of educational programs for Vietnamese students through validated tools, the quality of educational ODA projects can be improved, and through this, educational exchanges between countries can be better supported. For this, in addition to what was found in this research, future studies should be around analyzing the items including low validity, and revising them to develop an appropriate tool that can be fully applicable to Vietnamese students.

Second, there is a need for research on the development of qualitative tools to assess systems thinking that can be used with quantitative tools. The systems thinking assessment tools, as quantitative tools, used in this study have a limitation in measuring and describing systems thinking. Previous studies on system thinking assessment, such as Ben-zvi-Assaraf and Orion (2005a, 2005b, 2009), Park et al. (2019), and Lee (2020), used qualitative tools (e.g., word association, causal mapping, and drawing) combined with quantitative tools. For consistency in the analysis of qualitative tools, Hung (2008) and Lee et al. (2018) developed and used rubrics for systems thinking level evaluation. To accurately measure students' systems thinking and evaluate their level of systems thinking, it is important to develop qualitative assessment tools that can be used in Vietnamese education along with quantitative tools.

Finally, a collaborative network or international cooperation is needed in related research. Three versions of tools (i.e., Korean, English, and Vietnamese) were developed as a result of translation in this study. There is increased use of online platforms (e.g., Google Survey Form) after the recent situation with COVID-19. Given this, international comparison with collected data from various countries if researchers collaborate through international programs, such as ODA projects and abroad education volunteer programs.

V. Limitations

There are several possible interpretations for the inconsistencies between the results of the exploratory factor analysis of this study with Vietnamese students and the results obtained during the tool development process. The original tools were developed in other languages (i.e., Korean and English) and not developed for use targeting Vietnamese students who are in a different culture, learning environment, and language use group. Therefore, there might be differences occurred in interpreting and understanding the items among Vietnamese high school students when they read the items. Additionally, during the process of translating, the intended meaning of the words or sentences may not have been properly reflected in the translated versions. As the tools were translated from Korean to Vietnamese, and from English to Korean, and then Vietnamese, it is possible that the intended meaning of the questions was not accurately reflected or fully included in the Vietnamese version. This might have caused differences in the ways that Vietnamese students responded to the items. Researchers reported difficulties in using translated version even after conducting a back-translation or verification made by a bilingual expert for validity (Choi and Kim, 2015; Chung and Choi, 2018; Chung et al., 2012; Lee, 2016; Lee et al., 2019; Park and Han, 2017). In relation to this, there is a need for further validity testing through item modification and validation with high school students in Vietnam.

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Manuscript received: July 24, 2023
Revised manuscript received: August 27, 2023
Manuscript accepted: August 31, 2023