USING DYNAMIC SOFTWARE FOR DEVELOPING THAI STUDENTS' ANALYTICAL THINKING SKILLS IN MATHEMATICS

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ABSTRACT

The purposes of this study were (1) to develop student mathematics analytical thinking skills, targeting a benchmark of 70 percent in scores, and (2) to enhance students' mathematics achievement through the 5 E's instructional model and dynamic mathematics software, with the goal of surpassing 70 percent in both scores and classroom performance. A total of 29 students who participated in this study were from a school in Nakhonphanom Province, Thailand during the 2021-2022 academic year. The data collection included the collection of lesson plans, mathematics assessment, and behavioural assessment of analytical thinking skills. The statistics used in the data analysis are mean, standard deviation, percentage, and comparison with quality criteria. The results indicated that the proposed model could improve students' analytical thinking skills across three components: component analysis, relational analysis, and principle analysis, with average scores of 80.25%, 75.75%, and 54.25% respectively. The total mean score for analytical thinking was 70.25%. Additionally, students' mathematics achievement was 75.86%, meeting the established criteria.

Keywords: DMS, 5 E's instructional model, Analytical thinking skills, Mathematics achievement

1. Introduction

Analytical thinking is one of the important skills of the 21st century (Ichsan et al., 2021) it is necessary to develop the analytical thinking skills of a person who will just start their profession (Ratnaningsih, 2013). It is a set of soft skills that help students recognise, collect, and process data related to a problem that needs to be solved efficiently. Analytical thinking affects students' success in many areas (Sebetci & Aksu, 2014) for example, facilitating problem-solving processes in school and daily life (Mayarni & Nopiyanti, 2021) and creative thinking skills (Lestari et al.,2018). Therefore, analytical thinking skills are one of the skills that secondary school students should acquire in the Thai basic education curriculum in 2008, revised in 2017 (Ministry of Education, 2017).

A number of researchers in mathematics education claim that the 5 E's instructional model enhances students' analytical thinking skills (Uttaman & Art, 2012; Ainthason & Chaipichit, 2021). The learning cycle of 5 E's instructional model comprises five phases: engagement, exploration, explanation, elaboration, and evaluation (Bybee, et al., 2006). It begins with engagement during which teachers could show a problematic situation, define a problem, or develop questions under investigation together with the students and students' learning by doing and analysing information for answers (Schallert et al., 2020). Using the 5 E's instructional model, key characteristics in the classroom are (i) the participation of the learner in the science-focused question, (ii) the precedence of evidence in response to the question, and (iii) formulation of explanation from the evidence; (iv) explanations related to scientific knowledge; and (v) communication and justification of explanations (National Research Council, 2000).

Nowadays, digital tools are also used for developing students' analytical thinking and understanding of mathematics which has greatly influenced the education system. They can help teachers and students in teaching and learning mathematics. One of the digital tools for mathematics instruction is Dynamic Mathematical Software (DMS) (Zengin & Tatar, 2017). DMS is a tool that can be used for problem-solving and conceptual understanding. The DMS can be used to construct mathematical objects such as geometric figures, algebraic expressions, and graphs (Sedig & Sumner, 2006). DMS can be used for classroom management and interaction both online and on-site teaching and learning in order to develop students' mathematics concepts and analytical thinking skills (Mukhtar et al., 2021). However, the Program for International Student Assessment 2018 (PISA) suggests that Thai students possess low analytical thinking skills in mathematics as they score below the average score of the OECD countries. Results showed that Thai students can interpret, and perceive without simple commands, but are unable to find a suitable way to solve complex problems associated with the model (The Institute for the Promotion of Teaching Science and Technology, 2021). The Ministry of Education (MOE) reported that the students' average scores on the National Education Test (O-NET) of students at a lower secondary level at a school the year 2017-2020 of Chumchon Bankampok Thadokkeaw school are below the average national score of Thailand. From analysing the test items of O-NET, students should be able to apply their analytical thinking skills to solve real-world problems. From observing student behaviour in the mathematics classroom at Chumchon Bankampok Thadokkeaw school, it was found that students lacked analytical thinking skills. Therefore, teachers should design activities and teaching strategies to develop students' analytical thinking skills according to Table 1.

This research addresses the development of students' analytical thinking skills, which can be categorised into three components as follows: 1) component analysis, 2) relational analysis, and 3) principle analysis (Munkham, 2005). Students can apply their knowledge in daily life. The tools were tried out with students, and data were collected and analysed for development and feedback. This research provides a guideline for developing students' analytical thinking skills and mathematics achievement in mathematics instruction by using DMS and 5 E's instructional model. Implementing DMS in the classroom to foster mathematics learning students can be done via smartphone which facilitates learning for students. It also develops students' thinking skills through real practice in simulated situations.

2. Literature review

2.1 Conceptualising: Student analytical thinking skills in mathematics

Analytical thinking skills are one of those skills within the cognitive abilities of 21st Century skills (Mayarn & Nopiyanti, 2021). Analytical thinking is an important foundation for learning and living, as it consists of important skills: classification, grouping, error analysis, application, and prediction (Marzano, 2001). These analytical skills are essential for the development of the mathematics learning process enabling students to effectively solve mathematical problems (Belecina & Ocampo, 2018). This involves considering various factors with logical reasoning and offering innovations. It is important to understand the components of the situation, and be able to scrutinise and break down facts (Qolfathiriyus et al., 2019). Therefore, three types of analytical thinking abilities must be operationally defined: analysis of elements, analysis of relationships, and analysis of organisational principles (Art-In & Tang, 2017).

2.2 Dynamic software for promoting analytical thinking skills

Mathematical software is Computer technology in mathematics education is classified as Computer Algebra Systems (CAS) and Dynamic Geometry Software (DGS) (Hohenwarter & Fuchs, 2004) for mathematics teaching and learning (Kilicman et al., 2010). Dynamic Mathematics Software (DMS) has received a lot of attention because of its robust structure that combines DGS and CAS functions (Hohenwarter et al., 2009) such as GeoGebra, Geometer's Sketchpad, Desmos, Mathegon, etc. DMS can connect graphics, algebra, and table representations, as well as provide a dynamic learning environment and ease of use (Birgin et al., 2021). DMS is important for conceptualising and utilising dynamic mathematics and is frequently used as a learning and teaching tool at all levels of education. Learning strategies indicate the strategies adopted by the teacher when using DMS in mathematics education. Different learning strategies could be employed, for example, 5E inquiry Model learning is a student-centred approach in which students are guided to explore issues, find solutions, and organise their knowledge (Maaß & Artigue, 2013). Teachers can build activity/task-based learning to implement students' learning (Yohannes & Chen, 2021). DMS is an auxiliary tool to help students understand the mathematical operation process (Lin et al., 2020). DMS allows students to develop critical thinking skills, creative thinking skills, analytical thinking skills, communication skills, self-confidence, and innovative solutions to mathematical problems, enhancing problem-solving skills such as inquiry, exploration, creation, simulations, and reflection and positively influencing the development of students' STEM competencies (Ruzlan & Kim, 2018; Kramarenko et al., 2020; Wijaya et al., 2021; Yohannes & Chen, 2021). In addition, it allows students to develop decision-making, mathematics achievement, mathematics conceptual, motivation to learn, organise information, and support the investigations, exploration, reflection to understanding and reasoning in mathematics. Studies of different phenomena and help in different topics are discussed (Ziatdinov & Valles, 2022; Guerrero-Ortiz & Camacho-Machín, 2022). Here are some advantages of the 5 E's instructional model, namely: 1) encourages students to recall their previous knowledge, 2) helps develop students' scientific attitudes and their thinking abilities, 3) directs the students' focus on one problem to support conceptual understanding, 4) develops the students' potentials, 5) trains students to express a concept verbally, and 6) engages students in exploring, expanding and evaluating the concepts.

2.3 Earlier results in studying the enhancement of mathematical skills through mathematics software

Mathematical skills are conceptualised as a separate area that includes verbal components (number knowledge, counting, computation, and reasoning) and nonverbal components (mathematics notation, reasoning in time and space, and computation) (Daniel,2004). Analytical thinking involves using mathematics skills to understand ideas, discover relationships among the ideas, draw or support conditions about the ideas and their relationships and solve problems involving the ideas (Sam & Yong, 2006; Khusna, 2020; Huincahue et al., 2021). However, developing mathematical skills requires appropriate teaching tools and methods. Mathematical software is a software program designed for both teaching and learning, whose first and foremost goal is to make mathematical concepts clearer and easier for students to grasp. It is designed to enable proactive teaching and can, thus, be used to focus on problem-solving and assist with the development of mathematical experiments and concept introduction both face-to-face and in remote class settings (Ziatdinov & Valles, 2022). Students can practise problem-solving on their own through surveys, examinations, and problem simulations. Mathematical software can be used to visualise mathematical concepts as well as to create instructional materials for students. Mathematical software is important to understanding conceptualises and utilising dynamic mathematics and is frequently used as a learning and teaching tool. It supports the investigations, exploration, simulations, reflection to understanding, and reasoning in mathematics and develops mathematical thinking for students, and helps increase motivation and improve mathematical skills, self-awareness, and student learning involvement. However, the learning method is an integral part of being used in conjunction with Mathematical software to enable students to achieve the teacher's goals. 5 E's instructional model learning is an instructional model, where learning through inquiry follows five phases. The five phases are called (i) engagement, (ii) exploration, (iii) explanation, (iv) elaboration, and (v) evaluation (Bybee et al., 2006). Students are guided to explore issues, find solutions, and organise their knowledge through inquiry (Maaß & Artigue, 2013). Teachers can use 5 E's instructional model through Mathematical software that has the potential to foster active and student - centered learning by allowing for mathematical experiments, interactive explorations, as well as discovery learning. to enable students to learn and develop mathematical skills and processes and students develop their self-study and self-discovery abilities (Nguyen & Bui,2021). It also provides a dynamic learning environment for the exploration of the relationship between the concepts (Zengin Y., 2019). In addition to this, it is found that DMS helps students to develop their skills such as reasoning, analytical thinking, argumentation, and communication (Albaladejo et al., 2015). Exposing that using the DMS tongue 5 E's instructional model is able to enhance the learning environment and analytical thinking skills and learning achievement (Ramlee et al., 2019; Ranjan & Padmanabhan, 2019).

3. Research objectives and methods

3.1 The objectives of this research are:

1. To develop analytical thinking skills of students in grade 7 through the 5E inquiry model and DMS, aiming to meet the criteria of 70 percent of the score.

2. To develop mathematics achievement of students in grade 7 through the 5E inquiry model and DMS, with the goal of surpassing 70 percent in both scores and classroom performance.

The sample of this study were 29 students aged 13-14 years old who were first-year students at a lower secondary level at Chumchon Bankampok Thadokkeaw School in the Province of Nakhonphanom (Thailand) of the 2021-2022 academic year, which all students can learn by smartphone.

3.2 Implementation and Process

This research employed classroom action research by Kemmis, McTaggart & Nixon, (2014) together with a qualitative approach; this paper used a teacher-as-researcher methodology. The concept of teacher-as-researcher encourages teachers to be collaborators in revising their teaching and has its roots in action research. Action research is a deliberate, solution-oriented investigation that is owned and conducted by teachers. It is characterised by cycles of problem identification, systematic data collection, reflection, analysis, evidence-based action taken, and problem redefinition. The terms "action" and "research" highlight the essential features of this method: trying out ideas in practice as a means of increasing knowledge about and for teaching, and learning.

This classroom action research encompasses two cycles. In the first cycle, the researcher established the Professional Learning Community (PLC), which is a collaboration of teachers with a common goal of improving student learning (Panich, 2012, Vehachart, 2018). PLC is important in mathematics education as a key goal of teacher development and support students' understanding, analytical thinking skills, and processes (Brodie, 2020). Additionally, PLCs contribute to the improvement and development of lesson plans, mathematics assessments, and behavioural assessment of analytical thinking skills. In the second cycle, the researcher applied the designed activities to the students for 12 hours, in which every hour the teacher observed the behaviour and graded the students' analytical thinking skills through the assigned tasks. When the students have finished studying, they will take a test to measure their achievement. It is characterised by cycles of plan, action, observation, and reflection.

In this study, the researcher studied DMS as tools to help develop students' mathematics skills. GeoGebra, the researchers designed an activity for students to explore problems and simulations for solving them so that they could identify sub-elements of problems in solving problems. Desmos Activity, the researchers selected situational activities to enable students to make connections between simulations by graphing the situation and describing the resulting graph. Students then described the relationship of the elements of a problem and identified the principles that were relevant to the situation to solve the problem. With GeoGebra Classroom and Desmos Activity, teachers can observe students perform real-time activities, enabling teachers to assist students in groups or individually, as shown in Table 1.

Table 1: Lesson plan

Lesson plan	Topic	Analytical thinking skills	Period
1	Meaning of rank pairs	Component analysis Relational analysis	1
2	Graph of ordered pairs on the orthogonal coordinate system	Component analysis Relational analysis	2
3	Using pairs to show a correlation	Relational analysis	1
4	Graph of a linear equation in two variables	Relational analysis Principle analysis	3
5	Solving equations by graphing	Relational analysis Principle analysis	2
6	Reading and interpreting graphs	Relational analysis Principle anal	3
Total			12

The researcher designed a GeoGebra activity for students to create an ordered pair of relationships, then plot and graph them accordingly. Then students were asked to answer the questions, explain the relationship of the elements and solve the problem, as illustrated.

As an example of Desmos Activity, the researcher selected an activity for students to graph in order to solve real-life problems in which students can visualise the relationship graph describe the correlation among the elements of the problem and identify the principles corresponding to the situation.

3.3 Data analysis

In this study, the class analysis revealed that students had analytical thinking challenges, evident in their response behaviours. The 29 students in grade 7 at Chumchon Bankampok Thadokkeaw School were unable to distinguish the problem sub-elements and were unable to explain the relationship of the problem components, and unable to identify principles, rules, or theories that correspond to simulations to solve problems. After that, the researcher designed and selected the activities with DMS through the PLCs process and tried them out with students and debugged them, and then applied to the sample group. In the learning activities, students were divided into groups of 4-5 students, and then the 5 E's instructional model exam process was implemented as follows: At the beginning of the 5 E's instructional model, the teacher started with an interesting warm-up activity. In the second step, this is a survey or answer-finding process. At this stage, students explored activities designed by teachers using DMS with smartphones. The next stage involved explanations provided by the teacher and served as a guide to the fourth stage, which involved an in-depth explanation. The final stage was the evaluation phase in which both teachers and students evaluated the student's assessment. After that, the learning management results were mirrored with a group of PLCs, and any necessary error corrections were implemented.

Research instruments used in this study include 1) The lesson plans for teaching in topic two-variable linear equation for students grade 7 through DMS and 5 E's Instructional Model 6 lesson plans, 12 hours. 2) Mathematics assessments are used to measure the learning abilities of students. This is due to the process of learning and teaching that is a cognitive behaviour, such as remembering, understanding, applying, and analysing (Pradubwate, 2017). It is a four-choice multiple-choice test with 20 items. 3) Behavioural assessment of analytical thinking skills. It is divided into 3 components: component analysis, relational analysis, and principle analysis (Munkham, 2005). It is a three-question subjective exam, scored according to analytic rubrics as shown in Table 2 and the total outcomes of analytical thinking skills in Table 3.

Table 2: The rubrics behavioural assessment of analytical thinking skills: Improved from Munkham (2005)

Analytical thinking skills	Scoring /quality level	Consideration criteria
Component analysis	4 (very good)	Students can completely identify sub-components of situations or mathematics problems.
	3 (good)	Students can identify sub-elements of situations or mathematics problems correctly, but not completely.
	2 (fair)	Students can identify sub-elements of situations or mathematics problems that are mostly inaccurate and incomplete.
	1 (improve)	Students identify sub-elements of situations or mathematics problems incorrectly or indiscriminately.
Relational analysis	4 (very good)	Students can describe the relationships, relevance, connections, or conflicts of sub-elements of situations or mathematics problems accurately, completely, and to the point.
	3 (good)	Students can accurately, completely, and to the point describe the relationships, relevance, connections, or contradictions of the sub-elements of most situations or mathematics problems.
	2 (fair)	Students can accurately and completely describe the relationships, relevance, connections, or conflicts of sub-elements of situations or mathematics problems but may not be relevant.
	1 (improve)	Students incorrectly describe the relationships, relevance, connections, or contradictions of sub-elements of situations or mathematics problems.
Principle analysis	4 (very good)	Students correctly identify principles, rules, and theories that correspond to situations or mathematics problems.
	3 (good)	Students correctly identify principles, rules, and theories that correspond to situations or mathematics problems, but may not be complete.

Analytical thinking skills	Scoring /quality level	Consideration criteria
	2 (fair)	Students identify principles, rules, and theories that correspond to situations or mathematics problems correctly but not completely.
	1 (improve)	Students incorrectly identify principles, rules, and theories that correspond to situations or mathematics problems.

Table 3: The criteria outcomes of analytical thinking skills: Improved from Munkham (2005)

	Scoring /Quality level	Description
Analytical thinking skills	3.51 – 4.00 (very good)	Students possess the ability to thoroughly discern the constituent elements within situations or mathematical problems. They can articulate the associations, significance, interconnections, or discrepancies among these individual elements with precision and completeness. Moreover, students accurately recognise the principles, regulations, and theories that correspond to the given situations or mathematical problems.
	2.51 – 3.00 (good)	Students are capable of correctly identifying sub-elements within situations or mathematical problems, although their identification may not be entirely comprehensive. They can articulate the associations, complete, and succinct descriptions of the relationships, significance, connections, or discrepancies among these sub-elements in most situations or mathematical problems. Additionally, students demonstrate proficiency in recognising the principles, rules, and theories pertinent to situations or math problems, although their recognition may not encompass the entirety of such principles, rules, and theories.
	1.51 – 2.50 (fair)	Students often struggle to identify sub-elements accurately and comprehensively within situations or mathematical problems, resulting in inaccuracies and incompleteness. However, when it comes to describing the relationships, relevance, connections, or conflicts among these sub-elements, they tend to do so with accuracy and completeness, albeit sometimes in a manner that may not be directly relevant. Similarly, students correctly identify principles, rules, and theories that pertain to situations or mathematical problems, but this recognition may not encompass the entirety of these principles, rules, and theories.
	1.00 – 1.50 (improve)	Students often exhibit inaccurate or indiscriminate identification of sub-elements within situations or mathematical problems. Their descriptions of the relationships, relevance, connections, or contradictions among these sub-elements are likewise marked by inaccuracies. Furthermore, when it comes to identifying principles, rules, and theories relevant to the given situations or mathematical problems, students tend to do so incorrectly.

4. Results and Discussion

4.1 Result

The results of this study were as follows:

The results of the analytical thinking skills assessment results of students in grade 7 through DMS and 5 E's instructional model are shown in Table 4.

Table 4: Results of the students' analytical thinking skills (n=29)

Analytical thinking skills	**Score**		**Percentage**
	Mean	**S.D.**	
Component analysis	3.21	0.77	80.25
Relational analysis	3.03	0.98	75.75
Principle analysis	2.17	0.84	54.25
Total	**2.81**	**0.76**	**70.25**

From Table 2 The rubrics behavioural assessment of analytical thinking skills

Table 4 shows the mean score of the students' analytical thinking on learning through DMS and 5 E's instructional model. It was divided into 3 components: component analysis, relational analysis, and principle analysis, with average scores as follows: 80.25 %, 75.75%, and 54.25 % respectively. A total mean score is 70.25 % which is at a good quality level.

Results of the mathematics achievement of students in grade 7 through DMS and 5 E's instructional model are shown in Table 5.

Table 5: Results of the students' mathematics achievement (n=29)

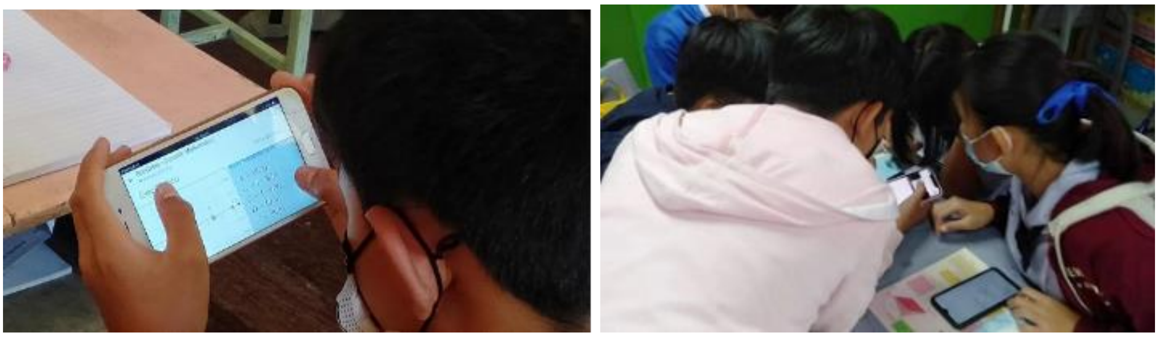
	Students	**Accumulated score**	**Mean**	**S.D.**	**Percentage**
Score less than 70%	7 (24.14%)	79	11.29	1.25	56.45
Score more than 70%	22 (75.86%)	356	16.18	1.22	80.90
Total	**29 (100%)**	**435**	**15.07**	**2.45**	**75.35**

Table 5 shows the mean score of the students' Mathematics achievements. There were 29 students in this study, 22 of whom accounted for 75.86 percent of the students, and 7 of those who failed to pass the criteria, representing 24.14 percent of the total students. The mean score of the students' scores is 15.07 representing 75.35 percent of the score.

4.2 Discussion

Results of analytical thinking skills and mathematics achievement of students learning activities by using DMS and the 5 E's instructional model were scores of analytical thinking skills and mathematics achievement of 2.81 points (70.25 %). It's at a good quality level, and 15.07 points (75.35%) respectively, which are more than the specified criteria. Since the 5 E's instructional model is an approach to systematic learning management, the students can have self-directed learning through active involvement, discussion, and reflection. In addition, DMS is an auxiliary tool to help students understand and have mathematical thinking process skills. Sometimes traditional learning is boring, so an innovative teaching medium is needed to assist in teaching. Integration of technology into the learning environment in the classroom promotes student learning and enhances mathematical knowledge and skills and the students can learn by doing through technology, and have enjoyable learning experiences in the classroom. In addition, students can share knowledge and interact with classmates as shown in Figure 1.

Figure 1: Students can learn by doing through technology and share knowledge and interact in the classroom



The results also suggest that DMS and 5 E's instructional model may serve as a terrific source to stimulate students' interest, leading to increased self-confidence. Since there was a clear improvement, the DMS and 5 E's Instructional model could be used as a tool to help teach and learn for students. When students pass learning activities, their mathematics achievement have increased, and it has transformed the classroom into a more interactive environment, promoting cooperative and collaborative learning. As a result, teachers need to shift their roles to be facilitators, with the duties of designing, guiding, helping, providing feedback, evaluating, and encouraging students to learn both inside and outside the classroom.

4. Conclusion

The incorporation of the Dynamic Mathematics Software (DMS) and the 5 E's instructional model results in the following: 1) the development of analytical thinking skills of students mean score is 70.25 % indicating at a good quality level. Prior to learning, the researcher had surveyed the students' knowledge through interviews. It was found that students lacked experience with the content, leading to challenges in identification, explanation of relationships, and application of mathematical theories. However, post-learning, students demonstrated enhanced abilities in identifying elements, accurately explaining relationships, and partially relating mathematical theories to situations. 2) the development of the mathematics achievement of students' mean score is 15.07 representing 75.35 percent of the score, aligned with the established criteria. The implemented approach has empowered students with self-directed learning through active involvement, discussion, and reflection which support students in exploring, expanding, and evaluating the concepts related to understanding and reasoning in mathematics. Moreover, students have displayed a positive attitude towards mathematics and demonstrated the ability to systematically apply technology to solve problems.

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