Development of a Mathematics Learning Management Model Emphasizing Authentic Assessment to Promote Executive Functions of Lower Secondary School Students

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Abstract

This research aimed to 1) study the state of mathematics learning management emphasizing authentic assessment and the state of executive functions, and 2) develop a model and verify the quality of mathematics learning management emphasizing authentic assessment to promote executive functions of lower secondary school students in Chiang Rai province. The sample consisted of 411 lower secondary mathematics teachers in Chiang Rai province. The data were analyzed using descriptive statistics, Exploratory Factor Analysis (EFA), and Second-Order Confirmatory Factor Analysis (CFA). The research findings revealed that: (1) The state of mathematics learning management consisted of 9 factors, explaining 87.92% of the total variance. Meanwhile, the state of executive functions consisted of 7 factors, explaining 87.38% of the total variance. All indicators exhibited high factor loadings, indicating clear construct structures. (2) The verification of the structural model quality demonstrated that the learning management model fitted the empirical data perfectly χ^2 /df = 2.35, RMSEA = 0.057, CFI = 0.936, TLI = 0.931, SRMR = 0.070). Similarly, the executive function model indicated a good fit with the empirical data χ^2 /df = 2.65, RMSEA = 0.053, CFI = 0.942, TLI = 0.932, SRMR = 0.070). These findings confirmed the construct validity of the developed models and measurement tools, verifying their quality and suitability to be utilized as guidelines for instructional design to effectively enhance students' executive functions.

Keywords: Executive Functions, Authentic Assessment, Mathematics Learning Management

Background and Statement of the problem

Education in the twenty-first century emphasizes the development of learners' higher-order competencies, including analytical thinking, problem-solving, adaptability, and self-regulation, to enable effective functioning in rapidly changing societal contexts. This orientation aligns with Thailand's National Education Plan (2017–2036), which prioritizes the holistic development of learners' potential. A key underlying mechanism of these competencies is Executive Functions (EF), a set of higher-order cognitive processes that regulate behavior, cognition, and emotion in alignment with goal-directed actions. Core components of EF include working memory, inhibitory control, cognitive flexibility, planning, and self-monitoring.

A substantial body of research has demonstrated a significant relationship between EF and mathematics achievement. Bull and Lee (2014) indicated that EF—particularly working memory, inhibition, and shifting—plays a critical role in mathematics learning, including computation, reasoning, and problem-solving. Similarly, Cragg et al. (2017) found that EF influences mathematics achievement both directly and indirectly, suggesting that success in mathematics is not solely dependent on content knowledge but also on learners' ability to organize information, regulate attention, and adapt their thinking strategies to situational demands. Furthermore, Živković et al. (2022), in a study of lower secondary students, reported that visuospatial working memory and cognitive flexibility were positively associated with mathematics achievement, whereas mathematics anxiety was negatively associated and may exert its effects through EF mechanisms. These findings underscore the critical role of EF during early adolescence, a developmental stage characterized by increasing mathematical complexity.

Despite this evidence, mathematics instruction continues to face significant limitations in assessment practices. Most assessments primarily focus on the correctness of answers through selected-response or constructed-response formats, rather than evaluating cognitive processes, reasoning, and the application of knowledge in authentic contexts. Nortvedt and Buchholtz (2018) argued that contemporary mathematics assessment must evolve toward approaches capable of capturing learners' complex competencies, including thinking, communication, and meaningful application of knowledge. In this regard, authentic assessment has gained increasing attention, as it provides opportunities for learners to demonstrate their capabilities through real-world tasks, incorporates continuous feedback, and promotes active engagement in the learning process.

Within the context of mathematics learning, McFeetors and Palfy (2021) suggested that the authenticity of assessment should not be confined to end-of-unit evaluations but should be continuously integrated into the learning process to support meaning-making and learner engagement. However, Syaifuddin (2020) found that lower secondary mathematics teachers, while attempting to implement authentic assessment, encounter challenges related to time constraints, workload, and scoring reliability. This indicates that the practical implementation of authentic assessment remains insufficiently structured and lacks systematic models.

From a theoretical perspective, authentic assessment holds substantial potential for fostering executive functions (EF), as its learning activities require sustained engagement in higher-order cognitive processes, including planning, problem-solving, strategy adjustment, and reflective thinking. These processes are directly aligned with core EF components such as working memory, inhibitory control, cognitive flexibility, and self-monitoring. Importantly, key instruments within authentic assessment—such as rubrics and self-assessment—function as explicit mechanisms for activating EF. The use of rubrics requires learners to simultaneously maintain and process multidimensional criteria within working memory while continuously comparing their performance against these standards, thereby enhancing information organization and attentional regulation. Concurrently, interpreting criteria and revising work based on feedback necessitate cognitive flexibility, as learners must shift perspectives and adapt their strategies in response to evolving task demands. Moreover, self-assessment promotes EF through metacognitive and self-regulatory processes, as learners engage in monitoring their thinking, evaluating the quality of their work, and planning subsequent improvements. This cyclical process of self-regulation is intrinsically linked to EF development. Therefore, authentic assessment should be conceptualized not merely as a tool for measuring learning outcomes but as a process-oriented mechanism that systematically cultivates executive functions within the context of mathematics learning.

A review of both national and international literature indicates that the current body of knowledge remains fragmented. Although research consistently confirms the relationship between EF and mathematics achievement, and highlights the potential of authentic assessment to promote meaningful learning, there is a lack of studies that systematically integrate these two constructs within mathematics instructional design, particularly at the lower secondary level.

Accordingly, a critical gap in the literature lies in the absence of a mathematics instructional model that explicitly integrates authentic assessment to promote learners' EF, supported by empirical evidence—especially within the Thai educational context. Furthermore, there is limited understanding of how specific components of authentic assessment—such as real-world tasks, the use of rubrics, self- and peer-assessment, and continuous feedback—contribute to the development of particular EF dimensions in mathematics learning.

In response to these gaps, the present study on the development of a mathematics instructional model based on authentic assessment to enhance executive functions among lower secondary students is of substantial significance, both theoretically and practically. Theoretically, the study contributes to a systematic integration of EF frameworks with mathematics assessment paradigms. Practically, it provides teachers with a structured approach to designing learning experiences and assessment practices that align with learners' cognitive processes and self-regulatory capacities, thereby fostering the development of essential competencies required for the twenty-first century.

Objective

1. To investigate the current conditions of mathematics instructional management emphasizing Authentic Assessment, as well as the Executive Functions of lower secondary school students.
2. To develop and examine the quality of a mathematics instructional model grounded in Authentic Assessment to enhance the Executive Functions of lower secondary school students.

Expected benefits

1. To identify the components and indicators of mathematics instructional management grounded in Authentic Assessment aimed at enhancing the Executive Functions of lower secondary students.

2. To obtain a concrete instructional model that can serve as a practical guideline for teachers and educational personnel in designing and implementing learning processes that promote students' Executive Functions.

3. To promote and develop the Executive Functions of lower secondary students, which constitute essential foundational skills for both academic learning and everyday life.

Conceptual Framework

1. The researcher synthesized relevant concepts and theories to establish the foundational basis for defining the variables and structural framework of the study, as follows:

Authentic Learning and Assessment Theory

This study draws upon the conceptual framework of Wiggins (1998) and the Ministry of Education, which emphasize organizing mathematics learning experiences that are meaningfully connected to real-life contexts. Within this framework, learners actively construct knowledge through engagement in authentic tasks. Assessment is integrated into the instructional process through formative assessment practices, with particular emphasis on continuous feedback to enable students to refine their learning strategies. Based on this theoretical foundation, the researcher synthesized a mathematics instructional model comprising nine core components.

Executive Functions (EF) Theory

The study is grounded in the cognitive neuroscience framework proposed by Diamond (2013) and further elaborated by the RLG Institute. This perspective explains the role of the frontal lobe in regulating cognition, emotion, and behavior toward goal-directed actions. Executive Functions encompass both core foundational skills and higher-order skills. The researcher integrated this theoretical framework with the context of mathematics learning and synthesized a structure of Executive Functions for lower secondary students consisting of seven components.

2. Conceptual Framework of the Study

Based on the literature review, the researcher developed a conceptual framework aimed at examining the structural relationship between a mathematics instructional model emphasizing Authentic Assessment (independent variable/process) and the development of students' Executive Functions (dependent variable/outcomes)

3. Research Hypotheses

3.1 The structural relationship model of the mathematics instructional approach emphasizing Authentic Assessment is consistent with the empirical data.

3.2 The structural relationship model of the Executive Functions of lower secondary students is consistent with the empirical data.

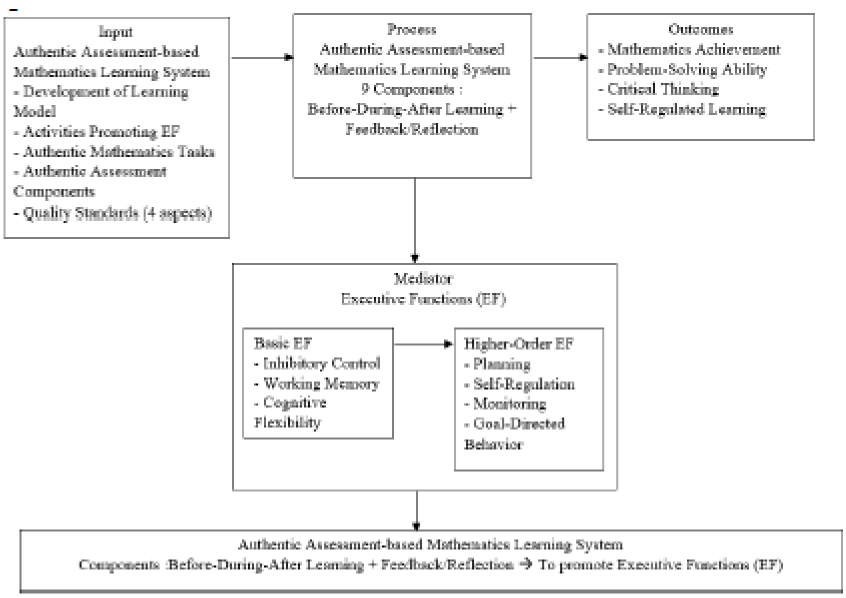


Figure 1 The proposed conceptual framework integrating authentic assessment-based mathematics learning and executive functions (EF)

Research Methodology

Population

The population comprised mathematics teachers teaching in educational institutions in Chiang Rai Province during the 2024 academic year (B.E. 2567). These included schools under the Office of the Basic Education Commission, categorized into

Secondary Educational Service Area Offices, Primary Educational Service Area Offices (Areas 1–4), local administrative organizations, and private institutions.

Try-Out Sample

In this study, data were collected from two independent samples to support distinct analytical procedures, as follows.

The sample for Exploratory Factor Analysis (EFA) consisted of 100 participants and was used for preliminary instrument validation (try-out phase). This sample size meets the minimum acceptable criteria for factor analysis (Gorsuch, 1983; Kline, 1994) and is consistent with Cattell's (1978) recommendation of a minimum sample-to-variable ratio of 3:1. Participants were selected using purposive sampling from schools with contextual characteristics similar to those of the target population, but not included in the actual study sample. The inclusion criteria were as follows: (1) participants were lower secondary mathematics teachers during the academic years 2022–2024, and (2) participants voluntarily agreed to participate in the study. This sample was employed to pilot the questionnaire, assess its reliability, and conduct EFA in order to refine and improve the instrument prior to its administration to the main sample.

The sample for Confirmatory Factor Analysis (CFA) comprised 411 lower secondary mathematics teachers in Chiang Rai Province and was used for the main data collection. Participants were selected using stratified sampling based on school size, including extra-large, large, medium, and small schools. Subsequently, proportionate stratified sampling was applied to ensure appropriate representation across strata. A total of 450 questionnaires were distributed, and 411 were returned, yielding a response rate of 91.33%. The CFA sample was independent from the pilot sample to minimize bias associated with using the same dataset for both instrument development and structural validation (Hair et al., 2019; Kline, 2016; Tabachnick & Fidell, 2013).

Research Instruments

The research instrument consisted of one questionnaire divided into three parts:

Part 1: General Information

A checklist format was used to collect demographic information from respondents.

Part 2: Instructional Management Emphasizing Authentic Assessment

This section comprised 34 five-point Likert-scale items measuring indicators of mathematics instructional management emphasizing Authentic Assessment to promote Executive Functions in lower secondary students.

The initial conceptual framework consisted of nine components: (1) Learning objective formulation promoting Executive Function (2) Principles of learning activity implementation (3) Learning activity management (4) Instructional media promoting Executive Function (5) Classroom environment promoting Executive Function (6) Authentic measurement and evaluation (7) Utilization of assessment results for learning improvement (8) Post-instructional documentation (9) Goal setting and strategic adjustment

Rating scale interpretation: 5 = Always practiced, 4 = Very frequently practiced, 3 = Frequently practiced, 2 = Occasionally practiced,1 = Rarely practiced. The empirical factor structure was subsequently verified using Exploratory Factor Analysis (EFA).

Part 3: Executive Function Behavioral Indicators

This section included 26 five-point Likert-scale items measuring students' Executive Function behaviors across seven components: (1) Inhibitory control (2) Working memory (3) Planning and self-management (4) Cognitive flexibility (5) Attention and focus (6) Self-regulation and self-monitoring (7) Goal-directed persistence

Rating scale interpretation: 5 = Always demonstrates behavior, 4 = Very frequently demonstrates behavior, 3 = Frequently demonstrates behavior, 2 = Occasionally demonstrates behavior, 1 = Rarely demonstrates behavior

Instrument Development and Quality Assurance

The instrument development process included:

1. Reviewing relevant literature on Authentic Assessment, EF-promoting instructional management, and EF behavioral indicators for lower secondary students.
2. Establishing a conceptual framework for questionnaire construction.
3. Developing items based on prior studies (Saengsawang, 2016; Jankhajorn, 2017; Santanarattavechmongkol, 2019).
4. Submitting the instrument to the thesis advisor for content accuracy and linguistic appropriateness.
5. Requesting formal appointment of expert reviewers from the Faculty of Education, Chiang Mai University.

6. Having five experts evaluate content validity using the Index of Item Objective Congruence (IOC). Items with IOC values between 0.60–1.00 were retained; items below 0.60 were revised or removed.

7. Conducting a try-out with 100 teachers and analyzing reliability using Cronbach's alpha. The reliability coefficient was 0.89.KMO = 0.723, Bartlett's Test = 3436.777, df = 561, $p < .001$ (statistically significant)

8. Performing EFA, which yielded nine empirical components: (1) Learning objective formulation promoting Executive Function (2) Principles of learning activity implementation (3) Learning activity management (4) Instructional media promoting Executive Function (5) Classroom environment promoting Executive Function (6) Authentic measurement and evaluation (7) Utilization of assessment results for learning improvement (8) Post-instructional documentation (9) Goal setting and strategic adjustment.

The structure was theoretically consistent and appropriate for subsequent Confirmatory Factor Analysis (CFA).

Data Collection

Data collection proceeded in two sequential phases—a pilot study and the main administration to perfectly align with the research design and analytical procedures.

Phase 1: Pilot Study (Instrument Refinement): To evaluate the quality of the research instrument, data were initially collected from a pilot sample of 100 lower secondary mathematics teachers. Participants were selected via purposive sampling from schools sharing contextual characteristics with the target population. This preliminary dataset was utilized to assess instrument reliability and conduct an Exploratory Factor Analysis (EFA) for initial construct validation and item refinement.

Phase 2: Main Study (Model Validation): The primary data collection involved 411 lower secondary mathematics teachers in Chiang Rai Province. Following official approval from the Faculty of Education, Chiang Mai University, and coordination with the relevant Educational Service Area Offices, questionnaires were distributed using proportionate stratified random sampling based on school size. Of the 450 distributed questionnaires, 411 valid responses were returned, yielding a robust response rate of

91.33%. All submissions were rigorously screened for completeness and accuracy prior to analysis. This final dataset was exclusively employed to conduct the Confirmatory Factor Analysis (CFA).

Importantly, maintaining strictly independent samples for the EFA and CFA phases prevented method bias, thereby maximizing the validity and methodological rigor of the instrument development process.

Data Analysis

Data Analysis Procedures

Part 1: Descriptive statistics (frequency, percentage, mean).

Part 2: Analysis of instructional management components using mean and standard deviation, interpreted according to the following scale:

4.51–5.00 = Highest level, 3.51–4.50 = High, 2.51–3.50 = Moderate, 1.51–2.50 = Low, 1.00–1.50 = Lowest

Part 3: Analysis of EF behavioral indicators using the same statistical procedures and interpretation criteria.

Part 4: Second-order Confirmatory Factor Analysis (CFA) to examine construct validity and model fit.

Statistical Techniques

Descriptive Statistics, Mean, Standard deviation, Instrument Quality Testing, Content validity (IOC), Reliability (Cronbach's alpha), Hypothesis Testing and CFA Procedures, Pearson correlation matrix, Bartlett's Test of Sphericity, Kaiser-Meyer-Olkin (KMO) Measure, First-order CFA, Second-order CFA

Model Fit Indices

Chi-square (χ^2), Goodness-of-Fit Index (GFI > 0.90), Adjusted Goodness-of-Fit Index (AGFI > 0.90)

Comparative Fit Index (CFI > 0.95), Relative Chi-square ($\chi^2/df \leq 3$), Standardized Root Mean Square Residual (SRMR < 0.08), Root Mean Square Error of Approximation (RMSEA < 0.06). These indices were used to determine the congruence between the theoretical model and the empirical data.

Research Results

The findings are presented in two major sections: (1) results of the Exploratory Factor Analysis (EFA), and (2) results of the Second-Order Confirmatory Factor Analysis (CFA), conducted to develop and validate the structural components of mathematics instructional management emphasizing Authentic Assessment to promote Executive Functions (EF), and the structural components of Executive Functions among lower secondary students.

Part I: Exploratory Factor Analysis (EFA)

1. Instructional Management Emphasizing Authentic Assessment.

Prior to factor extraction, data suitability was evaluated. The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was .723, exceeding the acceptable threshold of .70. Additionally, Bartlett's Test of Sphericity was highly significant (χ^2 = 3436.777, df = 561, p < .001), confirming that the correlation matrix was not an identity matrix. Together, these results demonstrate sufficient intercorrelation among the variables, indicating that the dataset met the necessary assumptions and was highly appropriate for Exploratory Factor Analysis (EFA).

Table 1 show Factor extraction results and explained variance

The nine components identified	Eigenvalue	% of Variance	Cumulative %
Learning objective formulation promoting EF	5.467	16.081	16.081
Principles of learning activity implementation	4.817	14.169	30.249
Learning activity management	3.791	11.149	41.398
Instructional media promoting EF	3.721	10.944	52.342
Classroom environment promoting EF	3.136	9.225	61.567
Authentic measurement and evaluation	2.557	7.520	69.087
Utilization of assessment results for learning improvement	2.485	7.308	76.395
Post-instructional documentation	2.387	7.020	83.415
Goal setting and strategic adjustment	1.532	4.507	87.922

Based on Kaiser's criterion (eigenvalues > 1), the Exploratory Factor Analysis (EFA) extracted a nine-factor solution. The initial three factors yielded the highest eigenvalues of 5.467, 4.817, and 3.791, respectively. The first factor alone accounted for 16.081% of the variance, while all nine factors collectively explained a substantial 87.922% of the total variance. This high level of cumulative variance indicates that the extracted factors efficiently and comprehensively represent the underlying data structure. Overall, the results confirm that the observed variables clustered into nine distinct, interpretable factors, providing a robust empirical foundation for the subsequent Confirmatory Factor Analysis (CFA).

Table 2 show Factor summary

Component	Factor Loading
Component 1: Formulation of Learning Objectives Promoting Executive Functions *Observed Variables*	
- Formulating learning objectives that encourage students to connect prior knowledge with new knowledge	.931
- Formulating learning objectives that promote the extension of knowledge to new situations	.942
Component 2: Principles of Learning Activity Implementation Promoting Executive Functions *Observed Variables*	
- Implementing learning activities that ensure continuous student participation	.924
- Implementing learning activities that promote reflective thinking before action	.922
- Implementing learning activities that stimulate students to explain their reasoning	.909
- Implementing learning activities that foster responsibility for assigned tasks	.898
Component 3: Learning Activity Management Promoting Executive Functions *Observed Variables*	
- Organizing learning activities that allow students to plan their work independently	.907
- Organizing learning activities that engage students in step-by-step hands-on practice	.895
- Organizing learning activities that encourage students to solve problems using multiple approaches	.928
- Organizing learning activities that provide opportunities for students to exchange ideas	.917
Component 4: Instructional Media Promoting Executive Functions *Observed Variables*	
- Utilizing instructional media appropriate to students' ability levels	.921
- Utilizing instructional media that enhance students' interest and sustained attention	.909
- Utilizing instructional media that encourage students to think, analyze, and make decisions	.867
- Utilizing diverse instructional media that support active learning	.919
Component 5: Classroom Environment Promoting Executive Functions *Observed Variables*	
- Organizing a classroom environment that supports collaborative learning	.924
- Establishing a classroom climate that allows students to express their opinions safely	.910
- Arranging seating or learning spaces that facilitate group work	.912
- Fostering positive teacher–student relationships	.909
Component 6: Measurement and Evaluation Emphasizing Authentic Assessment *Observed Variables*	
- Conducting assessment aligned with authentic assessment principles	.929
- Using observation of students' behaviors as part of the evaluation process	.930
- Assessing students in ways that reflect their thinking processes and work performance	.919
- Providing opportunities for students to participate in self-assessment	.900
Component 7: Utilization of Assessment Results for Reflective Learning Improvement *Observed Variables*	
- Using assessment results to continuously improve students' learning	.937
- Recording post-instructional reflections to refine teaching practices	.930
- Engaging in reflective discussion of learning outcomes with students	.951
- Applying reflective feedback to adjust subsequent learning activities	.904

Component	Factor Loading
Component 8: Post-Instructional Documentation *Observed Variables*	
- Managing instructional materials and resources to ensure adequacy and appropriateness for activities	.939
- Encouraging students to take responsibility for shared instructional materials	.911
- Designing activities that facilitate students' self-assessment	.889
- Encouraging students to monitor their own learning progress	.919
Component 9: Goal Setting and Strategic Adjustment *Observed Variables*	
- Organizing activities that help students set learning goals	.923
- Providing opportunities for students to adjust their own learning strategies	.933
- Offering feedback that supports students' self-regulation development	.935
- Designing learning experiences that encourage students to learn from mistakes	.940

The Exploratory Factor Analysis (EFA) yielded a well-defined nine-factor structure. All observed variables demonstrated strong factor loadings exceeding .80, indicating robust construct validity and confirming that each item contributed significantly to its underlying factor. Specifically, the extracted factors, their loading ranges, and conceptual representations are as follows:

-Formulation of Learning Objectives Promoting Executive Functions (.931–.942): Focuses on knowledge integration and extension.

-Principles of Learning Activity Implementation Promoting Executive Functions (.898–.924): Emphasizes student engagement, reflective thinking, and learner responsibility.

-Learning Activity Management Promoting Executive Functions (.895–.928): Provides opportunities for planning, active engagement, and diverse problem-solving.

-Instructional Media Promoting Executive Functions (.867–.921): Stimulates thinking, analysis, and decision-making.

-Classroom Environment Promoting Executive Functions (.909–.924): Facilitates collaborative learning through a supportive atmosphere and contextual conditions.

-Measurement and Evaluation Emphasizing Authentic Assessment (.900–.930): Reflects cognitive processes and promotes active learner participation.

-Utilization of Assessment Results for Reflective Learning Improvement (.904–.951): Highlights the role of feedback in enhancing the learning process.

-Post-Instructional Documentation (.889–.939): Underscores the importance of continuous monitoring and evaluation of student development.

-Goal Setting and Strategic Adjustment (.923–.940): Targets the development of learners' self-regulation and strategic planning abilities.

Overall, the EFA results confirm that this nine-factor structure effectively represents the multidimensional construct of mathematics instructional management based on authentic assessment to promote executive functions. The derived structure is consistent with the theoretical framework and provides a robust empirical foundation for subsequent validation through Confirmatory Factor Analysis (CFA).

2. Executive Functions

Prior to conducting the Exploratory Factor Analysis (EFA), data suitability was evaluated. The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was .742, exceeding the acceptable threshold of .70. Additionally, Bartlett's Test of Sphericity was highly significant (χ^2 = 2537.045, df = 325, p < .001), confirming that the correlation matrix was not an identity matrix. Together, these results indicate sufficient intercorrelation among the variables, demonstrating that the dataset met the necessary assumptions for factor extraction.

Table 3 show Factor extraction results and explained variance

The seven components identified	Eigenvalue	% of Variance	Cumulative %
Inhibitory control	5.167	19.873	19.873
Working memory	3.966	15.253	35.126
Planning and self-management	3.524	13.553	48.680
Cognitive flexibility	2.984	11.476	60.156
Attention and focus	2.812	10.816	70.972
Self-regulation and self-monitoring	2.153	8.281	79.253
Goal-directed persistence	2.112	8.122	87.375

Based on Kaiser's criterion (eigenvalues > 1), the Exploratory Factor Analysis (EFA) extracted a seven-factor model of executive functions (EF). The initial three factors—Inhibitory Control, Working Memory, and Planning and Self-Management—yielded the highest eigenvalues of 5.167, 3.966, and 3.524, respectively. The first factor alone explained 19.873% of the variance, while all seven factors collectively accounted for a substantial 87.375% of the total variance, demonstrating a highly efficient and comprehensive representation of the observed variables.

The extracted components comprise inhibitory control, working memory, planning and self-management, cognitive flexibility, sustained attention, self-regulation and self-assessment, and goal-directed behavior. These seven components strongly align with the theoretical framework of executive functions, which encompasses self-control, information management, cognitive adaptability, and the regulation of behavior toward goal attainment. Overall, the EFA results confirm a clearly defined seven-component structure, providing a robust empirical foundation for subsequent Confirmatory Factor Analysis (CFA).

Table 4 show Factor summary

Component	Factor Loading
Component 1: Inhibitory Control *Observed Variables*	
- Students are able to regulate their emotions when encountering unexpected situations	.933
- Students are able to wait and comply with classroom rules	.931
- Students are able to stop inappropriate behaviors when reminded by the teacher	.914
- Students do not disturb peers during learning activities	.929
Component 2: Working Memory *Observed Variables*	
- Students are able to remember and accurately follow task procedures	.899
- Students are able to apply prior knowledge to solve new problems	.949
- Students are able to follow multi-step instructions	.938
- Students are able to complete assigned tasks without forgetting essential details	.940
Component 3: Planning and Self-Management *Observed Variables*	
- Students are able to plan their work before beginning tasks	.898
- Students are able to appropriately sequence task procedures	.907
- Students are able to manage their time effectively during activities	.937
- Students are able to prepare necessary learning materials independently	.885
Component 4: Cognitive Flexibility *Observed Variables*	
- Students are able to adjust their thinking or working strategies when encountering obstacles	.892
- Students accept opinions that differ from their own	.917
- Students are able to solve problems using more than one method	.902
- Students are able to learn from mistakes and apply improvements to their work	.916
Component 5: Attention and Focus *Observed Variables*	
- Students are able to maintain sustained attention during learning activities	.931
- Students are not easily distracted during lessons	.956
- Students are able to refocus on tasks after being interrupted	.946
Component 6: Self-Regulation and Self-Assessment *Observed Variables*	
- Students are able to check the accuracy of their work before submission	.903
- Students are able to evaluate their own work according to established criteria	.865
- Students are able to reflect on what they have learned after completing an activity	.914
- Students are able to identify their strengths and areas for improvement	.899
Component 7: Goal-Directed Persistence *Observed Variables*	
- Students do not give up when tasks are difficult or complex	.941
- Students strive to complete tasks in accordance with the goals they have set	.937
- Students are able to complete tasks even when they require extended time	.942

The Exploratory Factor Analysis (EFA) yielded a clearly defined seven-factor structure for executive functions (EF). All observed variables exhibited exceptionally strong factor loadings ranging from .865 to .956, well above the acceptable threshold, indicating robust construct validity and confirming that each item contributed significantly to its respective factor. Specifically, the extracted factors, their loading ranges, and conceptual representations are as follows:

-Inhibitory Control (.914–.933): Reflects learners' ability to regulate their behavior and emotions appropriately in response to situational demands.

-Working Memory (.899–.949): Indicates the ability to retain and process information for problem-solving purposes.

-Planning and Self-Management (.885–.937): Represents the capacity to plan, sequence tasks, and manage work effectively.

-Cognitive Flexibility (.892–.917): Indicates the ability to adapt thinking and employ diverse problem-solving strategies.

-Attention and Focus (.931–.956): Reflects the ability to control attention and maintain focus during task performance.

-Self-Regulation and Self-Assessment (.865–.914): Indicates learners' ability to monitor and reflect on their own learning processes.

-Goal-Directed Persistence (.937–.942): Represents persistence and effort in achieving set goals.

Overall, these seven components provide a comprehensive representation of the EF constructs, aligning seamlessly with the theoretical framework of self-control, information management, cognitive adaptability, and behavioral regulation toward goal attainment. Consequently, the EFA results confirm the instrument's robust structural composition, establishing a solid empirical foundation for subsequent validation via Confirmatory Factor Analysis (CFA).

Part II: Second-Order Confirmatory Factor Analysis (CFA)

1. CFA of the Instructional Management Model

The Confirmatory Factor Analysis (CFA) results demonstrated robust construct validity for the proposed factor model. All indicators exhibited high factor loadings ranging from .786 to .901, well above the acceptable .50 threshold, indicating strong associations with their corresponding latent constructs. Furthermore, the t-values exceeded 1.96 ($p < .05$), confirming that these factor loadings were statistically significant and that the indicators meaningfully contributed to the latent variables.

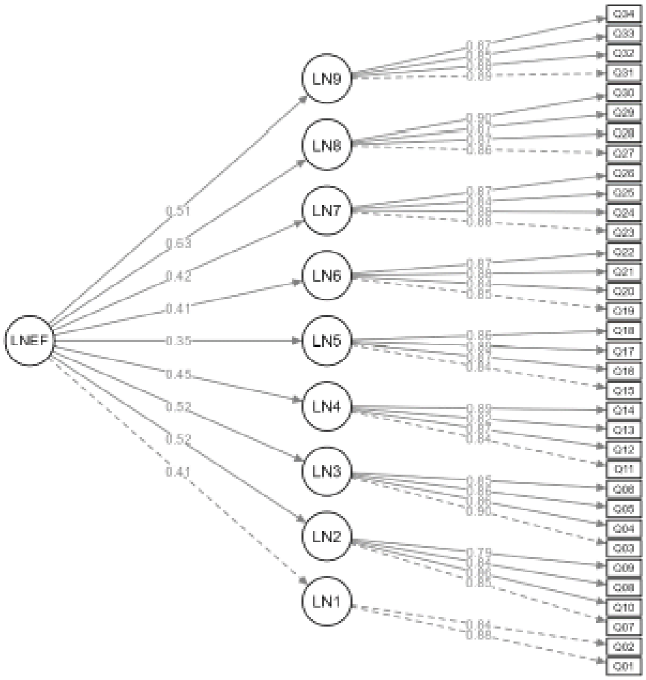
Additionally, the coefficients of determination (R^2) ranged from .618 to .814, demonstrating that the indicators explained a substantial proportion of variance in their respective constructs, with values exceeding .70 reflecting particularly strong explanatory power. Overall, the combination of high factor loadings, statistical significance, and strong R^2 values confirms that the developed mathematics instructional model—based on authentic assessment to promote executive functions—aligns well with the empirical data and effectively explains the underlying latent structure.

Model fit indices were as follows:

Table 5 Model Fit Statistics of the Second-Order Confirmatory Factor Structure of Mathematics Instruction Emphasizing Authentic Assessment to Promote Executive Function

Statistical Values	Analysis Results
χ^2	1223.00 ($p<.001$)
df	519
χ^2/df	2.35
RMSEA	0.057
CFI	0.936
TLI	0.931
SRMR	0.070

The goodness-of-fit for the second-order confirmatory factor model was evaluated. Although the chi-square statistic was significant (χ^2 = 1223.00, df = 519, $p < .001$)—a common occurrence sensitive to large sample sizes—alternative fit indices were examined to provide a more comprehensive assessment. The relative chi-square (χ^2/df) was 2.35, falling well within the acceptable range (≤ 3). Furthermore, the model demonstrated robust fit across both absolute and incremental indices: The Root Mean Square Error of Approximation (RMSEA) was 0.057 (≤ .06) and the Standardized Root Mean Square Residual (SRMR) was 0.070 (≤ .08). The Comparative Fit Index (CFI = 0.936) and Tucker–Lewis Index (TLI = 0.931) also comfortably exceeded the acceptable .90 threshold, despite being marginally below the more stringent .95 criterion. Collectively, these indices confirm that the second-order model of mathematics instructional management—based on authentic assessment to promote executive functions among lower secondary students—demonstrates a good fit with the empirical data.



chi-square = 1223.00; df = 519; relative chi-square = 2.35; RMSEA= 0.057; CFI = 0.936; TLI = 0.931; SRMR = 0.070

Figure 2. Second-order confirmatory factor analysis (CFA) model of the authentic assessment-based mathematics learning system.

(Note: LNEF= Mathematics Instructional Management Based on Authentic Assessment to Promote Executive Functions; LN1= Learning objective formulation promoting EF; LN2= Principles of learning activity implementation; LN3= Learning activity management; LN4= Instructional media promoting EF; LN5= Classroom environment promoting EF; LN6= Authentic measurement and evaluation; LN7=Utilization of assessment results for learning improvement; LN8= Post-instructional documentation; LN9= Goal setting and strategic adjustment.)

2. CFA of the Executive Functions Model

The Confirmatory Factor Analysis (CFA) results confirmed the construct validity of the seven-factor measurement model for executive functions (EF). All indicators demonstrated strong associations with their respective latent constructs, yielding high factor loadings ranging from .791 to .907 (well above the .50 threshold).

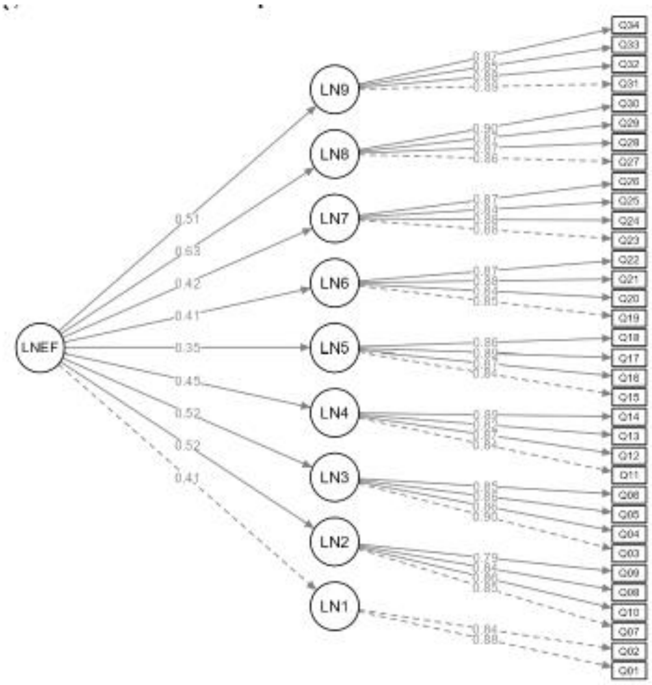
These loadings were highly significant, with t-values between 18.600 and 23.100 $p < .05$), confirming their meaningful contribution to the model. Furthermore, the coefficients of determination (R^2) ranged from .626 to .823, indicating moderate to strong explanatory power across the indicators. At the factor level, the seven EF components—inhibitory control, working memory, planning and self-management, cognitive flexibility, sustained attention, self-regulation and self-assessment, and goal-directed behavior—were robustly defined by these significant indicators. Consequently, the EF measurement model exhibits excellent construct validity, making it a reliable and highly appropriate framework for future research and the development of educational measurement instruments.

Model fit indices were as follows

Table 5 Model Fit Statistics of the Second-Order Confirmatory Factor Analysis of Executive Functions among Lower Secondary School Students

Statistical Values	Analysis Results
χ^2	1223.00 ($p<.001$)
df	519
χ^2/df	2.35
RMSEA	0.057
CFI	0.936
TLI	0.931
SRMR	0.070

The goodness-of-fit for the confirmatory factor model of executive functions was comprehensively evaluated. Although the chi-square statistic was significant (χ^2 = 738.00, df = 278, $p < .001$) due to its known sensitivity to sample size, the relative chi-square (χ^2/df) was 2.65, falling well within the acceptable threshold (≤ 3). Further examination of alternative fit indices demonstrated an acceptable to good overall model fit. Specifically, the Root Mean Square Error of Approximation (RMSEA) was 0.063, and the Standardized Root Mean Square Residual (SRMR) was 0.053, both satisfying their respective acceptable criteria (< .08). Additionally, the Comparative Fit Index (CFI = 0.942) and Tucker–Lewis Index (TLI = 0.932) comfortably exceeded the acceptable .90 threshold, despite being marginally below the stricter .95 cutoff. Collectively, these indices confirm that the measurement model appropriately represents the latent structure of executive functions among lower secondary students and aligns well with the empirical data.



chi-square = 1223.00; df = 519; relative chi-square = 2.35; RMSEA= 0.057; CFI = 0.936; TLI = 0.931; SRMR = 0.070

Figure 3. Second-order confirmatory factor analysis (CFA) model of the Executive Functions among Lower Secondary School Students

(Note: EFLS= Executive Functions among Lower Secondary School Students; EF1= Inhibitory control; EF2= Working memory; EF3= Planning and self-management; EF4= Cognitive flexibility; EF5= Attention and focus; EF6= Self-regulation and self-monitoring; EF7= Goal-directed persistence.)

Conclusion

The findings confirm that both the instructional management model emphasizing Authentic Assessment and the Executive Functions model possess sound construct validity and structural integrity. The models are empirically supported and suitable for application in promoting Executive Functions among lower secondary students.

Summary of the Study

This study investigated mathematics instructional management emphasizing Authentic Assessment to promote Executive Functions among lower secondary students in Chiang Rai Province. The findings are summarized as follows:

1. Exploratory Factor Analysis (EFA) of Mathematics Instructional Management

The results of the exploratory factor analysis indicated that the Kaiser–Meyer–Olkin (KMO) measure was 0.723 and Bartlett's Test of Sphericity was statistically significant ($p < .001$), demonstrating that the data were suitable for factor analysis. Nine components were extracted, accounting for 87.922% of the total variance. The nine components consisted of: (1) formulation of learning objectives, (2) principles of activity implementation, (3) learning activity management, (4) instructional media, (5) classroom environment, (6) authentic measurement and evaluation, (7) utilization of assessment feedback, (8) post-instructional documentation, and (9) goal setting and strategic adjustment. Factor loadings ranged from 0.867 to 0.951, exceeding the acceptable threshold of 0.40 and were statistically significant at the .01 level, indicating a clear and robust factor structure.

2. Second-Order Confirmatory Factor Analysis (CFA) of the Instructional Management Model

The second-order CFA results showed that the chi-square statistic (χ^2) was 1223.00 ($p < .001$), indicating statistical significance. However, given the sensitivity of the chi-square statistic to large sample sizes and model complexity, additional fit indices were considered. The relative chi-square (χ^2/df) was 2.35, the Comparative Fit Index (CFI) was 0.936, the Tucker–Lewis Index (TLI) was 0.931, the Root Mean Square Error of Approximation (RMSEA) was 0.057, and the Standardized Root Mean Square Residual (SRMR) was 0.070. All indices met acceptable evaluation criteria, indicating that the second-order confirmatory factor model of mathematics instructional management emphasizing Authentic Assessment demonstrated good fit with the empirical data.

3. Exploratory Factor Analysis (EFA) of Students' Executive Functions

The analysis of students' Executive Functions revealed a KMO value of 0.742 and a statistically significant Bartlett's Test ($p < .001$), confirming the suitability of the data for factor analysis. Seven components were extracted, explaining 87.375% of the total variance. These components included: (1) inhibitory control, (2) working memory, (3) planning and self-management, (4) cognitive flexibility, (5) attention and focus, (6) self-regulation and self-assessment, and (7) goal-directed persistence. Factor loadings ranged from 0.865 to 0.956, all exceeding 0.40 and statistically significant at the .01 level, indicating a well-defined and theoretically coherent structure.

4. Second-Order Confirmatory Factor Analysis (CFA) of Executive Functions

The second-order CFA of students' Executive Functions yielded a chi-square statistic (χ^2) of 738.00 ($p < .001$). Recognizing the sensitivity of chi-square to large sample sizes and complex models, alternative fit indices were examined. The relative chi-square (χ^2/df) was 2.65, the Comparative Fit Index (CFI) was 0.942, the Tucker–Lewis Index (TLI) was 0.932, the Root Mean Square Error of Approximation (RMSEA) was 0.053, and the Standardized Root Mean Square Residual (SRMR) was 0.070. These values satisfied acceptable model-fit criteria, demonstrating that the second-order confirmatory factor model of Executive Functions among lower secondary students exhibited good congruence with empirical data.

Discussions

The findings from the development of a mathematics instructional model emphasizing authentic assessment to promote executive functions (EF) among lower secondary students are synthesized and discussed in relation to the conceptual framework and relevant literature below.

1. Mathematics Instructional Practices and the Structure of Executive Functions

The Exploratory Factor Analysis (EFA) revealed a nine-component structure for mathematics instructional management based on authentic assessment, explaining 87.922% of the cumulative variance. This underscores that such practices operate as an "integrated system," seamlessly encompassing instructional design, activity implementation, assessment, and reflection. Theoretically, this affirms that authentic assessment transcends end-of-instruction evaluation, functioning instead as an embedded "learning mechanism." This aligns with Wiggins (1998) on context-aligned assessment and Black and William (1998) on the critical feedback role of formative assessment. Furthermore, integrating pre-, during-, and post-instructional phases reflects the "assessment as learning" paradigm, fostering learners' active self-regulation.

Regarding executive functions, the EFA identified a seven-component structure explaining 87.375% of the variance. This both aligns with and extends Diamond's

(2013) core EF framework, which comprises working memory, inhibitory control, and cognitive flexibility. The expansion into seven components within the context of mathematics suggests that complex, authentic assessment tasks demand a more integrated and sophisticated application of executive processes. This corroborates findings by Cragg et al. (2017) and Bull and Lee (2014), who identified EF as a critical mechanism underlying success in multi-step mathematical problem-solving.

2. Quality of the Instructional and Measurement Models

The second-order Confirmatory Factor Analysis (CFA) confirmed a robust empirical fit for both the instructional and EF measurement models. Although the chi-square statistic was significant ($p < .001$)—a common artifact of large sample sizes (Hair et al., 2010; Kline, 2016)—all relative and absolute fit indices (e.g., χ^2/df, CFI, TLI, RMSEA, and SRMR) met acceptable thresholds. These results provide strong evidence of the developed model's construct validity.

From an interdisciplinary perspective, this study demonstrates that a mathematics instructional model grounded in authentic assessment systematically functions as a "trigger" for EF development. This occurs through learning environments that inherently demand higher-order cognitive processing. Specifically:

-Rubrics require learners to process and retain multidimensional criteria within their working memory to evaluate their performance against established standards.

-Feedback activates cognitive flexibility, prompting learners to revise strategies when encountering errors or new information.

-Self-assessment directly promotes self-monitoring by necessitating that learners reflect upon, evaluate, and regulate their own learning processes.

These empirical mechanisms align with Clements et al. (2016), who emphasized that contextually grounded activities and continuous reflection are vital for adolescent EF development. Consequently, this study not only confirms the statistical adequacy of the proposed model but also advances theoretical understanding. It provides concrete evidence that authentic assessment operates as a highly effective, active mechanism for cultivating executive functions alongside mathematical competencies in lower secondary students.

Recommendations

Recommendations for Practical Implementation

1. Implementation of the Model in Classroom Practice

Given that the developed instructional model comprises nine essential components, educational institutions and lower secondary mathematics teachers—particularly within the context of Chiang Rai Province and similar settings—should adopt these nine components as a conceptual framework for designing lesson plans. Special emphasis should be placed on the utilization of assessment feedback and goal setting with strategic adjustment, as these processes are central to Authentic Assessment. They play a critical role in stimulating students' self-regulation and self-evaluation, which constitute core dimensions of Executive Functions.

2. Design of Mathematics Assessment and Evaluation

Teachers should reduce reliance on multiple-choice assessments that primarily measure rote memorization and instead design authentic performance tasks or mathematics projects connected to real-life contexts. Scoring rubrics should be constructed to assess two parallel dimensions: (1) the accuracy and rigor of mathematical processes, and (2) behavioral indicators of the seven Executive Function components. For example, cognitive flexibility may be evaluated when students employ novel or alternative strategies to solve complex mathematical problems

Recommendations for Future Research

1. Experimental Research to Examine Effectiveness

As the present study focused on model development and validation of construct validity using advanced statistical techniques (CFA), subsequent research should implement the developed mathematics instructional model emphasizing Authentic Assessment in actual classroom settings. A quasi-experimental research design should be employed to compare students' Executive Function development before and after the intervention. Such an approach would provide stronger empirical evidence regarding the model's effectiveness.

2. Investigation of Measurement Invariance

Future studies should examine the measurement invariance of both the Executive Functions model and the instructional management model across diverse contextual groups. For instance, comparisons may be conducted between students in large and small schools, or between groups with differing levels of mathematics achievement. This would strengthen the generalizability and robustness of the instruments for broader application across varied educational contexts.

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