JIL Journal of Information and Learning, (2024), 35(3), 1-12
Journal homepage: https://so04.tci-thaijo.org/index.php/jil

Research Article

Confirmatory Factor Analysis of Complex Problem Solving Skills of Upper Secondary School Students

Thadapanitsadee Sukonwiriyakul[1,2*], Jintavee Khlaisang[1,2], and Jaitip Na Songkhla[1]

[1]*Department of Educational Technology and Communications, Faculty of Education, Chulalongkorn University*
[2]*Educational Invention and Innovation Research Unit, Chulalongkorn University*

*Corresponding author: l.kulchaya@gmail.com

Received May 29, 2024 ■ Revised July 18, 2024 ■ Accepted July 23, 2024 ■ Published December 26, 2024

Abstract

Complex problem-solving skills are crucial for career development and future living in everyday life. Instilling complex problem-solving thinking methods in students at the school level will prepare them to face the future world effectively. The objective of this research is to study the confirmatory components and indicators of complex problem-solving skills of upper secondary school students. This research analyses the second-order confirmatory components of complex problem-solving skills among upper secondary school students. The study found that future skills consist of five components: 1) the ability to assess the complexity of situations, 2) the ability to identify problems, 3) the ability to analyze anomalies, 4) the ability to see the interconnectedness of each causal factor of problems, and 5) the ability to devise creative solutions to manage the causal factors and their impacts. The weight of each component of the latent variables was positive, ranging from 0.96 to 0.99. The components of the ability to identify problems and the ability to see the interconnectedness of each causal factor had the highest weights (ß = 0.99), followed by the ability to analyze anomalies and the ability to devise creative solutions to manage the causal factors and their impacts, which were equal in weight (ß = 0.98), and the ability to assess the complexity of situations (ß = 0.96). The Confirmatory Factor Analysis (CFA) model was examined for alignment or consistency with empirical data. The results indicated that the model is congruent with the empirical data, evidenced by a Chi-square value of 363.75, a p-value of 0.00, and degrees of freedom (df) of 235. This demonstrates that the Chi-square value is not significantly different from zero at the .05 level, indicating a good fit of the model to the data. Additionally, the model shows excellent fit indices: comparative fit index (CFI) and Tucker–Lewis index (TLI) both at 0.99, standardized root mean squared residual (SRMR) at 0.02, and root mean square error of approximation (RMSEA) at 0.03. These values confirm the hypothesis that the model aligns well with the empirical data.

Keywords: complex problem-solving, CFA, problem solving, technology and development, higher secondary education

Introduction

In the 21st century, complex problem-solving skills have become essential in both educational and professional fields, as well as in everyday life. As the world becomes increasingly interconnected and multifaceted, the ability to navigate and resolve complex issues is crucial. Problem-solving is foundational in the school learning process, with numerous studies highlighting its importance in preparing students for future challenges (Fischer et al., 2012; Greiff et al., 2012;. Each problem presents unique contributing factors that vary depending on the context, making the approach to solving these problems highly individualized.

The World Economic Forum's Future of Jobs Report (2023) emphasizes that over one-third of all sectors require complex problem-solving skills as a primary work skill, underscoring their significance in maintaining a competitive edge in today's dynamic job market. Employees with strong problem-solving skills can plan and make informed decisions to manage issues effectively and efficiently, benefiting both their personal career development and their organizations (World Economic Forum, 2023).

In today's rapidly advancing technological and social landscape, complex problem-solving skills have become one of the most crucial abilities for preparing students for the future. These skills are essential not only in everyday life, work, and further education but also in fostering creativity, flexibility in thinking, and reasoned decision-making. Research by Smith et al. (2022) found that these skills help students face challenges and adapt to changing situations more effectively. Furthermore, they enhance creativity and critical thinking in finding solutions to problems. Promoting complex problem-solving skills in education prepares students for more effective learning and real-world application. Wonsiri et al. (2022) discovered that training in these skills helps students apply the knowledge they have gained to various situations appropriately, making learning more meaningful and effective. Additionally, developing complex problem-solving skills contributes to decision-making, teamwork, and the development of other social skills (Smith et al., 2022).

This research aims to study the confirmatory components and indicators of complex problem-solving skills among upper secondary school students. By analyzing the second-order confirmatory components, this study seeks to provide insights into the specific abilities that constitute effective problem-solving skills and how they can be developed in an educational setting. The findings will contribute to the design of teaching methods and educational systems that emphasize these critical skills, preparing students to face the rapidly occurring challenges and changes in today's world.

Objectives

To study the confirmatory components and indicators of complex problem-solving skills of upper secondary school students.

Literature Review

Complex Problem-Solving

Complex problem solving (CPS) is a critical skill in today's interconnected and multifaceted world, extensively discussed in literature by Spering et al. (2005), Fischer et al. (2012), Jung (1971). CPS involves a process of addressing complex issues that require the integration of knowledge from various domains. The problem solver must understand the issue thoroughly and decide on the most appropriate and effective solution to achieve the desired goals. The critical components of CPS skills include: 1) Knowledge Management: This involves handling extensive knowledge related to the problem. If the knowledge base is vast, it needs to be condensed by breaking down the information into manageable, smaller segments. 2) Ill-Structured Problem: These are problems that can be solved in various ways, where solutions are not strictly right or wrong but are evaluated based on their effectiveness and appropriateness. 3) Metacognition is the ability to monitor and evaluate one's thought processes. It includes awareness and the ability to choose and implement different strategies to resolve the problem.

To assess CPS skills, educators must use rubrics to record students' learning behaviours and evaluate their performance on specific tasks. Additionally, students are encouraged to self-assess their CPS skills in five key areas:

1. Assessing Complexity: the ability to analyze and identify the significant factors that contribute to the complexity of a situation.

2. Problem Identification: The ability to detect and clearly define anomalies or issues as they arise.

3. Analyzing Anomalies: The ability to analyze the causes or factors contributing to these anomalies, considering variations and fluctuations.

4. Recognizing Interconnections: The ability to understanding the causes and effects of various factors clearly.

5. Creative Solution Formulation: The ability to effectively devise innovative approaches to manage the causal factors and their impacts.

These competencies are essential for students to develop as they prepare to navigate increasingly complex social and professional landscapes.

To achieve their set goals, an individual must undergo a process of problem-solving and decision-making behavior (Leighton, 2004). For a person to make a decision to solve a problem, they need to have certain thoughts that are connected to the problem, helping to frame the decision-making process. The decision-making process begins with the problem solver identifying what the problem requires and then evaluating and deciding what actions to prioritize. Crucial factors influencing decision-making include past experiences and current emotions. The problem solver's risk tolerance also affects decision-making. In complex problem-solving, choosing the best option from numerous alternatives is necessary. The problem solver must use their knowledge to make decisions while considering various factors with logic and reasoning (Isen, 2008).

According to Ahmed et al. (2012), decision-making is identifying and selecting the best and most suitable options for achieving specific objectives, utilizing intellectual capacities, reason, and emotional aspects. Arsham (2010) states that decision-making is crucial for an individual's success, involving analytical thinking through difficulties, confusion, and fear. Decision-making is a process within problem-solving aimed at achieving satisfactory outcomes. It involves arguments and emotions, which may or may not be rational, and the outcomes may be transparent or ambiguous, influenced by culture, knowledge, perspectives, or beliefs.

The decision-making process is rational but can become more subjective in personal matters, primarily based on individual behaviour. Choices or decisions result from information processed during decision-making (Neisiani, 2010). High-level cognitive processes are involved in decision-making because they relate to the brain's management capabilities, particularly the neocortex. Decision-making requires responsibility, following action plans, abstract thinking, and guiding towards suitable directions in alignment with the brain's interpretation of emotional data (Szmalec et al., 2010).

From the above definitions, it is concluded that decision-making involves identifying the best options to achieve the goals the decision-maker sets. It requires knowledge to analyze data and accept responsibility for those decisions.

The related research on complex problem-solving skills includes five components with 26 indicators, as follows: (referred to as Figure 1)

1. Assessing the Complexity of Events (6 indicators): (a) Articulate issues related to the event before solving. (b) Identify the relevance of each issue. (c) Identify the impacts arising from each issue. (d) Explain concepts to peers with principles and rationale. (e) Prioritize each issue. (f) Identify the complexity level of the event.

2. Problem Identification (5 indicators): (a) Notice fluctuations or changes in relevant factors. (b) Use credible principles and reasoning to identify problems. (c) Determine the source of the problem. (d) Use facts from similar events to clarify the problem. (e) Address the causes of the problem immediately upon identification.

3. Analyzing Anomalies (5 indicators): (a) Identify causes from past experiences. (b) Search for differences between events needing solutions and similar but non-problematic events. (c) Consider changes in relevant factors. (d) Confirm analyzed causes before problem-solving. (e) Tests should be conducted on hypotheses that could not confirm causes.

4. Recognizing Interconnections (5 indicators): (a) Identify the relevance of causal factors of anomalies. (b) Use facts to analyze the interconnections of causal factors. (c) Deeply analyze the reasons for fluctuations or changes in factors. (d) Identify the impacts of various causal factors. (e) Manage impacts within an appropriate timeframe.

5. Creating Strategies to Manage Causal Factors and Impacts (5 indicators): (a) Present innovative ideas for managing causal factors. (b) Propose new solutions for managing causal factors. (c) Consider potential problems that may arise from solution methods. (d) Explore technologies or innovative tools to manage problems permanently. (e) Find collaborative solutions with stakeholders.

Methodology

Participants

The sample group comprises 861 upper secondary school students, with 349 females (40.5%) and 512 males (59.5%) aged 16 to 18. The majority, 788 students (91.5%), are enrolled in a science curriculum, while 73 (8.5%) are in an arts curriculum. This data was collected through a national survey representing the population across six regions: Northern, Central, Northeastern, Eastern, Western, and Southern Thailand. The study employs confirmatory factor analysis (Hair et al., 2010) to examine the data. The researcher selected the sample group using cluster sampling, dividing Thailand into six regions: North, Central, Northeast, East, West, and South. This method ensures that the population from all areas of Thailand is represented. Then, the researcher selected the sample group using stratified sampling by dividing them according to the affiliation of schools into three categories: Government School, Private School, and Demonstration School. This method covers populations with different affiliations. One school from each affiliation will be randomly selected. After selecting the schools from each affiliation in each region, the researcher will use stratified sampling again, dividing students into three grades: Grade 10, Grade 11, and Grade 12. This layered approach ensures a diverse and representative sample, facilitating robust analysis of the variables under study.

Research Process

1. Study, analyze, and synthesize relevant documents and research to guide the structure and questions of the questionnaire.

2. Develop a data collection tool by creating new opinion survey questions. These questions will serve as indicators for each aspect of complex problem-solving.

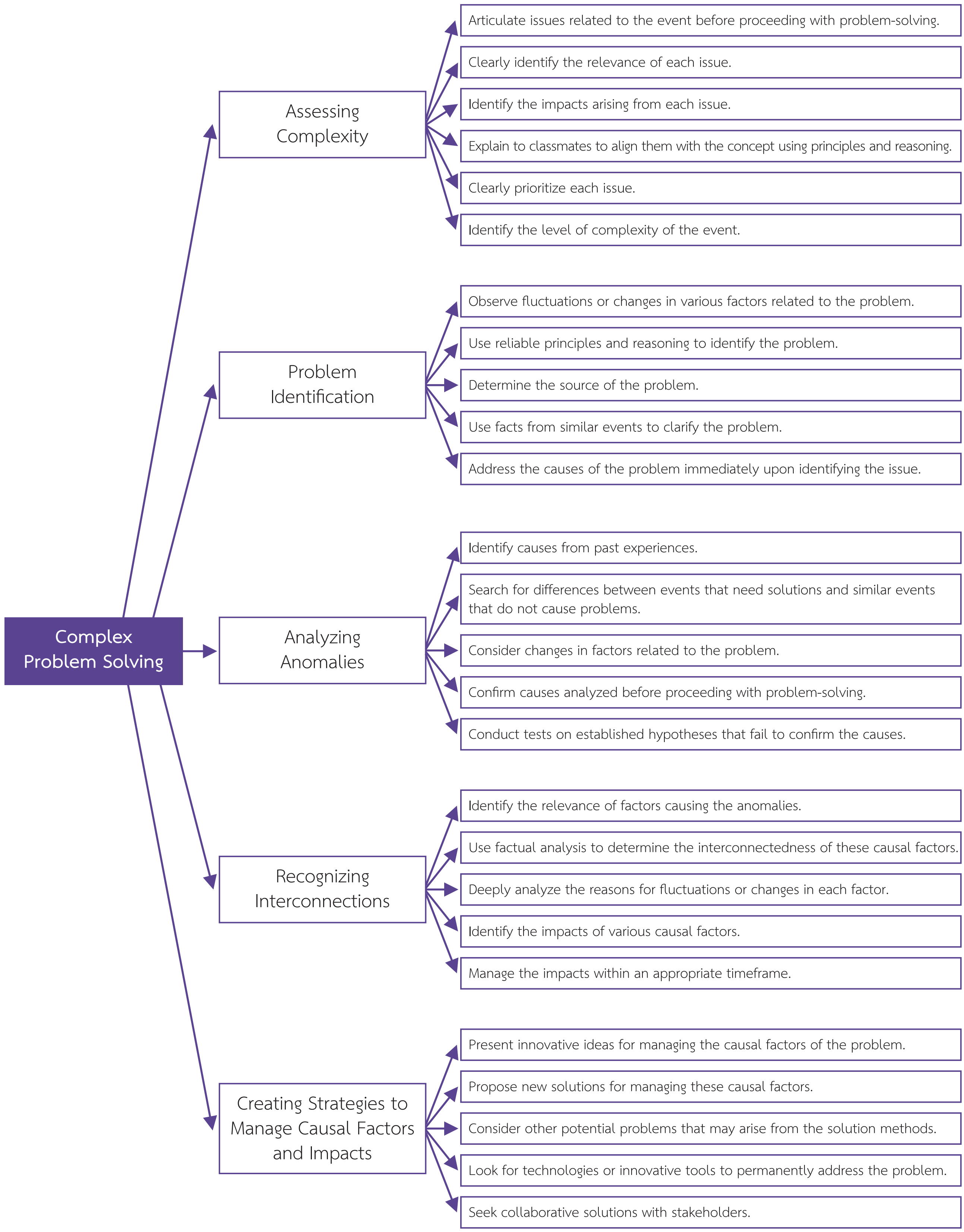
3. Submit the opinion survey to three experts to verify its validity (Index of item-objective congruence -IOC) and ensure the completeness and comprehensiveness of the questions. Additionally, the reliability of the questionnaire will be tested using Cronbach's Alpha Coefficient.

4. Collect data using the questionnaire. The researcher will then coordinate with the contacts at each school to distribute the questionnaires in two formats: online and paper. The questionnaires are expected to be returned within approximately two weeks. The researcher will collect and count the returned questionnaires, select those with complete responses, and analyze the data using descriptive statistics and PNI Modified to assess needs, structural equation modeling, and Confirmatory Factor Analysis (CFA) to determine the components for designing and developing the system.

5. Conduct AMOS software analysis and descriptive statistics to verify the model's validity and study the influence between variables in the model. This includes analyzing the preliminary statistics of the variables, assessing the quality of the data collection tool, examining the relationships between variables, validating the model, and investigating the influence between variables using statistical analysis.

Figure 1

Second Order Confirmatory Factor Analysis of Complex Problem Solving of Higher Secondary Students



Measure

The research tool used is a questionnaire to analyze the second-order confirmatory components suitable for developing complex problem-solving skills in upper-secondary students. It uses a 5-point rating scale comprising 26 items distributed across five components:

1. Assessing the Complexity of Events (6 items): This component includes items that assess a student's ability to evaluate the intricacies of various scenarios.
2. Problem Identification (5 items): This focuses on the ability to detect and define problems accurately.
3. Analyzing Anomalies (5 items): Items here gauge the ability to analyze the issues' root causes and contributing factors.
4. Recognizing Interconnections (5 items): This measures the ability to understand the relationships between different causal factors of a problem.
5. Creating Strategies (5 items): This involves innovating solutions for managing the causes and effects of problems.

The analysis of the relationships between the 26 behavioural indicators revealed a very high Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) of 0.98, indicating that the sample is adequate for the analysis. Additionally, Barlett's test of sphericity shows statistical significance at the 0.05 level, confirming that the indicators are sufficiently related for component analysis. The relationships within the main components are all positively directed, ranging from 0.49 to 0.75, significant at the 0.05 level, suggesting a solid internal consistency and reliability of the questionnaire for assessing complex problem-solving skills.

Data Collection

Data were collected through a structured questionnaire administered to the participants. The questionnaire aimed to capture detailed responses reflecting the students' complex problem-solving abilities.

Data Analysis

Confirmatory factor analysis (CFA) was conducted using AMOS software to validate the structure of the complex problem-solving skills model.

Ethical Consideration

In this study, the researchers obtained consent from the participants to respond. The informed consent was distributed to the teachers involved in our survey, and the signed privacy consent forms were collected. The researchers ensured the anonymity of the participants and their freedom to withdraw from the study at any time, with no need to explain their reasons. The data were kept during the study and were destroyed upon completion. Only researchers would have access to the data.

Results

Descriptive Analysis

The validation of complex problem-solving skills through second-order confirmatory factor analysis (CFA) checks the alignment or consistency of the model for developing indicators of complex problem-solving skills with empirical data. The results indicate that the model is congruent with the empirical data, as evidenced by a Chi-square value of 363.75 with a significance (p-value) of .05 and degrees of freedom (df) of 235, suggesting that the Chi-square value is not significantly different from zero at the .05 level. This demonstrates a good fit of the model to the data, which is further supported by excellent fit indices: the Comparative Fit Index (CFI) and Tucker–Lewis Index (TLI) are both 0.99, the Standardized Root Mean Squared Residual (SRMR) is 0.02, and the Root Mean Square Error of Approximation (RMSEA) is 0.03. These values confirm the hypothesis that the model aligns well with the empirical data.

When considering the individual components, the first component, the ability to assess the complexity of events, shows the following performance in prioritizing each issue with the highest clarity, achieving the highest average score (M = 3.86, SD = 0.87). The following highest scores are for identifying the impacts that arise from each issue (M = 3.85, SD = 0.82), articulating issues related to the event before proceeding with problem-solving (M = 3.82, SD = 0.83), and identifying the relevance of each issue (M = 3.80, SD = 0.82). Explaining to classmates to align them with the concept using principles and reasoning (M = 3.72, SD = 0.95) and identifying the level of complexity of the event (M = 3.68, SD = 0.91) also show substantial scores, indicating a robust ability to evaluate and articulate the complexities inherent in various scenarios.

When considering individual components, the findings for each component are as follows:

Component 1 - Assessing the Complexity of Events:

Shows the following performance in prioritizing each issue with the highest clarity achieving the highest average score (M = 3.86, SD = 0.87). The following highest scores are for identifying the impacts that arise from each issue (M = 3.85, SD = 0.82), articulating issues related to the event before proceeding with problem-solving (M = 3.82, SD = 0.83), and identifying the relevance of each issue (*M* = 3.80, *SD* = 0.82). Explaining to classmates to align them with the concept using principles and reasoning (*M* = 3.72, *SD* = 0.95) and identifying the level of complexity of the event (*M* = 3.68, *SD* = 0.91) also show substantial scores, indicating a robust ability to evaluate and articulate the complexities inherent in various scenarios.

Component 2 - Problem Identification Abilities:

1) Using reliable principles and reasoning to identify problems has the highest average score (*M* = 3.88, *SD* = 0.87). 2) Identifying the source of the problem follows closely (*M* = 3.85, *SD* = 0.85). 3) Using facts from similar events to clarify the problem achieves (*M* = 3.84, *SD* = 0.87). 4) Addressing the causes of the problem immediately upon detection scores (*M* = 3.74, *SD* = 0.91). 5) Observing fluctuations or changes in relevant factors records (*M* = 3.72, *SD* = 0.90).

Component 3 - Analyzing Anomalies Abilities:

1) Identifying causes from past experiences holds the highest mean (*M* = 3.91, *SD* = 0.88). 2) Considering changes in factors related to the problem (*M* = 3.77, *SD* = 0.88). 3) Searching for differences between similar events, one with problems and one without (*M* = 3.76, *SD* = 0.87). 4) Confirming analyzed causes before proceeding with problem-solving (*M* = 3.73, *SD* = 0.91). 5) Testing hypotheses that have been set, which could not confirm the causes (*M* = 3.64, *SD* = 0.92).

Component 4 - Recognizing Interconnections of Causal Factors:

1) Using factual analysis to determine the interconnectedness of causal factors scores the highest (*M* = 3.87, *SD* = 0.84). 2) Identifying the impacts of various causal factors (*M* = 3.82, *SD* = 0.86). 3) Identifying the relevance of causal factors causing anomalies (*M* = 3.80, *SD* = 0.84). 4) Managing impacts within an appropriate timeframe (*M* = 3.71, *SD* = 0.89). 5) Analyzing in-depth the reasons for fluctuations or changes in each factor (*M* = 3.69, *SD* = 0.88).

These detailed insights reflect the nuanced capabilities within each component, indicating areas of strength and potential focal points for further development or training.

Component 5 - Creativity in Developing Strategies to Manage Causal Factors and Impacts:

1) Finding collaborative solutions with stakeholders has the highest average score (*M* = 3.90, *SD* = 0.87), highlighting the importance of teamwork and cooperation in problem-solving. 2) Considering other potential problems that may arise from the solution methods is next, reflecting the ability to anticipate and prepare for possible future challenges (*M* = 3.86, *SD* = 0.86). 3) Searching for technologies or innovative tools to permanently manage the problem underscores a focus on sustainability and long-term effectiveness (*M* = 3.85, *SD* = 0.88). 4) Presenting innovative ideas for managing the causal factors of the problem indicates a capacity for creative thinking and innovation (*M* = 3.73, *SD* = 0.87). 5) Proposing new solutions for managing these causal factors ranks last but is still significant, suggesting a readiness to adapt and improve (*M* = 3.69, *SD* = 0.93).

These results demonstrate strong competencies in innovative and collaborative approaches within complex problem-solving contexts, particularly in identifying and integrating long-term solutions with the involvement of various stakeholders.

Test of the measurement model

1. For the component "Ability to Assess the Complexity of Events," the standard score weightings for the indicators are arranged from highest to lowest as follows: Identifying the event's complexity level (ß = 0.83) followed by Identifying the relevance of each issue (ß = 0.81), Articulating issues related to the event before problem-solving (ß = 0.78), Identifying the impacts arising from each issue (ß = 0.78), Explaining to classmates to align them with the concept using principles and reasoning (ß = 0.78) and Prioritizing each issue (ß = 0.77).

2. For problem identification skills, the weights of the indicators arranged from highest to lowest are as follows: Using facts from similar events to identify problems (ß = 0.85), followed by managing the causes of problems immediately upon encountering issues (ß = 0.81). Observing fluctuations or changes in factors related to the problem, using reliable principles and reasoning to identify issues, and determining the origins of problems all have equal weights (ß = 0.79).

3. For the component "Ability to Analyze Anomalies," the standard score weightings for the indicators are arranged from highest to lowest as follows: Considering changes in factors related to the problem (ß = 0.85) followed by Searching for differences between events requiring solutions and similar events without issues (ß = 0.83), Confirming causes analyzed before proceeding with problem-solving (ß = 0.83), Identifying causes from past experiences (ß = 0.81) and Conducting tests on established hypotheses that fail to confirm the causes (ß = 0.75)

4. For the component "Ability to Recognize Interconnections of Causal Factors," the standard score weightings for the indicators are ranked from highest to lowest as follows: Identifying the impacts of various causal factors (ß = 0.84) followed by Identifying the relevance of causal factors causing anomalies (ß = 0.82),

Using factual analysis to determine the interconnectedness of these causal factors (ß = 0.82), Analyzing in-depth the reasons for fluctuations or changes in each factor (ß = 0.81) and Managing impacts within an appropriate timeframe (ß = 0.80).

5. For the component "Ability to Create Strategies to Manage Causal Factors and Impacts," the standard score weightings for the indicators are arranged from highest to lowest as follows: Presenting innovative ideas for managing the causal factors of the problem (ß = 0.85) followed by Proposing new solutions for managing these causal factors (ß = 0.83), Considering other potential problems that may arise from the solution methods (ß = 0.83), Seeking collaborative solutions with stakeholders (ß = 0.75) and Looking for technologies or innovative tools to permanently address the problem (ß = 0.73).

From the second-order component analysis of complex problem-solving skills among upper secondary students, the findings indicate that all latent variable weights are positive, ranging from 0.96 to 0.99. This suggests a strong and positive relationship between the observed indicators and their respective latent variables, reflecting robust constructs within the problem-solving framework. The breakdown is as follows: Ability to Identify Problems (ß = 0.99) and Ability to Recognize Interconnections of Causal Factors (ß = 0.99) have the highest weights. This underlines the critical importance of these skills in complex problem-solving, where identifying the core issues accurately and understanding how different factors are interconnected are essential for effective resolution. Followed by Ability to Analyze Anomalies (ß = 0.98) and Ability to Create Strategies to Manage Causal Factors and Impacts (ß = 0.98) are slightly lower but still very high, indicating these abilities are almost equally crucial. Analyzing anomalies involves understanding the root causes and differentiating between normal and problematic conditions, while creating strategies focuses on developing actionable and innovative solutions to address these causes. Ability to Assess the Complexity of Events (ß = 0.96), although the lowest, still holds significant importance. This ability involves evaluating the overall complexity of situations, which is fundamental to setting the stage for deeper analysis and solution development.

These results demonstrate that each of these skills plays a vital role in the complex problem-solving process, with particular emphasis on the identification and interconnection of problems. These findings could be visually illustrated in graphs or tables (referred to as Table 1 and Figure 2), providing a clear, structured overview of how these components contribute to effective problem-solving in educational contexts.

Table 1

Results of the Second-Order Confirmatory Factor Analysis of the Complex Problem-Solving

Indicators	Factor loading		*t*	*p*	R^2	Factor score coefficient
	b(SE)	ß				
First-order confirmatory factor analysis						
Assessing the Complexity of Events						
1. Articulate issues related to the event before proceeding with problem-solving	0.87(0.03)	0.78	26.00	0.00	0.61	0.08
2. Clearly identify the relevance of each issue	0.89 (0.03)	0.81	28.59	0.00	0.66	0.10
3. Identify the impacts arising from each issue	0.85(0.03)	0.78	26.82	0.00	0.60	0.10
4. Explain to classmates to align them with the concept using principles and reasoning	0.99(0.04)	0.78	27.05	0.00	0.61	0.10
5. Clearly prioritize each issue	0.89(0.03)	0.77	26.58	0.00	0.59	0.08
6. Identify the level of complexity of the event	1.00(0.00)	0.83	999.00	0.00	0.69	0.11

Table 1
(continued)

Indicators	Factor loading		t	p	R^2	Factor score coefficient
	b(SE)	β				
Problem Identification						
1. Observe fluctuations or changes in various factors related to the problem	0.96(0.03)	0.79	29.08	0.00	0.63	0.07
2. Use reliable principles and reasoning to identify the problem	0.92(0.03)	0.79	28.93	0.00	0.62	0.06
3. Determine the source of the problem	0.90(0.03)	0.79	28.70	0.00	0.62	0.09
4. Use facts from similar events to clarify the problem	1.00(0.00)	0.85	999.00	0.00	0.72	0.10
5. Address the causes of the problem immediately upon identifying the issue	0.98(0.03)	0.81	29.85	0.00	0.65	0.06
Analyzing Anomalies						
1. Identify causes from past experiences	0.95(0.03)	0.81	29.02	0.00	0.66	0.14
2. Search for differences between events that need solutions and similar events that do not cause problems	0.95(0.03)	0.83	30.00	0.00	0.69	0.19
3. Consider changes in factors related to the problem	0.98(0.03)	0.85	33.42	0.00	0.72	0.09
4. Confirm causes analyzed before proceeding with problem-solving	1.00(0.00)	0.83	999.00	0.00	0.70	0.19
5. Conduct tests on established hypotheses that fail to confirm the causes	0.91(0.03)	0.75	26.88	0.00	0.56	0.10
Recognizing Interconnections						
1. Identify the relevance of factors causing the anomalies	0.95(0.03)	0.82	30.48	0.00	0.67	0.06
2. Use factual analysis to determine the interconnectedness of these causal factors	0.95(0.03)	0.82	32.78	0.00	0.67	0.10
3. Deeply analyze the reasons for fluctuations or changes in each factor	0.98(0.03)	0.81	31.37	0.00	0.65	0.09
4. Identify the impacts of various causal factors	1.00(0.00)	0.84	999.00	0.00	0.72	0.10
5. Manage the impacts within an appropriate timeframe	0.98(0.03)	0.80	29.20	0.00	0.64	0.10
Creating Strategies to Manage Causal Factors and Impacts						
1. Present innovative ideas for managing the causal factors of the problem	0.97(0.03)	0.85	35.04	0.00	0.72	0.14
2. Propose new solutions for managing these causal factors	1.00(0.00)	0.83	999.00	0.00	0.69	0.11
3. Consider other potential problems that may arise from the solution methods	0.92(0.03)	0.81	28.64	0.00	0.66	0.15
4. Look for technologies or innovative tools to permanently address the problem	0.84(0.03)	0.73	24.61	0.00	0.53	0.06
5. Seek collaborative solutions with stakeholders	0.85(0.03)	0.75	25.52	0.00	0.56	0.07

Table 1
(continued)

Indicators	Factor loading		*t*	*p*	R^2	Factor score coefficient
	b(SE)	β				
Second-order confirmatory factor analysis						
Assessing the Complexity of Events	0.96(0.04)	0.96	27.57	0.00	0.92	
Problem Identification	0.99(0.04)	0.99	28.47	0.00	0.99	
Analyzing Anomalies	0.99(0.03)	0.98	30.20	0.00	0.96	
Recognizing Interconnections	0.96(0.03)	0.99	29.91	0.00	0.99	
Creating Strategies to Manage Causal Factors and Impacts	1.00(0.00)	0.98	999.00	0.00	0.96	

Chi-square = 363.75; *df* = 235; *p* = 0.00; CFI = 0.99; TLI = 0.99; SRMR = 0.02; RMSEA = 0.03

Discussion

The key components of complex problem-solving skills for upper secondary students encompass the following essential elements:

Ability to Assess the Complexity of Events: This involves the student's capability to understand and evaluate the intricacies of situations. Indicators for this skill include identifying the complexity of events, understanding the relevance of each issue, assessing the impact, and being able to explain these with rational justification and prioritize accordingly. This aligns with research by Fischer et al. (2012), which emphasizes the importance of understanding complex scenarios to effectively navigate and resolve them.

Ability to Identify Problems: This skill focuses on the student's ability to pinpoint issues accurately within a complex scenario. It involves recognizing the nuances and specific details that frame the problem.

Ability to Analyze Anomalies: Students need to differentiate between normal and abnormal conditions and determine the root causes of the anomalies. This involves a detailed analysis where past experiences and close comparisons are leveraged to identify the reasons behind the anomalies.

Ability to Recognize Interconnections of Causal Factors: This capability entails understanding how different factors within a problem are related and how they interact to affect the overall situation. This skill is crucial for developing effective strategies to address complex problems comprehensively.

Ability to Create Strategies to Manage Causal Factors and Impacts: This involves generating innovative solutions to address the root causes and manage the consequences effectively. It requires creativity, a forward-thinking approach, and often collaboration with others to devise and implement solutions.

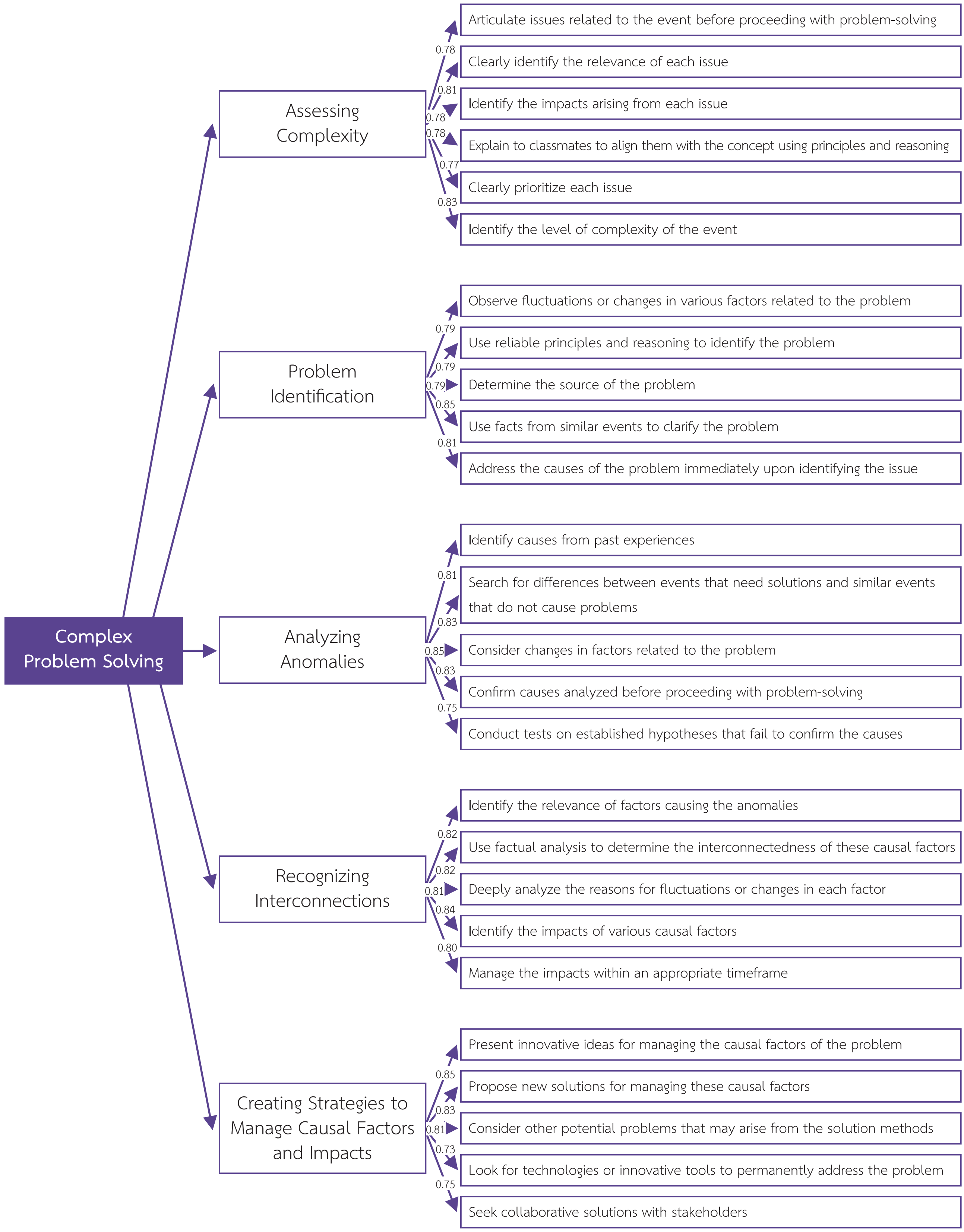
These components are deeply interconnected, with each building on the others to enhance the overall problem-solving ability of students. For instance, the ability to assess complexity directly supports the capabilities to identify problems and analyze anomalies, while the ability to recognize interconnections and create strategies are necessary for implementing effective solutions.

The research findings underscore the importance of a holistic approach to problem-solving where knowledge from past experiences is utilized to inform current solutions, echoing Dörner (1996) perspective on complex problem-solving. This approach is not just about solving the problem at hand but also about applying learned principles and logical reasoning to develop and execute plans effectively. These skills are essential for students as they prepare not only for academic challenges but also for real-world issues they will encounter in the future.

The ability to identify problems in complex problem-solving for upper secondary students involves key skills such as using facts from similar events to enhance problem clarity, promptly managing the root causes once identified, observing changes and fluctuations in relevant factors, applying logical reasoning and reliable principles for precise problem identification, and understanding the origins of issues. These skills align with research by Jonassen (2000), who emphasizes comparing current problems with past experiences to enhance problem-solving, and Rittel and Webber (1973), who define essential problem identification criteria such as clarity, specificity, and

Figure 2

Second Order Confirmatory Factor Analysis of Complex Problem Solving of Higher Secondary Students



Chi-square = 247.62; *df* = 215; *p* = 0.06; CFI = 0.99; TLI = 0.99; SRMR = 0.01; RMSEA = 0.01
Note: **p<.001

measurability. Incorporating these skills into educational settings helps students not only understand theoretical content but also apply practical problem-solving methods effectively.

In the realm of analyzing anomalies as part of complex problem-solving, studies have identified key indicators such as the assessment of changes in factors related to the problem, and comparing events that resulted in issues with those that did not to spot differences. Before proceeding with solutions, it's crucial to confirm the causes identified and utilize past experiences to establish reasons for these issues. Additionally, hypothesis testing is performed to validate these causes, which may not always confirm the initial analysis. This methodology aligns with Sterman's (2000) research, which emphasizes the necessity of considering relevant factors and applying existing knowledge to analyze and solve problems. Similarly, Dörner and Funke (2017) highlight that beyond analyzing the causes of problems, learners must also identify what information the problem presents, what needs solving, and then proceed to formulate and test hypotheses. These processes are fundamental in equipping students with the analytical skills required to effectively address and solve complex problems.

The ability to discern the interconnectedness of various factors causing problems is a critical skill in complex problem-solving. Research findings indicate that the primary indicator is the ability to identify the impacts of these factors. Following this, it is essential to recognize the relationships between the factors causing disruptions and use factual data to analyze these relationships. Deep analytical insights into the reasons for variability or changes in each factor are also crucial. Effective management of the consequences within an appropriate timeframe is necessary for resolving such complex scenarios.

This approach aligns with Senge's (2006) methodology, which emphasizes the importance of first understanding the causal factors of a problem, then breaking them down into manageable components, and exploring how these components interlink. Similarly, Meadows (2008) emphasizes using existing knowledge or past experiences to solve problems by analyzing all facts comprehensively, examining the interrelations among problem factors, and understanding the reasons for changes in each factor. This thorough analysis aids in crafting effective solutions to complex problems, highlighting the importance of a systematic and integrated approach in educational settings and real-world applications. This skill not only facilitates problem resolution but also fosters a deeper understanding of system dynamics and their applications in various disciplines.

The ability to creatively develop solutions for managing the factors causing problems and their impacts is crucial in complex problem-solving. The primary indicator of this skill is the ability to introduce innovative ideas for managing these causative factors. This is followed by presenting new solutions, considering potential subsequent issues that may arise from the solutions, and collaboratively finding remedies with stakeholders, potentially involving innovative technologies or tools for permanent resolution.

This approach is supported by research from Dyer et al. (2011), which suggests that handling the causative factors of problems effectively requires creative thinking. This includes the ability to adapt thought processes to overcome obstacles as they occur. Additionally, Heifetz et al. (2002) emphasize that learners must adopt a systematic thinking approach that allows them to understand and connect various factors involved in solving a problem, and to effectively communicate these strategies within a team. This comprehensive understanding and application of innovative problem-solving strategies are essential for dealing with complex issues in a way that not only addresses the immediate problem but also anticipates and mitigates potential future complications.

Conclusion

The key components of complex problem-solving skills for upper secondary school students encompass five main areas: 1) The ability to assess the complexity of situations, 2) The ability to identify problems, 3) The ability to analyze anomalies, 4) The ability to perceive the interrelations among causal factors of problems, and 5) The ability to creatively devise strategies to manage the causative factors of problems and their impacts. Among these, the ability to identify problems and to perceive the interrelations of causative factors holds the highest weight. Following these are the abilities to analyze anomalies and to creatively devise management strategies, with the ability to assess the complexity of situations ranking last. These components form a structured framework that guides students in systematically tackling complex challenges, emphasizing the integration of analysis, identification, and innovative problem-solving strategies.

To design an educational system for enhancing complex problem-solving skills in upper secondary school students, it is crucial to emphasize essential capabilities such as identifying problems by understanding their characteristics and origins, recognizing interrelationships among causative factors, analyzing anomalies by comparing similar situations, creatively formulating strategies for managing these factors, and assessing the complexity of scenarios. Using real-world scenarios and simulations can make the learning process engaging and practical, equipping students with direct applications to real-life challenges.

References

Ahmed, A., Hasnain, N., & Venkatesan, M. (2012). Decision making in relation to personality types and cognitive styles of business students. *The IUP Journal of Management Research, 11*(2), 20-29, https://ssrn.com/abstract=2156758

Arsham, H. (2010). *Leadership decision making.* ResearchGate. https://www.researchgate.net/profile/Dr-Hossein-Arsham/publication/260638276_Leadership_Decision_Making/links/00463531e0bb3dfc85000000/Leadership-Decision-Making.pdf

Dörner, D. (1996). *The logic of failure: Recognizing and avoiding error in complex situations.* Perseus Books.

Dörner, D., & Funke, J. (2017). Complex problem solving: What it is and what it is not. *Frontiers in Psychology, 8,* Article 1153. https://doi.org/10.3389/fpsyg.2017.01153

Dyer, J., Gregersen, H., & Christensen, C. M. (2011). *The innovator's DNA: Mastering the five skills of disruptive innovators.* Harvard Business Review Press.

Fischer, A., Greiff, S., & Funke, J. (2012). The process of solving complex problems. *Journal of Problem Solving, 4*(1), 19-42. https://doi.org/10.7771/1932-6246.1118

Fischer, A., Greiff, S., & Funke, J. (2017). The history of complex problem solving. In B. Csapo', & J. Funke (Eds.), *The nature of problem solving using research to inspire 21st century learning* (pp. 107-121). Education Research and Innovation. https://doi.org/10.1787/9789264273955-9-en

Greiff, S., Wüstenberg, S., & Funke, J. (2012). Dynamic problem solving: A new assessment perspective. *Applied Psychological Measurement, 36*(3), 189-213. https://doi.org/10.1177/0146621612439620

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis* (7th ed.). Pearson.

Heifetz, R. A., Linsky, M., & Laurie, D. L. (2002). *Leadership on the Line: Staying alive through the dangers of leading.* Harvard Business Review Press.

Isen, A. M. (2008). Positive affect and decision processes: Some recent theoretical developments with practical implications. In C. P. Haugtvedt, P. M. Herr, & F. R. Kardes (Eds.), *Handbook of consumer psychology* (pp. 273-296). Taylor & Francis Group/ Lawrence Erlbaum Associates.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63-85. https://doi.org/10.1007/BF02300500

Jung, C. G. (1971). *Psychological types.* Princeton University.

Leighton, J. P. (2004). Defining and describing reasoning and problem solving. In J. P. Leighton & R. J. Sternberg (Eds.), *The nature of reasoning* (pp. 3-18). Cambridge University.

Meadows, D. H. (2008). *Thinking in systems: A primer.* Chelsea Green Publishing.

Neisiani, A. A. (2010). Anti-rational decision making. *African Journal of Business Management, 4*(8), 1652-1653. https://academicjournals.org/journal/AJBM/article-full-text-pdf/64BFF8826462

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences, 4*(2), 155-169. https://doi.org/10.1007/BF01405730

Senge, P. M. (2006). *The fifth discipline: The art and practice of the learning organization.* Doubleday.

Smith, A. H., Grupp, L. L., Doukopoulos, L., Foo, J. C., Rodriguez, B. J., Seeley, J., Boland, L. M., & Hester, L. L. (2022). Taking teaching and learning seriously: Approaching wicked consciousness through collaboration and partnership. *To Improve the Academy: A Journal of Educational Development, 41*(1), 38-67. https://doi.org/10.3998/tia.453

Smith, N., Sankaran, S. K., & Dick, B. (2022). Wicked theorising: Theory building to solve complex problems. *Academy of Management Proceedings.* https://doi.org/10.5465/AMBPP.2022.15098abstract

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world.* McGraw-Hill Education.

Spering, M., Wagener, D., & Funke, J. (2005). Brief report. *Cognition and Emotion, 19*(8), 1252-1261. https://doi.org/10.1080/02699930500304886

Szmalec, A., Duyck, W., Notebaert, W., & Brysbaert, M. (2010). Working memory and executive control: A festschrift for André Vandierendonck. *Psychologica Belgica, 50*(3-4), 147-152. https://doi.org/10.5334/pb-50-3-4-147

Wonsiri, N., Pantapalangkoor, B., & Ketsing, J. (2022). Developing ninth graders' complex problem solving competency via engineering design problem-based learning. *Journal of Education and Innovation, 24*(3), 147-157. https://so06.tci-thaijo.org/index.php/edujournal_nu/article/view/240810

World Economic Forum. (2023). *The future of jobs report 2023.* https://www.weforum.org/reports/the-future-of-jobs-report-2023