Research Article

RESEARCH ON THAI STUDENTS' MISCONCEPTIONS IN MATHEMATICS: A SYSTEMATIC LITERATURE REVIEW

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Abstract

Misconceptions have been determined as one of the most important barriers on students' learning in mathematics. The purpose of this study is to investigate and review prior research studies on Thai students' misconceptions in mathematics. The systematic literature review seeks to understand: (i) the distribution and amount of research, (ii) research foci, and (iii) methods for determining students' misconceptions had been used during 2004 to 2022. Within the scope of the study, 56 articles were selected based on a set of criteria. Findings revealed that most of the studies investigated Grade 7–9 students' misconceptions, while only one study explored on lower elementary levels. Numbers & algebra was the mathematical content strand given the most attention, while there was not much attention given on geometry. Five foci of research on students' misconceptions in mathematics were categorized based on research objectives and results. It showed that most of the studies focused on determining students' misconceptions in specific concepts, not for eliminating the misconceptions. Different diagnostic tests and methods were developed and used, e.g., open-ended tests, and interviews. The methods were employed in various ways to identify and enrich researchers' understanding of students' misconceptions.

Keywords: Misconceptions in Mathematics, Thai Students, Systematic Literature Review

Introduction

Students' misconceptions can be defined as students' misunderstandings and misinterpretations of the concepts, based on incorrect meanings (Ojose, 2015). It is one of the most crucial barriers to students learning mathematics (Durkin & Rittle-Johnson, 2015). If a student has misconceptions existing in previous concepts, it is highly likely that the student will also have these misconceptions when tackling new concepts. Thus, correcting students' misconceptions is considered as a part of teaching and learning. Researchers and educators seek methods to diagnose the misconceptions and develop instructional strategies to eliminate those from a student (Ay, 2017). Furthermore, some studies suggested that the students' errors and misconceptions can be viewed as opportunities to engage students in mathematical discussions in the classroom (NCTM, 2018). Students can reflect on and learn from their errors and misconceptions. These show the importance of investigating and doing research on the students' misconceptions in mathematics.

In Thailand, many researchers also studied students' misconceptions in mathematics. The 2003 review research by Aunganapattarakajohn reported the synthesis of 58 research studies on students' misconceptions from 1978 to 2003 (Aunganapattarakajohn, 2003). The result revealed that Thai students had misconceptions in several mathematical content strands. Students' misconceptions could be found in all the four categories: (i) problem interpretation, (ii) use of theories, laws, definitions, and properties, (iii) calculation, and (iv) checking the solution. Aunganapattarakajohn's study also addressed issues of students' misconceptions in mathematics classrooms and needs of improving the quality of mathematics lessons in Thailand. However, the study did not focus and report on ways or instructional methods to eliminate students' misconception. Additionally, to the best of our knowledge, no review article has been reported on research studies related to Thai students' misconceptions in mathematics after 2003.

Learning from previous studies would help us to improve teaching and learning as well as guide us for further work in this area. The present study provides a review and synthesis of prior research studies on students' misconceptions in mathematics conducted in Thailand during the period from 2004 to 2022. The following three research questions guide the study:

1. What is the distribution and amount of research on Thai students' misconceptions in mathematics published from 2004 to 2022 in terms of grade levels, strands, and contents?
2. What is the distribution of research foci and the extent of coverage on instructional methods for eliminating students' misconceptions in mathematics conducted in Thailand?
3. Which methods were employed to determine students' misconceptions in mathematics conducted in Thailand?

Literature Review

Students' errors and students' misconceptions are different. Students' errors can be expressed in terms of carelessness, overloading working memories, faulty algorithms, and if it has a certain conceptual basis can be called misconceptions (Li & Li, 2008). Regarding constructivism, a student comes to the class with their existing experiences or informal knowledge, and one has individually interpreted those experiences in different views (Confrey, 1990). The interpretation might be inappropriate or incomplete that impedes the student's conception (Ojose, 2015). Misconceptions are the students' conceptions that are in conflict with the accepted meaning or the standard curriculum (Pines, 1985). Knowing students' misconceptions was essential to design an instruction.

Detecting students' misconceptions is not easy since they might be disguised by a "correct" answer (Nesher, 1987). For example, Nesher (1987, p. 35) posted these two questions to determine the misconceptions of the comparison of decimal numbers:

I. Which is the larger of 0.4 and 0.234?

II. Which is the larger of 0.4 and 0.675?

Student A answered in Question I that "0.234 is larger than 0.4", and answered in Question II that "0.675 is larger than 0.4. Student B chose that "0.4 is the larger number" in both questions. Both of them got one answer right. With these two close-ended questions, the conclusion of what students' misconceptions were could not be drawn. Then, individual interviews were utilized to gather the students' explanations on their answers. Student A explained that "...the number with the longer number of digits (after the decimal point) is the larger number (in value)" (Nesher, 1987, p. 35). Student B explained that "Tenths are bigger than thousandths [after the decimal point], therefore the shorter number that has only tenths is the larger one." (Nesher, 1987, pp. 35-36). It showed that the students might provide the right answer for the wrong reasons.

One concept has specific possible misconceptions. This set of misconceptions is not easy to detect. It is important for a diagnostic test designer to be aware of the possible misconceptions of a concept so that discriminating items can be included (Nesher, 1987). For example, to test the same misconceptions (decimal comparison), if a test designer used only one item "Which is the larger of 0.456 and 0.895?" it could not discriminate neither Student A's nor Student B's misconception. Moreover, to find a misconception, several kinds of tests could be utilized, e.g., interview, open-ended test, ordinary multiple-choice test, and multi-tier test. All have strengths and limitations as discussed in Gurel et al. (2015).

Elimination of misconceptions in mathematics is important for teaching and learning. Initially, a cognitive conflict approach was proposed as a method to eliminate the misconceptions (Swedosh & Clark, 1997, Alkhateeb, 2020). According to the misconceptions of decimal comparison, Durkin and Rittle-Johnson (2012) examined the effectiveness of using incorrect examples to help students learn decimal magnitude. They compared two groups of students who learned examples of decimals in the number lines. One group worked with comparing incorrect examples to correct examples. For example, the students were provided two cases:

Case I: Matt said "the line is divided into 10 pieces. I put 0.15 between 1 tenth and 2 tenths because 0.15 is 1 tenth plus some." (Correct example)

Case II: Justin said "0.15 has two numbers after the decimal point, which makes it a medium-sized number. So, I put 0.15 near the middle."

Another group was given two cases of comparing correct examples:

Case I: Matt said "the line is divided into 10 pieces. I put 0.15 between 1 tenth and 2 tenths because 0.15 is 1 tenth plus some." (Correct example)

Case II: Laura said "I know 15 hundredth is small and close to 0. So, I marked 0.15 a little after 0."

This study concluded that contrasting incorrect examples with correct examples led to better performances in both concepts and procedures, and reduced decimal magnitude misconceptions related to the whole number concept.

Later, it was revealed that other approaches could also eliminate misconceptions such as the 5E model for trigonometry (Tuna, 2013), technology-supported learning for fractions (Yilmaz et al., 2018; Alkhateeb, 2020), and Bruner's theory for equation solving (Alamian et al., 2020). However, no elimination method fits all mathematical concepts since they were different in terms of concept constructions, students' prior knowledge, and so on. All literatures agree that when a misconception is found, it is important to help students overcome that and guide them to an appropriate concept construction.

Methods

This study conducted a systematic literature review of studies related to students' mathematical misconceptions in primary and secondary education during the period from 2004 to 2020. The five-step systematic review process was applied in the study as shown in Figure 1. The process was adapted from the guidelines of Newman and Gough (2020).

The three research questions guided the decisions about what types of studies to include in this study. A set of criteria for selection was developed to reduce researcher bias and provide transparency to the process. First, we investigated the studies related to students' mathematical misconceptions in primary and secondary education rather than pre-service and in-service teachers' misconceptions. Second, the selected studies were published in peer reviewed academic journals, theses, or dissertations during the period from 2004 to 2022. Technical reports, project anecdotes, or proceedings were excluded from the review. Third, the studies were written in Thai or English. Lastly, all of them were empirical research.

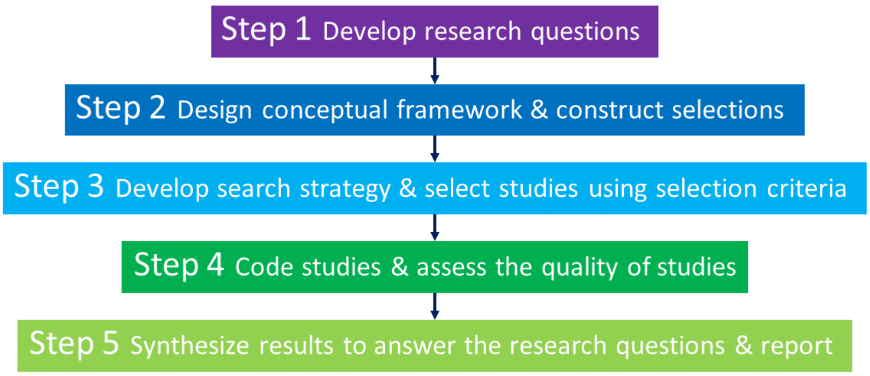

Figure 1 The systematic review process (adapted from Newman and Gough (2020)

Several relevant online databases were used to explore the studies: Thai Journals Online (ThaiJO), Thailand Library Integrated System (ThaiLiS), Digital Research Information Center created by National Research Council of Thailand (NRCT), Google scholar, Thomson Reuters Web of Knowledge, ERIC, EBSCO Host Education Research Complete, ProQuest, Wiley International Science, JSTOR, ACM Digital Library, IEEE Explore, Science Direct, Citeseerx, and Springerlink. Keywords used in the search were in different combinations including "Misconception", "Thailand", "Thai", "Mathematics", "Math", "Primary", "Secondary", "Concept", "Deficiencies", "Understanding", and "Error" in English or "คณิตศาสตร์" "ประถมศึกษา", "มัธยมศึกษา", "มโนทัศน์ที่คลาดเคลื่อน", "มโนคติที่คลาดเคลื่อน", "สังกัป", "ความคิดรวบยอด", "มโนทัศน์ที่ผิดพลาด", "มโนทัศน์ที่ไม่สมบูรณ์", "มโนทัศน์ที่บกพร่อง" in Thai. The inclusion and exclusion criteria were applied to filter out the irrelevant studies. After removing the duplicates and manual filtering by three researchers, a total of 60 studies were obtained from all retrieved sources. To ensure the validity and reliability of the filtering process, peer debriefing was employed (Creswell & Creswell, 2018). If there were inconsistencies and disagreements during the filtering process, three researchers discussed to reach a conclusion.

After relevant studies were selected, the researchers systematically identified and recorded the information from the studies that will be used to answer the research questions. Open coding (Cresswell, 2013) was utilized to gather information including authors, year of publications, objectives, mathematical concepts, and content strands, participants' grade levels, methodology, data collection methods, and data analysis methods. In this step, the researchers also assessed the quality of the selected studies by considering three elements (i) the appropriateness of the study design in the context of the present study research questions, (ii) the quality of the execution of the study methods, and (iii) the study's relevance to the present study research questions (Gough, 2007). Four articles were excluded from the analysis because of their lack of relevance to the review questions. Finally, 56 studies were included in the analysis and synthesis step (see Appendix). We searched for patterns in data, checked the quality of the synthesis, and integrated data to answer the review questions (Thomas et al., 2012). Content analysis was applied to the information extracted on measures used within studies to compile the range of measures used across all studies, and descriptions generated for each category of measure. Three researchers cross-checked the codes and reached inter-coder agreement to enhance reliability of data analysis (Creswell & Creswell, 2018). Descriptive statistics such as frequency and percentage were also applied.

Results and Discussion

Distribution and amount of research during 2004 to 2020

1. Articles Classification by Year of Publication

Figure 2 shows the categorized studies according to publication years. During 2004 to 2011, the number of studies on the topic of students' mathematical misconceptions were quite limited, none to two papers a year. After 2011, the number of studies gradually increased, with a highly significant increase in 2012 with four studies. The highest number of publications was in 2016. We believe that the rise in interest after

2011 might partly be attributed to the announcement of the Basic Education Core Curriculum B.E. 2008 (Ministry of Education Thailand, 2008) related to the concern for the new mathematics curriculum. The revised mathematical standards and indicators of the national curriculum were announced again in 2017. The number of the studies decreased slowly between 2018 and 2022. And most of these papers were from the 2008 curriculum.

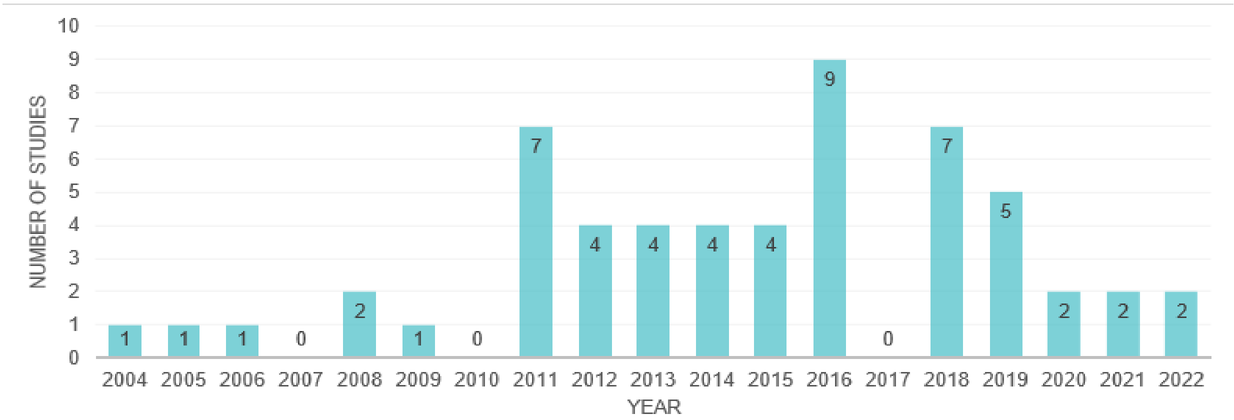

Figure 2 The number of studies published from 2004 to 2022.

The 56 studies were classified by grade levels, strands, and contents as shown in Table 1. Although most of the studies reported the mathematical concepts based on the strands and contents of the Basic Education Core Curriculum B.E. 2008. To be more beneficial, we analyzed the strands and contents using the revised mathematical standards and indicators released in 2017, which is more up to date and will be beneficial for future research.

Table 1 The number of studies classified by grade levels, strands, and contents

Strand	Content	Grade			
		1-3 (n=1, 2%)	4-7 (n=7, 13%)	7-9 (n=36, 64%)	10-12 (n=12, 21%)
Numbers & Algebra (38)	Natural numbers and zero		4		
	Fractions		2	4	
	Pattern			1	
	Decimal numbers			2	
	Ratios and percentages			2	
	Rational numbers			3	
	Exponents			4	
	Real numbers			3	

Strand	Content	Grade 1-3 (n=1, 2%)	Grade 4-7 (n=7, 13%)	Grade 7-9 (n=36, 64%)	Grade 10-12 (n=12, 21%)
	Polynomials			2	
	Polynomial factorization			1	
	Linear equations in one variable			9	1
	Linear equations in two variables			1	
	Linear inequality with one variable			3	1
	Quadratic functions			1	
	*Algebra			1	
	Functions				4
	Sequences & series				1
	No study - Polynomial factorization, A system of linear equations, Sets, Introduction to Logic, Interest and money, Exponential & logarithmic functions, Trigonometric functions, Complex numbers, Matrix				
Measurement & Geometry (11)	Volume and capacity			4	
	2-dimensional shapes	1	1	1	
	2-dimensional shapes	1	1	1	
	3-dimensional shapes			1	
	Surface areas			4	
	Pythagorean theorem			1	
	Circle			1	
	Analytic geometry				2
	No study - Money, Time, Length, Weight, Geometry, Geometric construction, Geometric dimensions, Geometric transformation, Parallel lines, Congruence, Similarity, Trigonometric ratios, Vectors in 3-dimensional space				
Statistics & Probability (4)	Statistics			1	
	Probability			1	1
	Fundamental principle of counting				1
	No study - Data and data presentation, Probability distributions				
Calculus (1)	Introduction to calculus				1

Remark:

To illustrate the change between curriculum the 2008 version and its revision version (2017) the color codes were used as follows:

(i) Green shading and green letters denote the contents in Grade 1-6.

(ii) Blue shading and blue letters denote the contents in Grade 7-9.

(iii) Yellow shading and yellow letters denote the contents in Grade 10-12.

e.g., *Fractions is in* Grade 1-6 of the 2017 version curriculum, while it was for Grade 4-6 and Grade 7-9 in the 2008 curriculum.

(iv) Red numbers denote the number of studies conducted on the participants' grade level that do not fit in the 2017 version curriculum, but they followed the 2008 curriculum.

e.g., *in Fractions*, 2 in black and 4 in red mean that there are two studies investigating Grade 4-6 students' misconceptions of fraction, and there are four studies investigating Grade 7-9 students' misconceptions.

2. Articles Classification by Grade Levels

From Table 1, it reveals that the included studies were conducted on varied grade levels. However, only one study (2%) was conducted on students in Grade 1-3, particularly in Grade 3. Seven studies (13%) were conducted on students in Grade 4-6. The majority of the studies (36 studies or 64%) were conducted on students in Grade 7-9. The remaining studies (12 studies or 21%) were conducted on students in Grade 10-12. It shows that Grade 7-9, lower Secondary level, were the most popular grade level, followed by Grade 10-12, upper Secondary level. Not many studies conducted research to find out students' misconception in Primary level, especially in low Primary level (Grade 1-3). It is recommended that research on the misconceptions of students in low Primary level should be explored more in the future. None of these did the research to find out students' misconceptions on Grade 1-2 students. As pointed out by Duran (2013), it is necessary to explore misconceptions of the basic concepts learned in early grades such as Grade 1-3.

3. Articles Classification by Mathematical Strands and Contents

In terms of the strand and content, as shown in Table 1, we classified the mathematical concepts into four strands including (i) numbers & algebra; (ii) measurement & geometry; (iii) statistics & probability; and (iv) calculus (only for an upper secondary school level). The majority of the studies (38 studies or 68%) paid attention to the numbers & algebra strand. The reason might be because this strand contains the most contents compared to the other strands in the Thai mathematics curriculum for Grade 1-12. The second ranked was the measurement & geometry strand (11 studies or 20%). One study investigated misconceptions across two strands: the number & algebra strand, and measurement & geometry strand. There were not many studies on the statistics & probability strand (4 studies or 7%), and calculus strand (1 study or 2%). The comparison between each strand and grade levels showed in Figure 3. The findings also revealed that researchers tend to explore misconceptions on similar contents. For example, nine studies explored misconception in the content of linear equations in one variable. Six studies were on fraction concepts. Four studies each conducted on natural numbers and zero, exponents, linear inequality with one variable, linear inequality with one variable, volume and capacity, and surface areas. However, several contents were not in the light of the research on misconceptions. For example, the contents related to geometry, e.g., geometric construction, geometric dimensions, geometric transformation, and trigonometric ratios for Grade 7-9. They were overlooked in the studies, although it is advocated in many researches since students have many misconceptions in different geometry topics (Dobbins, Gagnon & Ulrich, 2014). There are rooms for research on misconceptions in many topics.

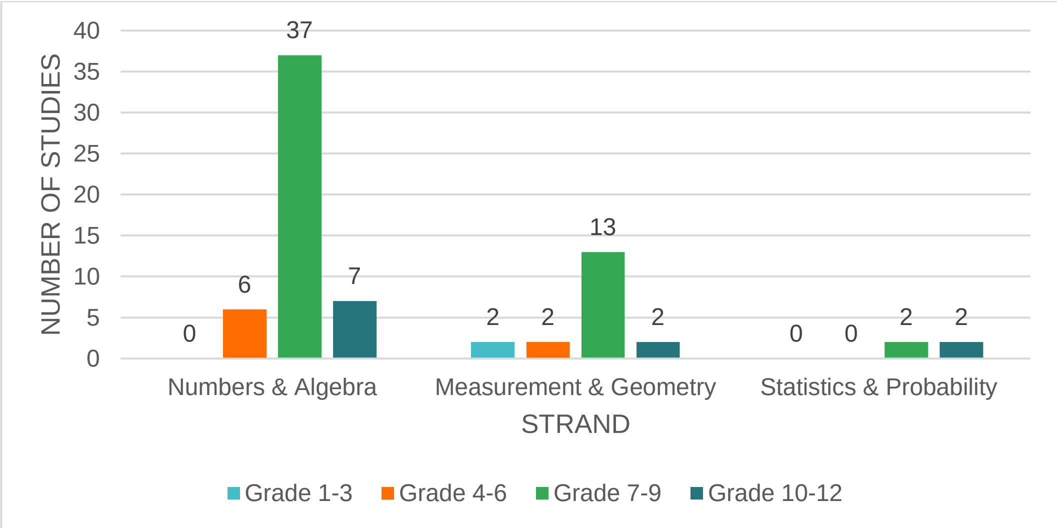

Figure 3 Number of the studies classified by mathematical strands and grade levels.

Foci of studies on students' mathematical misconceptions

From the analysis of the 56 studies, most research studies on students' misconception in mathematics had more than one objective. The objectives and the results related to students' misconceptions could be classified into five foci. The first four foci were: (i) determining misconceptions, (ii) finding causes of misconceptions, (iii) eliminating misconceptions, and (iv) comparing methods or instruments used to determine misconceptions. The fifth one was (v) indirectly discovering misconceptions during their interventions to develop students' mathematical concepts in classrooms.

The findings, as shown in Table 2, reveal that most of the studies, 37 studies out of 56 studies (66%) aimed to diagnose and determine students' misconceptions in specific mathematical concepts. They included a variety of concepts the students often showed mistakes or the important mathematical concepts e.g. long division algorithm (Nimitipun, 2016), inequality (Promtrud & Pumsanthia, 2019). Twenty-five studies, out of these 37 studies, also seek for causes of these misconceptions. For example, Promtrud and Pumsanthia (2019) found that Grade 9 students had mistaken and misconceptions on inequalities in two aspects: (1) language involving inequality and (2) theories, rules, formulas, definitions and properties. This study also reported that the causes of these misconceptions were student's misinterpretation of terminology involving inequalities, lack of understanding related to a mathematical sentence, misunderstanding of addition property of inequalities, misunderstanding of multiplication property of inequalities and weak calculation skills.

There are 26 studies proposing methods to eliminate students' misconceptions, although some of them (14 studies) did not state this purpose clearly as one of the research objectives. This result shows that the researchers valued the significance of instructions to eliminate students' mathematical misconceptions. Unfortunately, most of the proposed methods to eliminate students' misconception were from researchers and experts' views without testing out these methods to the students. The methods were also quite general, not applying to specific mathematical concepts. For example, Punsupa et al.'s study (2014) which investigated misconceptions on surface area and capacitance of Grade 9 students suggested some possible solutions, e.g., Polya's problem solving technique, using group activities, awaking students to realize the undesirable consequences of careless calculation, providing a positive reinforcement and practicing interpreting various mathematic questions. The suggested methods from empirical research were still limited. Only one study, Awae's study (2016), applied a teaching method as a treatment to see whether it was able to eliminate students' present misconceptions. Awae studied the effects of teaching using concept attainment models on Grade 3 students' concept and achievement. He developed a 16-hours lesson plan in the topic of geometry and then taught it to the students. The results from pre-test and post-test revealed that the student's correct concepts increased, and the student's incorrect concepts and misconceptions decreased (Awae, 2016). In addition, some studies suggested that teaching and learning interventions such as active learning in inequality lessons (Thongwiset et al., 2019), 4E×2 model in surface area and volume lessons (Ponkwunchotica, 2011), and Concrete-Pictorial-Abstract (C-P-A) approach in two-dimensional and three-dimensional geometry lessons (Janhom et al., 2020) could be methods to eliminate some students' misconception. These studies discovered that the suggested interventions had potentials to eliminate students' mathematical misconceptions during developing student's concept processes.

Table 2 Classification, description and frequency of the focus of studies

Foci	Descriptions	Number of studies (percent of 56 studies)
Determining misconceptions (DM)	Diagnose/determine students' misconceptions in specific mathematical concepts.	37 (66%)
Findings causes of misconceptions (CM)	Explore and explain possible causes of students' misconceptions in specific mathematical concepts.	25 (45%)
Eliminating misconceptions (EM)	Propose possible methods to eliminate students' misconceptions in specific mathematical concepts.	26 (46%)
Developing/Comparing assessment or diagnostics tools (DT)	Developing or comparing assessment or diagnostics tools for students' misconception	3 (5%)
Discovering misconceptions during intervention or investigation (DMI)	Investigate and discover students' misconceptions emerging during instruction or intervention in classroom	14 (25%)

For other foci, we found three researches (5%) compared methods or tests used to determine students' misconceptions, e.g., comparing the quality of a concept mapping assessment using two different scoring methods (Chukhuan, 2005), comparing quality of three-tier diagnostic tests using different levels of confidence (Insawat, 2016). Although the amount of research on this issue was quite limited, it showed a valuable contribution to the body of work in the development of diagnostic assessment tests to identify students' misconceptions. Fourteen studies (25%) indirectly discovered students' misconceptions during investigating students' understanding of concepts. Lastly, none of the 56 studies reported or discussed on using students' errors and misconceptions to engage students in mathematical discussions in the classrooms.

Methods to determine students' misconceptions in mathematics

Different methods and diagnostic tools had been developed and used to determine Thai students' misconceptions in mathematics (Figure 4). The result shows that some studies did not use only one method, but there were combinations of two or three methods. From 36 studies in determining misconception, 26 studies (70.3%) used single methods, 8 studies (21.6%) used a combination of two methods, three studies (8.1%) used a combination of three methods. Among them open-ended tests (28 studies or 75.7%), two-tier tests (7 studies of 18.9%), multiple-choice tests (6 studies or 16.2%), and interviews (6 studies or 16.2%) were commonly used.

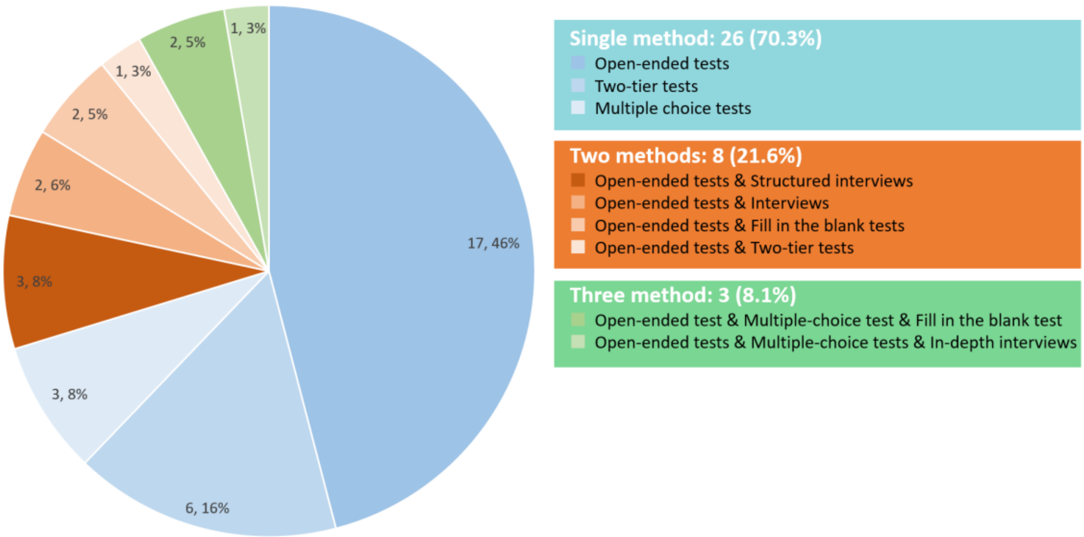

Figure 4 Frequency of the number of methods for diagnosis.

As suggested from the previous literature, a combination of many methods is better than a single method (Gurel, Eryilmaz & McDermott, 2015), this might be a reason why some studies used two methods, e.g. open-ended test and interview for five studies or 13.5% (Nasomtruk et al., 2012; Polakhun et al., 2013; Punsupa et al., 2014; Bantao, & Pavaputanon, 2015) and open-ended test and fill in the blank test for two studies or 5.4% (Chaiprasert et al., 2012; Promtrud & Pumsanthai, 2019). Open-ended tests and interviews were the two most common methods used together because teachers or researchers could firstly analyze students' responses to open-ended questions and then uncover students' understanding and misunderstanding through the interview (Donni, 2015). However, the written responses might not be clear enough to identify students' misconceptions, especially when the students write short answers using keywords, symbols, or short sentences. Thus, some researchers used other methods to clarify students' understanding and the interview was a method employed to fill this gap. The interview has been found to be one of the best (Osborne & Gilbert, 1980) and the most common method used in uncovering students' views and possible misconceptions. The finding shows that some researchers valued the needs of clarifying students' misconceptions using a combination of methods. However, there were several studies that used only one method, without opportunities for students to clarify their thinking. It might affect the quality of interpreting students' concepts.

In addition, some studies developed and used two-tier tests (3 studies or 8.3%) as their diagnostic tools. Generally, the two-tier tests are composed of (i) first tier responses on the content questions including multiple-choice or true-false questions, and (ii) second tier responses on the reasons for the answer chosen in the first tier including multiple-choice or free writing. The multi-tier test was usually developed to overcome the limitations of the multiple-choice test. For example, a student might choose the correct answer, but not provide correct justifications. Students' responses in the second tier were considered as students' reasoning or interpretation behind their selected response, and link their choices to misconceptions of the target concept (Wang, 2004).

Fill in the blanks were used in a few studies (Table 3). We do not have a consensus regarding the best diagnostic method; however, it is obvious that good methods were the ones providing a rich source of students' misconceptions. The number of alternative diagnostic methods e.g., three tier tests or thinking aloud is still limited. As Caleon and Subramanian (2010) study, a question in a three-tier test comprises the content tier, which measures content knowledge; the reason tier, which measures explanatory knowledge; and the confidence tier, which measures the strength of conceptual understanding of the respondents. Moreover, they found that the think aloud approach was applied while asking students to state their answer and supporting reason when choosing their answers can examine for problems in the students' interpretation of instructions, questions, and choices. Think aloud approach can provide a useful resource to students' understanding (Young, 2005).

Conclusions

Learning from previous studies might help us to understand existing situations, trends of researches, as well as guide us for further work. This systematic review of studies on students' misconceptions in mathematics was conducted due to the lack of synthesis in Thailand context. The findings pointed out the situations and trends of research in several aspects. First, the review found out that the numbers of studies on students' misconceptions each year during 2004-2022 were quite fluctuating. Although most of the studies were conducted with various groups of students, especially in Grade 7-9, students' misconceptions in early grades such as Grade1-3 were insufficiently investigated. The topics in Number & Algebra strand were the most common topics studied among the three mathematical strands, across all grade levels. Different groups of researchers repeatedly studied similar contents while some contents had been overlooked (e.g., polynomial, money, geometry, data and data presentation).

Most of the studies aimed to determine students' misconceptions and causes of them; however, the empirical research on methods or teaching approaches to eliminate students' misconceptions was quite limited. The findings showed that researchers were concerned about how to eliminate students' misconception and ways to construct correct mathematical concepts to the students. However, most of the suggested teaching methods were quite general, not applying to specific mathematical concepts. They mostly were suggested from experts and researchers' ideas. Only one study applied a treatment to see whether the treatment was able to eliminate students' misconceptions. Only a few studies provided evidence of how those interventions would help students to eliminate misconceptions or avoid creating misconception in lessons. It aligns with the result of Ay's study (2017) that the studies about misconceptions in mathematics were mostly conducted for the purpose of determining misconceptions, not eliminating misconceptions. Furthermore, none of 56 studies sought out and discussed using students' errors and misconceptions to engage students in mathematical discussions in classrooms.

Lastly, this study revealed that Thai researchers used various methods and developed many diagnostic tools to determine students' misconceptions. Some studies did not use only one method, but there were combinations of two or three methods. It showed that researchers valued the needs of clarifying students' misconceptions using a combination of methods. However, there were several studies that still used only one method, without opportunities for students to clarify their thinking. Moreover, there were a few attempts to develop multi-tier tests and used in the studies, to overcome the limitations of a multiple-choice test.

These findings call for researchers to fill in the gaps in literature. Further exploration in the causes of misconception is needed. Moreover, we need research investigating ways to eliminate Thai students' misconceptions in several content areas e.g., linear equation with one variable. There is also a lack of studies related to mathematical misconceptions in early grades. Moreover, the research on methods or instruments to identify students' misconceptions, especially for the contents given less attention (e.g., geometry) are also interesting to develop for future research.

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APPENDIX

No.	Authors/Year of publication	Strand	Content	Grade	Focus**	Data collection tool
1	Polakhun, Suwapanich, & Jansila (2013)	Numbers & Algebra	Introduction to real numbers	8	DM, CM, EM	1. Open-ended test* 2. Structured interview* 3. Expert evaluation form
2	Punsupa, Suwapanich, & Jansila (2014)	Measurement & Geometry	Surface areas and volume	9	DM, CM, EM	1. Open-ended test* 2. Structured interview* 3. Expert evaluation form
3	Sukkrom, & Makanong (2015)	Numbers & Algebra	Real numbers and exponents	11	DM	Open-ended test*
4	Kongkaluang, & Heingraj (2014)	Numbers & Algebra	Applications of linear equations in one variable	8	DM	1. Open-ended test* 2. Multiple-choice test* 3. In-depth interview*
5	Nakornphan, & Heingraj (2014)	Measurement & Geometry	Pythagorean theorem	8	DM	1. Two-tier test* 2. Open-ended test*
6	Bantao, & Pavaputanon (2015)	Numbers & Algebra	Division of fractions	6	DM	1. Open-ended test* 2. Structured interview*
7	Nasomtruk, Suwapanich, & Jansila (2012)	Numbers & Algebra	Linear equations in one variable	7	DM, CM, EM	1. Open-ended test* 2. Structured interview* 3. Expert evaluation form

No.	Authors/Year of publication	Strand	Content	Grade	Focus**	Data collection tool
8	Ngao-Ngam, Kaewkhao, & Intep (2019)	Numbers & Algebra and Measurement & Geometry	Integer system, exponents, ratios and percentages, surface area and volume, and system of linear equations	7-9	DT	Two types of multiple-choice tests (MCT) - MCT with normal choices - MCT with distraction choices
9	Nimitipun (2016)	Numbers & Algebra	Long division algorithm	4	DM	Open-ended test*
10	Ponerut, Janjaruporn, & Sirininlakul (2019)	Calculus	Calculus	12	DMI	1. Students' belief test 2. Open-ended test (students' ability to apply a mathematical model to solve real world situations) 3. Interview (teaching and learning) 4. Open-ended test (basic knowledge of algebra)
11	Promtrud, & Pumsanthia, (2019)	Numbers & Algebra	Linear inequality	9	DM, CM	1. Fill in the blank test* 2. Open-ended test*
12	Chalaewchalad, Klangphahot, Juithong, & Kongthong (2020)	Numbers & Algebra		7-9	DM	Multiple-choice test*
13	Tessing (2011)	Numbers & Algebra	Addition and subtraction of fractions	7	DM, CM, EM	1. Open-ended test* 2. Structured interview (cause of misconceptions) 3. Expert evaluation form
14	Srichaimool (2011)	Numbers & Algebra	Ratios and percentages	8	DM, CM, EM	1. Open-ended test* 2. Structured interview (cause of misconceptions) 3. Expert evaluation form

No.	Authors/Year of publication	Strand	Content	Grade	Focus**	Data collection tool
15	Seesomba, S. (2011)	Numbers & Algebra	Linear inequality	9	DM, CM, EM	1.Open-ended test* 2.Structured interview (cause of misconceptions) 3. Expert evaluation form
16	Chanthakhad (2011)	Numbers & Algebra	Addition and subtraction of polynomials	7	DM, CM, EM	1.Open-ended test* 2. Structured interview (cause of misconceptions) 3. Expert evaluation form
17	Bootwong (2011)	Numbers & Algebra	Linear equations in one variable	7	DM, CM, EM	1. Open-ended test* 2. Structured interview (cause of misconceptions) 3. Expert evaluation form
18	Inthidech, T. (2012)	Numbers & Algebra	Applications of linear equations in one variable	8	DM, CM, EM	1. Open-ended test* 2. Structured interview (cause of misconceptions) 3. Expert evaluation form
19	Boodsawisade (2013)	Measurement & Geometry	Analytic geometry and conic section	10	DM, CM, EM	1. Open-ended test* 2. Structured interview (cause of misconceptions) 3. Expert evaluation form
20	Srijuang (2014)	Measurement & Geometry	Surface areas and volume	9	DM, CM, EM	1. Open-ended test* 2. Structured interview (cause of misconceptions) 3. Expert evaluation form
21	Longthong (2016)	Statistics & Probability	Probability	11	DM, CM	1. Open-ended test* 2. Structured interview (cause of misconceptions)
22	Chaiprasert (2012)	Numbers & Algebra	Functions	10	DM	1. Fill in the blank test* 2. Open-ended test*
23	Chaipeng (2016)	Numbers & Algebra	Fractions	7	DM, CM	1. Open-ended test* 2. Semi-structured interview (cause of misconceptions)

No.	Authors/Year of publication	Strand	Content	Grade	Focus**	Data collection tool
24	Kayanklang (2016)	Numbers & Algebra	Linear equations in one variable	7	DM, CM	1. Open-ended test* 2. Structured interview (cause of misconceptions)
25	Luangsoontorn (2009)	Numbers & Algebra	Integer system, and exponents	7	DM, CM, EM	1. Open-ended test* 2. Structured interview (cause of misconceptions)
26	Thongchuea (2016)	Numbers & Algebra	Decimal numbers and fractions	8	DM, CM	1. Multiple-choice test* 2. Interview (cause of misconceptions)
27	Awae (2016)	Measurement & Geometry	2-dimensional shapes	3	DM, EM	Two-tier test*
28	Yimlamai (2014)	Numbers & Algebra	Linear equations in one variable	8	DM	Multiple-choice test*
29	Thongwiset, Lertamornpong, & Chuntra (2019)	Numbers & Algebra	Linear inequality	9	DMI, EM	1. Learning achievement test 2. Two-tier test (conceptual mathematical test)
30	Sirikampla, & Poonpaiboonpipat (2020)	Numbers & Algebra	Addition, subtraction, multiplication, and division of natural numbers and zero	4	DMI, EM	1. Reflective form after learning activity 2. Two-tier test
31	Janhom, Viriyapong, & Supap (2020)	Measurement & Geometry	2- and 3-dimensional shapes	7	DMI, EM	1. Interview about instance 2. Multiple-choice test
32	Bunmapa (2018)	Numbers & Algebra	Sequences	11-12	DM, CM, EM	1. Open-ended test* 2. Interview*
33	Insawat (2016)	Numbers & Algebra	Relations and functions	10	DT	1. Three-tier test with 2 confident levels 2. Three-tier test with 3 confident levels 3. Think aloud form

No.	Authors/Year of publication	Strand	Content	Grade	Focus**	Data collection tool
34	Takraiklang (2011)	Numbers & Algebra	Addition, subtraction, multiplication, and division of natural numbers and zero	6	DM, CM, EM	1. Open-ended test* 2. Structured interview (cause of misconceptions)
35	Napaphun (2012)	Numbers & Algebra	number sentences and relational thinking (numbers)	4-5	DMI	1. Questionnaire (true/false, fill in missing numbers, how to find the missing numbers) 2. In-depth interview
36	Talawat (2014)	Statistics & Probability	Probability	9	DM, CM, EM	1. Lesson observation 2. Two-tier test* (multiple choice and open-ended tests) 3.Teacher interview
37	Lakam (2018)	Statistics & Probability	Statistics	9	DM, CM, EM	1. Open-ended test* 2. Interview (cause of misconceptions)
38	Boonyakiat (2018)	Numbers & Algebra	Linear equations in one variable, and linear inequality with one variable	10	DM	1. Two-tier test* 2. Teacher Interview
39	Chukhuan (2005)	Numbers & Algebra	Natural numbers and integers	7	DT	1. Concept mapping test 2. Multiple-choice test
40	Aunganapattarakajohn (2009)	Measurement & Geometry	Conic sections	10	DM	1. Open-ended test (from textbook)* 2. Open-ended test*
41	Ponkwunchotica (2011)	Measurement & Geometry	Surface areas and volume	9	DMI, EM	Multiple-choice test
42	Isarangkoon Na Ayutthaya (2013)	Numbers & Algebra	Exponents	7	DMI	Multiple-choice test

No.	Authors/Year of publication	Strand	Content	Grade	Focus**	Data collection tool
43	Thongdonam (2018)	Numbers & Algebra	Addition, subtraction, multiplication, and division of fractions	6	DM, CM	1. Two-tier test* 2. Interview (cause of misconceptions)
44	Maneeprawat (2019)	Numbers & Algebra	Decimal numbers and fractions	8	DM, CM	1. Two-tier test* 2. Interview (cause of misconceptions)
45	Hanpitak (2016)	Measurement & Geometry	Triangles	5	EM	1. Open-ended conceptual test 2. Open-ended mathematical problem-solving ability test
46	Yosphan (2013)	Numbers & Algebra	Introduction to real numbers	8	DMI, EM	1. Multiple-choice test (conceptual test) 2. Open-ended mathematical problem-solving ability test
47	Vacharathai, Lumduanhom, & Piasai (2018)	Statistics & Probability	Permutation	11	DM	1. Multiple-choice test* 2. Fill in the blank test* 3. Open-ended test*
48	Chinnasa, Lumduanhom, & Piasai (2018)	Numbers & Algebra	Polynomials	8	DM	1. Multiple-choice test* 2. Fill in the blank test* 3. Open-ended test*
49	Laohawiroongool, & Nuamnoom (2016)	Numbers & Algebra	Relations and functions	10	EM	1. Multiple-choice test 2. Connection ability test (Pre- and post-test)
50	Sakpakornkan (2004)	Numbers & Algebra	Algebra (pattern, linear equation, polynomials)	7-8	DMI	1. Open-ended test 2. Multiple-choice test 3. Semi-structured interviews
51	Vaiyavutjamai, & Clements (2006)	Numbers & Algebra	Quadratic Equations	9	DMI	1. Open-ended test 2. Interviews

No.	Authors/Year of publication	Strand	Content	Grade	Focus**	Data collection tool
52	Prommakas & Kijkuakul (2021)	Numbers & Algebra	Factoring polynomials of second degree	8	DMI, EM	1. Activities Worksheet 2. GeoGebra Worksheet 3. Two-tier test
53	Mapracha, Hudcharoen, & Chanfoy (2021)	Numbers & Algebra	Functions	10	DMI	1. Open-ended test
54	Ruangphet (2018)	Numbers & Algebra	Graphs and linear relation	7	DM, DT	1. Open-ended test 2. Interview 3. Two-tier test*
55	Promtrud (2022)	Numbers & Algebra	Linear equations in one variable	7	DMI	1. Open-ended test 2. Multiple-choice test 3. Semi-structured interviews
56	Yannarut, Kasemsukpipat, & Somchaipeng (2022)	Measurement & Geometry	Circle	9	DMI	1. Open-ended test

*Data collection tools for determining misconceptions

** Related to misconceptions