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# Developing a Systems Thinking Skills Assessment for Upper Primary Students in Thailand

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## Abstract

**Background/purpose.** The purposes of this research are to develop a reliable and valid assessment tool for measuring systems thinking skills in upper primary students in Thailand and to establish a normative criterion for evaluating their systems thinking abilities based on educational standards.

**Materials/methods.** The study followed a three-phase data collection process, involving a total of 1,000 students from 17 schools in the Thai educational context. The sample was divided into three groups: 70 students for item analysis difficulty (p) and discrimination (r), 430 students for construct validation using Confirmatory Factor Analysis (CFA), and 500 students for T-score ranking and normative criteria development. The Systems Thinking Skills Assessment for Upper Primary Students was developed as a multiple-choice test.

**Results.** The results showed that the assessment had strong content validity (IOC = 0.60–1.00), appropriate item difficulty (p = 0.30–0.66), acceptable discrimination indices (r = 0.20–0.45), and high internal consistency (KR-20 = 0.82). The CFA confirmed that the assessment model was well-aligned with empirical data, with $\chi^2 = 0.24$, p = 0.62, RMSEA = 0.00, CFI = 1.00, GFI = 1.00, and AGFI = 1.00. Additionally, T-score ranking was established, providing normative criteria for interpreting students' systems thinking performance.

**Conclusion.** This study was conducted to develop and validate a reliable assessment tool for measuring systems thinking skills in upper primary students. The research followed a three-phase data collection process, involving content validation, construct validation through Confirmatory Factor Analysis (CFA), and the establishment of normative criteria using T-score ranking.

## 1. Introduction

Learning is a fundamental process through which individuals acquire knowledge, develop skills, and refine their ability to analyze and solve problems. In the context of education, fostering critical thinking and problem-solving skills is essential for preparing students to navigate an increasingly complex world. Among these cognitive skills, systems thinking plays a crucial role in helping learners recognize patterns, understand relationships between different components, and predict the potential outcomes of various interactions. By developing systems thinking, students can enhance their ability to approach challenges holistically, making it a valuable skill across multiple disciplines.

Understanding how different elements interact within a system is an important skill for students in the current era, as it helps them make sense of various issues they encounter in daily life and academics (Arnold & Wade, 2015; Cabrera & Cabrera, 2023). Systems thinking enables learners to see connections between ideas, improving learning quality, essential leadership capacity, trace how one factor influences another, and anticipate possible consequences, which can be useful in subjects like science, mathematics, and social studies (Kioupi & Voulvoulis, 2019; Sockman et al., 2023; Sheridan & Satterwhite, 2024; Chaidir et al., 2024). Sometimes, we don't have the right tools or methods to analyze the system effectively (Basile & Caputo, 2017). While Thailand's national education curriculum highlights the importance of 21st-century skills, there remains a lack of emphasis on directly assessing systems thinking at the primary level (Kongtoom et al., 2024). Occasionally, we don't have the right tools or methods to analyze the system effectively. Without well-designed evaluation tools, educators may find it difficult to gauge students' progress in developing these essential cognitive abilities.

Most research on systems thinking (e.g., Chowdhury, 2023; Dolansky et al., 2020; Nguyen & Santagata, 2021; Streiling et al., 2021) has been conducted at the secondary and higher education levels, leaving a significant gap in understanding how younger students develop and use these skills. This gap is particularly concerning because primary school students are at a critical stage of cognitive development, where foundational skills in systems thinking can be nurtured. Although some frameworks, such as those developed by Dolansky et al. (2020), have been created to assess systems thinking, they were primarily designed for older students with more advanced cognitive abilities. These frameworks often include complex terminology and concepts that require prior knowledge, which younger students may not yet possess. As a result, existing tools are less suitable for primary school learners, who may struggle with abstract reasoning and cannot fully demonstrate their thinking abilities. This limitation underscores the importance of conducting research to develop a new assessment tool specifically tailored for upper primary students in Thailand. Such a tool would align with their developmental level, enabling educators to better support and evaluate their progress in systems thinking, which is crucial for their academic growth and future problem-solving capabilities.

The purpose of this study is to create and validate a systems thinking skills assessment for students in upper primary school students, which in the Thai educational context categorizes them as second rank (out of four) covering grades 4-6 (The Ministry of Education, 2008). Specifically, the study aims to design an instrument that can evaluate key components that contribute to the skills of systems thinking. This is to ensure that the assessment tool is reliable and valid, and it could provide educators with a practical method for measuring students' progress in developing systems thinking skills. Therefore, the findings would contribute to educational research as they offer useful data on how primary school students engage with systems thinking concepts.

Moreover, creating an assessment tool that effectively evaluates systems thinking skills would provide important consequences for how teaching and curriculum development are approached in Thailand, where educational reforms increasingly emphasize critical thinking but often lack concrete strategies for measuring cognitive skills beyond rote memorization (Sarasean, 2024; Suyaprom & Manmee, 2018). To exemplify, if teachers can accurately assess students' thinking ability using a tool that is designed for their developmental stage, they could adapt their teaching strategies, accordingly. This is to ensure that students receive appropriate instruction that helps them build analytical skills in a structured and progressive manner.

In addition, policymakers responsible for shaping national education guidelines can use the findings from this study to inform future curriculum revisions, ensuring that educational policies actively promote practices that cultivate systems thinking from an early age. This study not only addresses a gap in Thailand's primary education system, where structured assessment tools for systems thinking are limited but also provides a foundation for further research on how young learners develop and apply these cognitive skills in different subject areas.

## 2. Literature Review

### *2.1. Systems Thinking*

Several scholars have attempted to define systems thinking, highlighting different aspects of its meaning and application. Richmond (1994), who first coined the term, describes systems thinking as both an art and a science aimed at making reliable inferences about behavior by deeply understanding underlying structures. The author emphasizes the importance of seeing both the broader picture and the details simultaneously, though his definition lacks clarity regarding the interconnections between elements in a system. Senge (2006), another key figure in the field, defines systems thinking as a discipline that allows individuals to see a whole picture, interrelationships, and patterns of change rather than isolated components. His definition underscores the intuitive aspect of systems thinking but does not clearly articulate its purpose.

Sweeney and Sterman (2000) focus on the ability to represent and assess dynamic complexity, listing specific skills such as identifying feedback processes, recognizing delays, and understanding stock and flow relationships. Although their definition provides a structured breakdown of systems thinking skills, it does not explain how these elements interact within a whole system. Hopper and Stave (2008), as well as Kopainsky, Alessi, and Davidsen (2011), further expand on these definitions by emphasizing the importance of feedback loops, nonlinear relationships, and collaborative planning. However, like the previous definitions, they do not fully address interconnections or the overarching purpose of systems thinking. Ultimately, while each of these definitions contributes valuable insights, a widely accepted and comprehensive definition remains elusive. Arnold and Wade (2015) define systems thinking as a skill that involves several key elements. It includes recognizing interconnections between components, understanding feedback mechanisms that influence system behavior, and analyzing system structures. Additionally, it involves distinguishing between different types of stocks, flows, and variables, identifying nonlinear relationships, and interpreting dynamic behavior over time. Systems thinking also emphasizes making complex ideas comprehensible through conceptual modeling and understanding systems at multiple scales to see both broader patterns and detailed interactions. The previous definitions of the terms can be inferred that systems thinking is a cognitive approach enabling individuals to recognize patterns, analyze relationships among elements, and understand how different components interact within a larger system to produce specific outcomes.

Given that system thinking emphasizes recognizing relationships between components to understand complex concepts, the skill is valuable for students in the upper primary school grades, who are at a developmental stage where they transition from concrete to more abstract thinking (Van Deur & Murray-Harvey, 2005). At this level, children begin to engage with more sophisticated cognitive processes, such as logical reasoning, problem-solving, and cause-and-effect analysis (Hughes, 2013). Their learning in school increasingly involves making connections between different

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subjects and concepts rather than simply memorizing isolated facts. Therefore, systems thinking aligns with this natural progression as it encourages students to explore how different elements within a system influence one another. This helps in learning subjects like science, mathematics, and social studies. For example, when learning about ecosystems, upper primary students can use systems thinking to see how plants, animals, and environmental factors interact rather than viewing them as separate entities. Additionally, systems thinking enhances critical thinking skills by helping students recognize patterns, anticipate consequences, and evaluate multiple perspectives when approaching a problem (Daellenbach et al., 2017). Consequently, integrating systems thinking into their learning process would be significant as it allows students at this stage to develop an ability to analyze complex issues, which also benefits them in both their academic journey and real-world decision-making.

### *2.2. Components of Systems Thinking*

Respective scholars (e.g., Arnold & Wade, 2015; Cabrera & Cabrera, 2023; Hopper & Stave, 2008; Kopainsky et al., 2011; Richmond, 1994; Senge, 2006) have presented various elements that contribute to systems thinking, highlighting its significance in analyzing complex relationships and structures. However, this study employs Peter Senge's model (2006), which identifies five key components: Personal Mastery, Mental Models, Shared Vision, Team Learning, and Systems Thinking. These components provide a comprehensive framework for understanding how students develop systems thinking skills in learning environments. The details of each component are described below. (Senge, 2006).

#### *2.2.1. Personal Mastery*

Personal mastery was defined as a commitment to lifelong learning and personal development. This includes such qualifications as curiosity, fortitude, and the capacity to evaluate one's own educational path among upper primary students. Those who embrace personal mastery often set clear academic goals, identify their strengths and areas for improvement, and take ownership of their educational progress.

#### *2.2.2. Mental Models*

Senge described mental models as a component of system thinking as ingrained assumptions, beliefs, or generalizations that influence individuals to perceive the world. For students, mental models shape their understanding of different subjects and their approach to problem-solving which would help them to recognize, question, and refine their mental models to avoid misconceptions.

#### *2.2.3. Shared Vision*

In Senge's model, shared vision was described to be a collective commitment to a common goal, which fosters motivation and teamwork. In education, this means encouraging students to collaborate, share ideas, and work toward common learning objectives. The circumstance that students feel a sense of shared purpose would make them more likely to engage in meaningful discussions and problem-solving.

#### *2.2.4. Team Learning*

Team Learning involves developing the ability to think and learn collectively through dialogue and collaboration – the idea that is relevant for upper primary students, as they are at an age where they begin to appreciate different perspectives and refine their ability to communicate ideas effectively. Team learning helps students recognize interdependence, which is a key aspect of systems thinking.

#### 2.2.5. Systems Thinking (The Core Discipline)

Systems Thinking ties together all other elements by encouraging students to see relationships, patterns, and structures rather than isolated events. Students can analyze cause-and-effect relationships and understand how different parts of a system interact over time.

### 2.3. Iceberg Model in Systems Thinking

The iceberg model in system thinking (Maani & Cavana, 2007) was utilized into the study as a model in developing question items in assessing system thinking. The model consists of 4 levels explained below.

2.3.1. Event Level or Situation level refers to the ability to analyze and understand problems by perceiving the overall situation as a whole and identifying key issues accurately from the given event or scenario.

2.3.2. Pattern Level refers to the ability to identify the root cause of a problem by breaking down the major components of an issue, event, or scenario into smaller parts, recognizing relationships among these elements, and correctly identifying contributing factors and causes of the problem.

2.3.3. Structure Level refers to the ability to recognize the interconnected relationships between various contributing factors and how these factors influence the identified issue, leading to the occurrence of a specific event or situation.

2.3.4. Mental Model Level refers to the ability to understand feedback loops and the systemic relationships among different factors that are part of a larger issue. It involves recognizing cause-and-effect connections in a structured manner and being able to address the root cause of a problem effectively and in a timely manner.

### 2.4. Previous studies on systems thinking assessment

Scholars (Chowdhury, 2023; Dolansky et al., 2020; Nguyen & Santagata, 2021; Streiling et al., 2021) have conducted studies to develop and assess systems thinking, with varying degrees of validity and reliability. The synthesis on the previous study indicates that certain studies were found to provide both content and construct validity, while others focus only on certain aspects of validity or do not present validity evidence at all. In detail, a validated Systems Thinking Scale (STS) was developed by Dolansky et al. (2020) to measure individuals' systems thinking abilities. Through factor analysis, they refined the scale to focus on a single systems thinking factor, demonstrating strong internal consistency and test-retest reliability. They also established discriminant validity by comparing groups with different levels of systems thinking education, showing the scale's effectiveness in distinguishing varying levels of expertise. In contrast, Nguyen and Santagata (2021) conducted a quasi-experimental study to examine the impact of computer modeling on students' systems thinking, particularly in causal reasoning and classroom interactions. They assessed systems thinking using written tests, which provided content validity and reliability, but did not establish construct validity. Other studies take a different approach to understanding systems thinking. Chowdhury (2023) conceptualizes systems thinking as a cognitive skill, arguing that this perspective makes it more accessible beyond traditional frameworks and methodologies. The study introduces Holistic Flexibility, which helps practitioners manage complexity through adaptability and iterative learning loops, illustrated through case studies. However, it does not focus on developing an assessment tool for measuring systems thinking. Streiling et al. (2021), on the other hand, explored the role of teachers' content knowledge (CK) and pedagogical content knowledge (PCK) in fostering systems thinking. Using a quasi-experimental pre- and posttest design, they found that teacher training significantly improves students' systems thinking abilities, with PCK being as crucial as CK in this process. Their study employed the Heuristic Competence Model of Systems Thinking, which categorizes systems thinking into four dimensions and assesses both content and construct validity, along with reliability.

In the Thai context, scholars (Kongtoom et al., 2024; Noonchoocan, 2022; Phewngam et al., 2023; Sukkird et al., 2021) have also conducted research on systems thinking, but most studies lack comprehensive validity evidence. For example, Petchngam (2022) explored problem-based learning and STAD as methods to develop language learning and systems thinking, using a holistic rubric for assessment but did not provide validity or reliability evidence. Kongtoom et al. (2024) developed a systems thinking assessment, performing content validity analysis using the Index of Item-Objective Congruence (IOC) and conducting item analysis for difficulty and discrimination, but did not test construct validity. Similarly, Noonchoocan (2022) created a science instructional model to enhance the systems thinking process, using a systems thinking assessment form, but only provided content validity through IOC. Sukkird et al. (2021) also developed a learning model to enhance systems thinking, employing a systems thinking test as the assessment tool but only verifying content validity through IOC.

It can be noted that a major gap in research in the Thai context is the lack of construct validity testing in systems thinking assessments. Most studies either provide only content validity (IOC) or do not report validity evidence at all. Among the studies focusing solely on assessment tool development, such as Kongtoom et al. (2024), construct validity was not established. Additionally, there is no existing assessment tool specifically designed for upper primary school students, highlighting the need for further research in this area. Therefore, the current study aims to develop an assessment tool for Thai upper primary graders with both constructed and content validity. The purpose of this research is to develop a reliable and valid assessment tool for measuring systems thinking skills in upper primary students in Thailand and to establish a normative criterion for evaluating their systems thinking abilities based on educational standards.

## 3. Methodology

### *3.1. Research design*

The study followed a structured data collection and analysis process to ensure the validity and reliability of the systems thinking skills assessment for upper primary students. Data collection involved coordinating with schools, administering the test, and retrieving responses for analysis. Statistical procedures included item difficulty and discrimination analysis, reliability testing using KR-20, and confirmatory factor analysis (CFA) to validate the assessment's structural model. Additionally, normative criteria were established using predictive equations and standardized T-scores to provide benchmarks for measuring students' systems thinking skills.

### *3.2. Samples*

The population for this study was 12,118 students in Grades 4 to 6 from 174 schools under the Sakon Nakhon Primary Education Service Area Office 1, which is an organization that takes responsibility for public primary schools in an area of Sakon Nakhon province, Thailand. The data collection took place during the second semester of the 2023 academic year. The sample group was 1,000 students from 17 schools, selected using Yamane's sample size at a 95% confidence level ($\propto$ = .05) with an acceptable margin of error of ±3%. The sample was divided into three groups for three rounds of testing, following different sampling techniques: 1) first Test (70 students) – Selected through Simple Random Sampling, this group was used to analyze item difficulty and discrimination; 2) Second Test (430 students) – Selected using Multi-stage Sampling, this group was tested to determine item difficulty, item discrimination, internal consistency (reliability), and construct validity through Confirmatory Factor Analysis (CFA); 3) Third Test (500 students) – Selected using Multi-stage

Sampling, this group was used to establish normative criteria for interpreting the assessment results. The participants were treated considering ethical issues in human research during the data collection.

### *3.3. Instruments*

#### *3.3.1. Systems Thinking Skills Assessment for Thai Upper Primary Students*

The sole instrument used in this study was the Systems Thinking Skills Assessment for Upper Primary Students, developed by the researcher. This assessment was a multiple-choice test consisting of 10 problem scenarios with a total of 40 questions, designed to evaluate systems thinking skills in students in the Thai educational context. The development of this assessment was guided by the Iceberg Model of Systems Thinking, structural validity was examined across the four levels of systems thinking skills: Event Level, Pattern Level, Structure Level, and Mental Model Level, ensuring that the test items measured students' ability to recognize interconnections, analyze structures, and understand patterns of change rather than just isolated events.

### *3.4. Data collection and data analysis*

The data collection process was conducted in three phases, each involving different groups of students to ensure a comprehensive evaluation of the Systems Thinking Skills Assessment for Upper Primary Students. Phase 1 focuses on testing content validity and conducting item analysis. In Phase 2, a larger group of 430 students was selected to examine test reliability and construct validity. Phase 3 involved 500 students to establish T-score ranking, enabling the development of normative criteria for interpreting the assessment results.

In terms of data analysis, content validity was assessed using the Index of Item-Objective Congruence (IOC), with values ranging between 0.60 and 1.00 to confirm the alignment with the intended construction of each item. Item analysis was conducted to determine item difficulty (p) values between 0.20 and 0.80 and item discrimination (d) values between 0.20 and 1.0. To establish reliability, the Kuder-Richardson Method (KR-20) was employed. Analysis conducted using the RTAP research tool analysis program (Academic Service Center and Educational Innovation Dissemination, Department of Educational Research and Development, 2022).

Confirmatory Factor Analysis (CFA) was conducted to examine construct validity. Finally, T-score ranking was applied to standardize students' scores and develop normative benchmarks for measuring systems thinking skills.

## 4. Results

### *4.1. Content validity of the test*

The Systems Thinking Skills Assessment for Thai Upper Primary Students was developed through the review of theoretical literature and relevant research to establish an operational definition and determine the number of questions required for measurement In the initial phase, 15 problem scenarios were created. There are four multiple-choice questions (n=60) in each scenario. One point was awarded for a correct answer and zero for an incorrect answer. The assessment underwent content validity testing by five experts, who evaluated the Index of Item-Objective Congruence (IOC). After expert validation, all 60 items from 15 scenarios were retained. The Items with an Index of Item-Objective Congruence (IOC) ranging from 0.50 to 1.00 were retained, and it was found that all 60 items met the content validity criteria and could be used for further testing.

### *4.2. Item analysis on the selected scenarios*

In the item analysis process, 60 items across 15 scenarios were revised based on the recommendations of expert reviewers to ensure content alignment with the set criteria. The items were later administered in the first pilot test with 70 students to analyze item difficulty (p) and item discrimination (r). The results indicated that item difficulty was 0.10 -0.73, while item discrimination was - 0.11 - 0.66. In detail, only 49 items met the quality criteria, and only scenarios in which all items passed the criteria were selected. The details of an item analysis on the selected items can be seen in table 1.

**Table 1.** Difficulty and Discrimination of the selected items

| Item | Difficulty (p) | Discrimination (r) | Interpretation |
|---|---|---|---|
| Scenario 1 | | | |
| 1 | 0.42 | 0.24 | Moderate difficulty and Moderate discrimination |
| 2 | 0.41 | 0.34 | Moderate difficulty and Moderate discrimination |
| 3 | 0.66 | 0.42 | Relatively low difficulty and Relatively high discrimination |
| 4 | 0.43 | 0.20 | Moderate difficulty and Moderate discrimination |
| Scenario 2 | | | |
| 5 | 0.62 | 0.30 | Relatively low difficulty and Moderate discrimination |
| 6 | 0.32 | 0.22 | Relatively high difficulty and Moderate discrimination |
| 7 | 0.45 | 0.31 | Moderate difficulty and Moderate discrimination |
| 8 | 0.62 | 0.20 | Relatively low difficulty and Moderate discrimination |
| Scenario 3 | | | |
| 9 | 0.57 | 0.42 | Moderate difficulty and Relatively high discrimination |
| 10 | 0.43 | 0.33 | Moderate difficulty and Moderate discrimination |
| 11 | 0.50 | 0.38 | Moderate difficulty and Moderate discrimination |
| 12 | 0.35 | 0.22 | Relatively high difficulty and Moderate discrimination |
| Scenario 4 | | | |
| 13 | 0.41 | 0.32 | Moderate difficulty and Moderate discrimination |
| 14 | 0.48 | 0.26 | Moderate difficulty and Moderate discrimination |
| 15 | 0.43 | 0.35 | Moderate difficulty and Moderate discrimination |
| 16 | 0.39 | 0.20 | Relatively high difficulty and Moderate discrimination |
| Scenario 5 | | | |
| 17 | 0.44 | 0.22 | Moderate difficulty and Moderate discrimination |
| 18 | 0.31 | 0.26 | Relatively high difficulty and Moderate discrimination |
| 19 | 0.51 | 0.45 | Moderate difficulty and |

| Item | Difficulty (p) | Discrimination (r) | Interpretation |
|---|---|---|---|
| | | | Relatively high discrimination |
| 20 | 0.31 | 0.23 | Relatively high difficulty and Moderate discrimination |
| Scenario 6 | | | |
| 21 | 0.52 | 0.22 | Moderate difficulty and Moderate discrimination |
| 22 | 0.56 | 0.22 | Moderate difficulty and Moderate discrimination |
| 23 | 0.35 | 0.24 | Relatively high difficulty and Moderate discrimination |
| 24 | 0.43 | 0.25 | Moderate difficulty and Moderate discrimination |
| Scenario 7 | | | |
| 25 | 0.44 | 0.30 | Moderate difficulty and Moderate discrimination |
| 26 | 0.30 | 0.34 | Relatively high difficulty and Moderate discrimination |
| 27 | 0.36 | 0.25 | Relatively high difficulty and Moderate discrimination |
| 28 | 0.34 | 0.23 | Relatively high difficulty and Moderate discrimination |
| Scenario 8 | | | |
| 29 | 0.45 | 0.44 | Moderate difficulty and Relatively high discrimination |
| 30 | 0.41 | 0.40 | Moderate difficulty and Relatively high discrimination |
| 31 | 0.37 | 0.22 | Relatively high difficulty and Moderate discrimination |
| 32 | 0.43 | 0.24 | Moderate difficulty and Moderate discrimination |
| Scenario 9 | | | |
| 33 | 0.47 | 0.27 | Moderate difficulty and Moderate discrimination |
| 34 | 0.46 | 0.36 | Moderate difficulty and Moderate discrimination |
| 35 | 0.40 | 0.25 | Moderate difficulty and Moderate discrimination |
| 36 | 0.43 | 0.27 | Moderate difficulty and Moderate discrimination |
| Scenario 10 | | | |
| 37 | 0.46 | 0.36 | Moderate difficulty and Moderate discrimination |
| 38 | 0.45 | 0.33 | Moderate difficulty and Moderate discrimination |
| 39 | 0.58 | 0.23 | Moderate difficulty and Moderate discrimination |
| 40 | 0.54 | 0.24 | Moderate difficulty and Moderate discrimination |

According to table 1, the refined version of the assessment includes 10 scenarios with 40 items. The final selection had an item difficulty range of 0.30 to 0.66 and an item discrimination range of 0.20 to 0.45.

### 4.3. Reliability of the assessment

The systems thinking skills Assessment was administered in the second test phase with 430 students. The results of the study indicate that the overall reliability of the developed systems thinking skills assessment was 0.82. This falls within the commonly accepted reliability range of 0.70 to 1.00, and it could be interpreted that the assessment is of high quality and suitable for further testing.

### 4.4. Constructed validity of the assessment

Construct validity of the assessment was tested through Confirmatory Factor Analysis (CFA) to assess the model's fit to empirical data for the four levels of systems thinking skills based on the Iceberg Model framework. The results confirmed that the model was well-aligned with the empirical data, as illustrated in the figure 1.

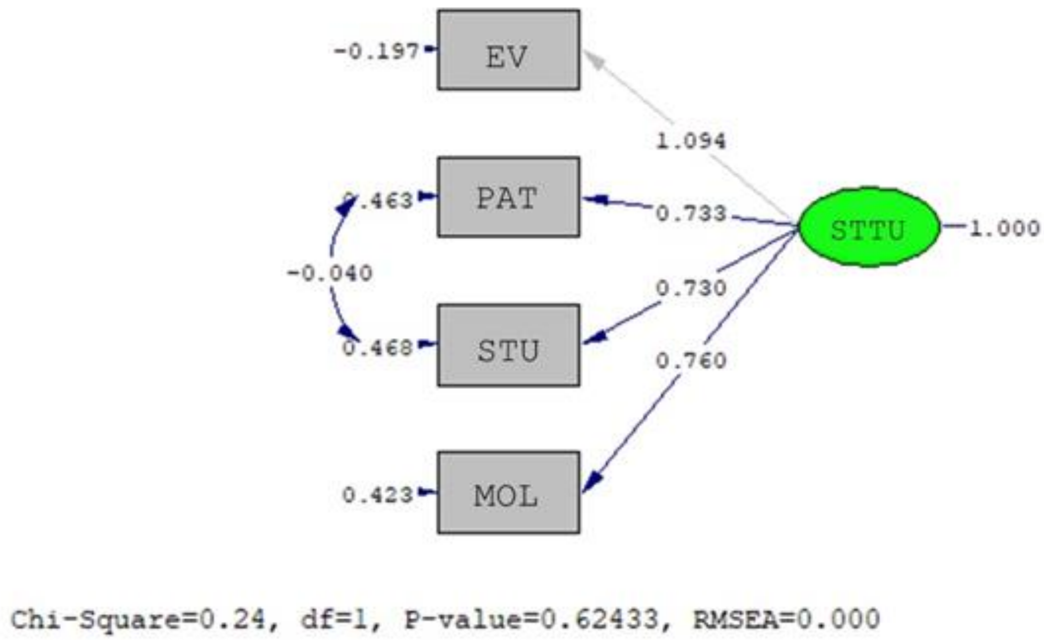


**Figure 1.** Confirmatory Factor Analysis (CFA) Model for the Four Levels of Systems Thinking Skills Based on Iceberg Model framework

According to figure 1, the model aligns well with the empirical data, as evidenced by the following fit indices: Chi-square ($\chi^2$) = 0.24, P-value = 0.62, with 1 degree of freedom (df), and RMSEA = 0.00. This could infer that the model's fit to the data is not significantly different from zero at a statistically significant level. These results support the acceptance of the hypothesis that the research model is consistent with the empirical data. Additionally, structural validity was examined across the four levels of systems thinking skills: Event Level, Pattern Level, Structure Level, and Mental Model Level. The results are summarized in Table 2.

**Table 2.** Construct validity of systems thinking skills

| Components | Factor Loading (b) | t-value | Coefficient of determination ($R^2$) | Standard Error of Factor Loading (S.E.) |
|---|---|---|---|---|
| Event Level (EV) | 1.094 | | 1.197 | -0.197 |
| Pattern Level (PAT) | 0.733 | 23.6 | 0.537 | 0.463 |
| Structure Level (STU) | 0.730 | 23.4 | 0.533 | 0.468 |
| Mental model level (MOL) | 0.760 | 23.2 | 0.578 | 0.423 |
| CFI=1.00 , GFI=1.00, AGFI=1.00 | | | | |

According to table 2, the factor loadings for each component were positive and ≥ 0.7 (b=0.730 - 1.094) This indicates that the latent variable can explain more than 50% of the variance in the observed indicators. The factor loadings, ranked from highest to lowest, were as follows: Event Level (1.094), Mental Model Level (0.760), Pattern Level (0.733), and Structure Level (0.730). The fit indices also met the required criteria, with CFI = 1.00, AGFI = 1.00, and GFI = 1.00, confirming that the Systems Thinking Skills Assessment Model is well-aligned with the empirical data.

### *4.5. The Normative Criteria and Interpretation of Scores from the Assessment*

The third phase of testing was conducted with 500 students, and the test scores were analyzed to determine basic statistical properties. The results showed that the mean score was 20.95 (S.D =7.32) out of a total of 40 points. Normative criteria were developed using standardized T-scores to interpret the results of the Systems Thinking Skills Assessment. The percentile ranks were calculated by comparing raw scores with standardized T-scores. The T-score values were computed using the predictive equation: Tc = 21.39+1.37X. The results are demonstrated in table 3.

**Table 3.** Normative Criteria of Scores from the Assessment

| Test Score (X) | T-score (Tc) | Test Score (X) | T-score (Tc) | Test Score (X) | T-score (Tc) | Test Score (X) | T-score (Tc) |
|---|---|---|---|---|---|---|---|
| 40 | 76* | 29 | 61 | 18 | 46 | 7 | 31 |
| 39 | 75* | 28 | 60 | 17 | 45 | 6 | 30 |
| 38 | 74 | 27 | 58 | 16 | 43 | 5 | 28 |
| 37 | 72 | 26 | 57 | 15 | 42 | 4 | 27 |
| 36 | 71 | 25 | 56 | 14 | 41 | 3 | 26 |
| 35 | 69 | 24 | 54 | 13 | 39 | 2 | 24 |
| 34 | 68 | 23 | 53 | 12 | 38 | 1 | 23 |
| 33 | 67 | 22 | 52 | 11 | 37 | 0 | 21* |
| 32 | 65 | 21 | 50 | 10 | 35 | | |
| 31 | 64 | 20 | 49 | 9 | 34 | | |
| 30 | 63 | 19 | 47 | 8 | 32 | | |

* indicates the expansion of standardized T-scores.

The normative criteria for the assessment have raw scores ranging from 0 to 40, corresponding to standardized T-scores between T21 and T76. These T-scores can be interpreted and evaluated according to the established criteria as presented in table 4.

**Table 4.** Interpretation of Scores from the Assessment

| T-score | Test score | Levels of Systems Thinking Skills |
|---|---|---|
| T65 or higher | 32-38 | Very high |
| T55 -T64 | 25-31 | High level |
| T45 -T54 | 17-24 | Moderate level |
| T35 - T44 | 10-16 | Low level |
| T35 or lower | 1-9 | Needs Improvement |

The interpretation of scores is categorized into five levels: Very High (T-score = T 65 or higher, or Test score = 32-38), High (T-score = T 55 -T 64 or Test score = 25-31), Moderate (T-score = T 45 -T54 or Test score = 17-24), Low (T-score = T 35 - T 44 or Test score = 10-16), and Needs Improvement (T-score = T 35 or lower, or Test score = 1-9).

## 5. Discussion

The results of this study provide significant insights into the development and assessment of systems thinking skills in upper primary students in the Thai context. The findings confirm that the Systems Thinking Skills Assessment aligns with the Iceberg Model (Maani & Cavana, 2007), ensuring that the test comprehensively evaluates students' ability to recognize interconnections, analyze patterns, and understand deeper structures and mental models within systems. The assessment development went in line with previous studies (Dolansky et al., 2020; Streiling et al., 2021; Hengpiya, 2021) who also employed similar principles throughout their scaling development.

The study demonstrates that the assessment tool possesses strong content validity, as verified by expert review, and construct validity, supported by Confirmatory Factor Analysis (CFA). Additionally, the test's difficulty and discrimination indices fall within appropriate ranges, ensuring that the assessment is both challenging and effective at distinguishing between varying levels of systems thinking skills among students. The high reliability score (KR-20 = 0.82) further establishes the consistency and dependability of the assessment, making it suitable for educational applications.

The development of normative criteria through T-score ranking provides an essential benchmark for interpreting students' performance. This criterion allows educators to categorize students' systems thinking skills into five levels—ranging from "Needs Improvement" to "Very High"—and develop instructional strategies accordingly. The ability to measure and interpret systems thinking in a standardized way offers practical benefits for improving curriculum design and teaching approaches aimed at enhancing complex cognitive skills in young learners (Brookhart & Nitko, 2018; Brown et al.,1984).

The results indicate that most students (n = 332, 66.64%) scored below 50% on the assessment, suggesting that Thai upper primary school students face challenges in systems thinking skills. This finding aligns with previous studies by Kongtoom et al. (2024), Noonchoocan (2022), Phewngam et al. (2023), and Sukkird et al. (2021), which also highlight similar issues regarding the underdevelopment of systems thinking in Thai students. These results emphasize the need for urgent intervention by educators, policymakers, and curriculum developers to integrate effective instructional strategies that enhance students' ability to think systemically. Therefore, stakeholders should prioritize systems thinking development in the curriculum and explore pedagogical approaches that strengthen students' cognitive abilities in analyzing interconnected systems.

Despite these strengths, some limitations and future research opportunities should be addressed. While the assessment demonstrated validity and reliability, further longitudinal studies could examine how systems thinking skills develop over time and across different age groups. Additionally, exploring the relationship between systems thinking skills and students' performance in specific subjects, such as science or mathematics, could provide deeper insights into the role of systems thinking in interdisciplinary learning.

Moreover, the critical area that needs to be discussed is the practical implications of integrating systems thinking into the classroom. Teachers need targeted training to implement systems thinking effectively, particularly in guiding students to analyze the deeper structures and interconnections within systems. The results of this study suggest that educational policymakers should prioritize systems thinking as a core skill in curriculum standards and provide resources for its integration into teaching practices.

## 6. Conclusion

This study was conducted to develop and validate a reliable assessment tool for measuring systems thinking skills in upper primary students in Thailand. The research followed a three-phase data collection process, involving content validation, construct validation through Confirmatory Factor Analysis (CFA), and the establishment of normative criteria using T-score ranking. The results confirmed that the Systems Thinking Skills Assessment for Upper Primary Students meets content validity, construct validity, appropriate difficulty, discrimination, and reliability criteria, making it a comprehensive tool for evaluating students' ability to analyze and understand complex systems. In detail, this research validates the structural accuracy of the systems thinking skills Assessment for Grade 4-6 students, which consists of four levels—Event Level, Pattern Level, Structure Level, and Mental Model Level—based on the Iceberg model. The interpretation of scores is categorized into five levels: Very High, High, Moderate, Low, and Needs Improvement.

## 7. Suggestions

The study contributes to the key gaps in systems thinking assessment in the Thai educational context by developing a validated measurement tool specifically designed for upper primary students. As previous research either focused solely on content validity (IOC) or lacked validity testing altogether, this study ensures both content and construct validity through expert evaluation and Confirmatory Factor Analysis (CFA). It could be noted from this study that inventing an assessment tool that aligns with the Iceberg Model provides a comprehensive evaluation of students' systems thinking skills, considering event-level understanding, pattern recognition, structural analysis, and mental models. Teachers or educators can use this assessment for both pre-learning evaluation to determine students' initial systems thinking skills and identify those who may require further development, as well as for post-learning evaluation to assess whether students have improved their systems thinking abilities after instructional interventions. Furthermore, the study establishes normative criteria using T-score ranking, which was previously absent in Thai research. This allows for standardized interpretation of test scores, ensuring that educators can effectively assess and track students' systems thinking abilities.

## Declarations

**Author Contributions.** Thayaamol Upapong: Literature review, conceptualization, and data collection, Methodology, data analysis. Apantee Poonputta: Corresponding author, Review, editing, and manuscript preparation, Validation, data visualization, and critical revisions. All authors have read and approved the final version of the article for publication.

**Conflicts of Interest.** The authors declare no conflict of interest.

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**Ethical Approval.** This study was conducted in compliance with ethical standards and was approved by the Mahasarakham University, under approval number 051-019/2567. All participants provided informed consent prior to participation, and their privacy and confidentiality were protected throughout the study.
**Data Availability Statement.** The data supporting the results reported in this study are available from the corresponding author upon reasonable request.
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