



IDENTIFYING CAUSES OF MATHEMATICAL MISCONCEPTIONS AND PROPOSED STRATEGIES: A STUDY ON 4TH-GRADE STUDENTS USING TIMSS 2015 ITEMS

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ABSTRACT

This study aimed to identify the primary causes of mathematical misconceptions (MMCs) among 4th-grade elementary school boys when solving selected items from the Trends in International Mathematics and Science Study (TIMSS) 2015, and to propose appropriate strategies for addressing them. The independent variable was the instructional intervention using targeted strategies, while the dependent variable was the occurrence of MMCs. The sample consisted of 40 male students from Shahid Beheshti Public Elementary School in Tehran, Iran, randomly assigned to an experimental group ($n = 20$) and a control group ($n = 20$). After a pretest, the experimental group received strategy-based instruction aimed at reducing MMCs, whereas the control group received no intervention. Both groups then completed a post-test. Data were analyzed using analysis of covariance (ANCOVA). The results showed that implementing targeted instructional strategies significantly reduced the frequency of MMCs. Six common misconceptions were identified, and corresponding strategies were introduced. These findings suggest that strategy-based instruction can be a valuable tool for promoting deeper conceptual understanding in mathematics education.

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1. INTRODUCTION

Mathematics is a fundamental discipline that plays a crucial role in understanding and interpreting the world. It encompasses a range of skills, knowledge, and competencies necessary for problem-solving, logical reasoning, and quantitative thinking (Jorgensen & Dole, 2011). Despite its significance, mathematics education continues to face persistent challenges, among which **mathematical misconceptions (MMCs)** are particularly concerning. These misconceptions often stem from inadequate teaching methods, lack of conceptual understanding, and flawed mental models developed during instruction (BakhshaliZadeh, 2013).

MMCs represent a major obstacle to meaningful learning. They occur when students construct incorrect understandings or apply inaccurate procedures in solving mathematical problems (Moosapoor, 2023). Without timely intervention, these misconceptions can replace correct conceptual understanding and become deeply ingrained (Seyf, 2013). According to Bottle and Team (2005), students commonly make two types of errors—calculation mistakes due to inattention and systematic errors stemming from deeper misunderstandings. While the former are often temporary and correctable, the latter require targeted pedagogical strategies to address.

The traditional classroom approach rarely provides sufficient opportunities for students to revisit their mistakes or reflect on their thinking. As Thorndike (1983) suggested, learning through trial and error is one of the most basic mechanisms of cognitive development. Insight-based learning emerges when students are given regular chances to test and revise their mental models (Hergenhahn & Olson, 2009). Unfortunately, many classrooms fail to offer such opportunities, either due to limited instructional time or a lack of teacher awareness about how to identify and correct MMCs.

Evidence from international assessments reinforces this concern. In the Trends in International Mathematics and Science Study (TIMSS) 2015, Iranian 4th-grade students scored significantly lower than their peers in high-performing countries, such as Japan, Singapore, and South Korea. Specifically, Japanese students achieved an average score of 593, while Iranian students scored only 431 (Sharifi et al., 2018). Despite revisions to the Iranian mathematics curriculum intended to improve problem-solving skills (Danaei Zarchi, 2017; Kian et al., 2019), the gap in performance remains substantial.

Several studies have examined factors contributing to Iran's underperformance. Rahanjam (2015) noted that although the content and illustrations in Iranian textbooks are comparable to those in Japan, deficiencies in educational planning and classroom practices hinder student achievement. These findings highlight the need not only for curriculum reform but also for deeper changes in instructional strategies aimed at diagnosing and addressing student misconceptions.

Research has shown that identifying the causes of MMCs and addressing them through appropriate teaching strategies can significantly improve student learning (Borasi, 1994; Özdemir et al., 2017; Toptaş & Usluoğlu, 2023). Teachers who are aware of common misconceptions and their underlying causes are better equipped to design lessons that foster conceptual understanding and critical thinking. This requires shifting away from rote learning toward strategies that challenge students' assumptions and promote reflective thinking.

Further supporting this view, Gorzinnezhad (2017) emphasized the importance of integrating conceptual questions and process-based learning objectives into textbook design and instructional practice. Encouraging divergent thinking and probing students' reasoning can enhance their ability to construct accurate mathematical knowledge.

A study by BakhshaliZadeh (2013), using TIMSS items from 2003, 2007, and 2011, identified 17 common MMCs among Iranian 4th-grade students, ranging from errors in basic arithmetic to misinterpretations of problem conditions, modeling, and graph reading. Similarly, English (2018) emphasized the role of early instructional design, including hands-on activities and educational games, in supporting cognitive development and preventing the formation of misconceptions.

Given these insights, the present study aims to **identify the most prevalent mathematical misconceptions among 4th-grade elementary school boys** when solving selected items from TIMSS 2015. It also seeks to **develop and test strategies for addressing these misconceptions** in order to promote deeper and more meaningful mathematical learning. By identifying specific areas of misunderstanding and designing interventions to target them, the study hopes to contribute to more effective teaching practices and improved student outcomes in mathematics education.

2. METHOD

This study employed a quasi-experimental design with a pretest-posttest control group to investigate the effectiveness of instructional strategies in reducing mathematical misconceptions (MMCs) among 4th-grade elementary school boys in Tehran, Iran. The study targeted all 4th-grade male students in District 3 during the 2019–2020 academic year and used multi-stage cluster sampling to select participants. Two classrooms were chosen from Shahid Beheshti Public Elementary School for Boys, representing the final sample. Forty students were randomly assigned to either the experimental group (EG) or control group (CG), with 20 students in each group.

The intervention for the experimental group consisted of 15 instructional sessions, each lasting 60 minutes, aimed at addressing and correcting MMCs. Prior to the intervention, a 14-item pretest was administered to assess students' baseline understanding. The control group received no such intervention. Due to the COVID-19 pandemic, the post test was administered online via Google Forms.

Pretest and posttest items were adapted from the TIMSS 2015 assessment. Four mathematics teachers from Shahid Beheshti Elementary School reviewed the TIMSS items, selecting 14 that were most frequently associated with student misconceptions and deemed appropriate for 4th-grade learners. Teachers emphasized that increasing the number of test items might reduce response quality. To ensure content validity, the Content Validity Ratio (CVR) was calculated. Each teacher rated the items using a three-point Likert scale ("necessary," "useful but not necessary," and "not necessary"). Items with the highest CVR scores were included in the final assessment.

3. RESULTS AND DISCUSSION

3.1. Results

Descriptive and inferential statistics were used to analyze the data in this study. At the descriptive level, frequency tables, graphs, and mean and standard deviation (SD) along with variance were accordingly utilized. At the inferential level and in line with the research hypotheses and the comparison between the EG and CG, the analysis of covariance (ANCOVA) was practiced. In the qualitative part, content analysis was thus used to obtain the students' MCs. The descriptive indices of the study variables, including the intervention and MCs, are provided in Tables 1-4 by the group (viz., EG and CG).

Accordingly, the mean scores in both study groups were close to each other. The given value in the EG also experienced some changes during the pretest and posttest, which were incremental, but there were no variations in the CG, who did not undergo any interventions. Therefore, it was necessary to analyze each item, as illustrated in Tables 2 and 3.

As observed, the number of correct answers in the posttest increased after the intervention, but that of the wrong ones decreased. As shown, the number of correct answers in the posttest did not differ significantly from those in the pretest. According to the answers provided by the students of the CG and EG in the pretest and posttest and Tables 2 and 3, the MCs were expressed as percentages.

As illustrated, the students frequently faced MCs in arithmetic numbers as well as measurement and recognition of two- and three-dimensional geometric shapes, points, lines, and angles. The frequency of the MCs in the cognitive area of the items, including arguments, application, and recognition, among the study samples is provided in Tables 4 and 5.

Table 1. Mean, SD, and Minimum/Maximum Scores of Study Variables by Group

Groups	Pretest				Posttest			
	Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum
Intervention	9.7	3.33	3	16	16.05	2.6	13	20
Control	10.7	5.16	3	19	10.55	5.26	3	19

Table 2. Analysis of Items in EG

Items	Pretest			Items	Posttest		
	Correct	No answer	Incorrect		Correct	No answer	Incorrect
1	11	0	9	1	20	0	0
2	4	0	15	2	14	0	6
3	6	1	13	3	14	1	5
4	5	0	15	4	19	0	1
5	12	0	8	5	15	0	5
6	19	0	1	6	18	0	2
7	15	0	5	7	18	0	2
8	12	1	7	8	19	1	0
9	3	0	17	9	16	0	4
10	6	0	14	10	9	1	10
11	16	0	4	11	18	0	2
12	12	1	7	12	18	0	2
13	0	0	19	13	14	0	6
14	7	0	13	14	16	0	4

Table 3. Analysis of items in CG

Items	Pretest			Items	Posttest		
	Correct	No answer	Incorrect		Correct	No answer	Incorrect
1	13	0	7	1	13	0	7
2	4	4	12	2	4	2	14
3	9	1	10	3	11	0	9
4	10	1	9	4	13	0	7

Pretest				Posttest			
Items	Correct	No answer	Incorrect	Items	Correct	No answer	Incorrect
5	11	0	9	5	14	2	4
6	19	0	1	6	17	1	2
7	15	0	5	7	14	1	5
8	15	2	3	8	13	2	5
9	10	0	10	9	14	1	14
10	5	0	15	10	6	0	8
11	14	1	5	11	11	1	8
12	15	0	5	12	3	1	16
13	4	0	16	13	8	1	11
14	8	0	12	14	16	0	4

Table 4. MCs among CG and EG students during pretest and posttest

MCs	CG		EG	
	Pretest	Posttest	Pretest	Posttest
Understanding and operating arithmetic numbers	58%	55%	55%	15%
Simple expressions and equations	25%	24%	28%	17%
Measurement and recognition of two- and three-dimensional geometric shapes	46%	48%	48%	20%
Working with, interpreting, and displaying data	20%	22%	25%	12%
Understanding fractions	12%	10%	15%	6%
Understanding geometric shapes, points, lines, and angles	33%	31%	34%	10%

Table 5. Frequency of MCs in the cognitive area

Argument	Application	Recognition
74	31	35

Table 6. Kolmogorov-Smirnov test results for study variables in EG

Group	Variable MCs
Statistical test	0.11
Significance level	0.2

Table 7. Levene's test of study variables

Variable	Statistical indices			
	F	Degree of freedom 1	Degree of freedom 2	Significance level
X	0.27	1	32	0.87

We employed a pretest/post test research design with a control group, using one-way ANCOVA to control the pretest's effect in both study groups and test the items. Before the tests, the major assumptions were further analyzed with regard to covariances. The normality of the distribution of the scores was also checked via the Kolmogorov-Smirnov test.

Given that the normal distribution is a continuous probability in probability theory, the significance level of the main variable in the EG exceeded the error value of 0.05 (See Table 6), thereby accepting the null hypothesis that the data were normal. With reference to the homogeneity of variances using Levene's test, this assumption was assumed as part of the ANCOVA output but listed separately in Table 7.

Table 7 outlines that the significance level was greater than 0.05, thereby accepting the null hypothesis of equal variances. We further argued that the variances were homogeneous, which also met this assumption. According to Table 8, the significance level was greater than 0.05, so it was not significant, and the desired assumption was met. All the assumptions for the ANCOVA were also taken into account, and then the main and secondary research questions were addressed. The main research question is as follows: Are intervention strategies effective in reducing or eliminating MCs?

As given in Table 9, the F coefficient of the group effect in the TIMSS 2015 was equal to 21.44, and the significance level was less than 0.05. In addition, the effect size for this variable was 42%, so the research hypothesis was accepted at a confidence interval (CI) of 99%. It indicated that the intervention strategies had a significant effect on MCs. The homogeneity of regression slopes was assumed when the ANCOVA variables were linear in the whole data and each group had the same regression lines. If the regression was heterogeneous, then the ANCOVA results were not desirable. As a result, the assumption of homogeneity of regression slopes was a key to covariance. Table 8 displays the interaction between the covariance and the independent variable.

Accordingly, the students had more MCs in terms of arguments. In this line, the research questions were addressed using some statistical tests. As well, the dependent variables of social adjustment and academic enthusiasm were investigated. The EG also received training, but the CG continued routinely with no interventions.

Table 8. F interaction between covariance and independent variable

Variable	Source	Sum of Squares	Degree of Freedom	Mean of Squares	F	Significance level
X	Group×pretest	27.96	1	27.96	0.59	0.45

Table 9. ANCOVA results for TIMSS 2015 scores

Sources	Sum of Squares	Degree of Freedom	Mean of Squares	F	Significance Level	η Coefficient Effect Size
Pretest effect	150.54	1	150.54	25.51	0.001	0.38
Group effect	173.34	1	173.34	21.44	0.001	0.42
Error	291.22	36	8.09	-	-	-
Total	7986	40	-	-	-	-

3.2. Discussion

The study aimed to identify the top causes of MCs among 4th-grade elementary school boys in answering selected TIMSS 2015 items and present appropriate strategies to resolve them. The results showed that interventions had a significant impact on students in the EG, leading to significantly improved pretest and posttest average scores. Upon training completion, students' scores increased in the TIMSS 2015 posttest as compared to

the pretest in the EG, indicating they were able to reduce their MCs. These results were in agreement with the reports in some domestic studies, e.g., Gorzinnezhad (2017), and Bakhshalizadeh (2013).

The study found that students mostly had MCs of the carelessness type, which were considered arguments in the cognitive area. These students were unable to understand the content and concepts in their lessons, and they lacked the ability to solve mathematical problems or apply certain tools and knowledge. Students were found to have MCs in terms of lack of reasoning if they failed to answer a TIMSS item related to reasoning, but they often used the expression "I don't know." Many MCs of the reasoning type in the study samples were related to their insufficient knowledge.

To identify MCs, the study examined all answer sheets and considered wrong answers or unanswered items as MCs. In total, six MCs were identified: (1) understanding and operating arithmetic numbers; (2) simple expressions and equations; (3) measurement and recognition of two- and three-dimensional geometric shapes; (4) working with, interpreting, and displaying data; (5) understanding fractions; and (6) understanding geometric shapes, points, lines, and angles.

Teachers are suggested to provide situations with the possibility of efforts, mistakes, and the identification of MCs. Such rich, happy, and non-judgmental contexts can deepen and make learning meaningful. Teachers no longer need to focus on the number of correct answers students provide, instead focusing on identifying and correcting mistakes and resolving common MCs. By providing challenging opportunities, students gain a deeper understanding of many concepts, which in turn enhances their knowledge and deepens their learning.

To reduce students' MCs, intervention strategies such as increasing brain capacity, accuracy, and concentration should be practiced through individual and group activities. These include exercises and movements called the brain club, a series of exercises to augment accuracy and concentration, such as those for strengthening visual memory and accuracy, balance, coordination of both hemispheres, spatial visualization, reading comprehension, listening accuracy, and breathing, worksheets to encourage accuracy, attention, and thinking skills, as well as some exercises and practical and grammatical activities using tools individually and in group.

However, there were some limitations to the study's results. First, the study focused solely on male students without considering gender separation, thereby limiting the generalizability of the results to females. Second, the closure of all schools due to the COVID-19 outbreak presented another limitation, necessitating the completion of some study procedures online.

Further research is necessary to identify students' MMCs and their underlying causes. Teachers are also recommended to introduce MMCs to students, as more awareness in this regard encourages them to reach better resolutions and improve their problem-solving skills. Teachers should be patient and try to identify and reduce students' MCs, as learning in a safe setting with no judgment or fear can come about more deeply.

4. CONCLUSION

This study, using a quasi-experimental method, concluded that students could solve their MMCs. According to Danaie Zarchi (2017) and Rahanjam (2015), as well as the researchers as teachers, the content of the educational textbooks for Iranian students was rich enough, mainly based on thinking, reasoning, problem-solving, games, and manual work. Therefore, competent teachers could help students make progress in mathematics by practicing appropriate strategies. With regard to the mathematical structure and the need to

understand mathematical concepts continuously, training can be a useful tool for students to achieve coherence and continuity between the learning materials. Teaching along with various trainings, such as grammatical practices, movie displays, etc., can further make the educational context more inclusive and dynamic. Ultimately, students are likely to feel more interested in such environments.

The main idea raised in this study was that developing educational protocols in addition to investigating the top causes of MCs could improve students' cognitive areas, as observed in the study findings.

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