



ORIGINAL RESEARCH ARTICLE

## Improving Math Performance Using the Written Think-Aloud Strategy

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### ABSTRACT

**Purpose:** Written Think-Aloud strategy, which is rooted in the think-aloud strategy, gives students mental order and helps teachers explore thought processes; specifically, these methods are useful to study test response processes and map cognitive models of complex thought processes. The purpose of this research was to investigate the effect of Writing mathematical thoughts and arguments in non-mathematical and non-formulaic language improved elementary students' mathematical performance.

**Method:** The statistical population of the present study included the fifth-grade students of elementary school (n=60). The statistical sample was 32 students (control group (n=16) and experimental group (n=16)), who were selected by available sampling method. A pre-test-post-test design with a control group was used for the implementation of the present study.

**Result:** The results covariance analysis test indicated that the difference in the average scores of students in the control and experimental groups is significant ( $p \leq 0.000$ ). This research also indicated that the use of written think-aloud strategy in students' math assessment led to students' success in solving math problems.

**Conclusion:** This research showed that the use of the Written Think-Aloud strategy in the math assessment of students affected their math success. This success in solving math problems can be related to creating mental order and focusing more on the task and finally strengthening self-regulation skills, which is a necessary condition for achieving any kind of success. It also provides the basis for receiving quick and timely feedback improves the thinking process and leads to success in solving problems. ©authors

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## 1. Introduction

Written Think-Aloud (WTA) strategy is rooted in the strategy of thinking aloud. The strategy of writing down thoughts for solving mathematical problems is an innovative strategy of the researcher, which was inspired by the strategy of thinking aloud.

The think-aloud protocol is a strategy that offers unique approaches to capture participant thought processes when engaging with instruments and problems. TA is a unique area of education research, exploring the participant interpretation and thought processes that occur during an activity; this could include information about decisions the participants make, how they interact with a tool or instrument, and/or factors that may influence how they answer a posed question. Think-aloud protocol is often used in revealing the strategic decisions learners use in learning and performing tasks (Gu, 2014). Thinking aloud is the concurrent verbalization of thoughts while performing a task (Hayes, 1986). When this method is applied, participants are asked spontaneously report everything that goes through their minds while doing a task, and they are instructed not to interpret or analyze their thinking.

Verbal protocol is another term often used as a synonym for thinking aloud (Güss, 2018). Ritchhart and Perkins (2008) used the term visible thinking. They concluded when learners speak, write, or draw their ideas, they deepen their cognition (Ritchhart, & Perkins, 2008).

TAPs focus on nuances of the problem-solving process, which often evaluates working memory (i.e., the information used by the participant while they actively solve a problem). TAPs are often used to confirm, elaborate, or refine cognitive models (Gawad, 2020).

This strategy has been used extensively in psychological and educational research contexts and offers unique approaches to capture participant thought processes when engaging with instruments and problems (Wolcott, & Lobczowski, 2021). The Think Aloud strategy provides an effective scaffolding technique that is advocated in Vygotsky's conceptualization of ZPD<sup>1</sup> (Duggirala, 2021). Vygotsky's goal was to understand what influenced students' decision-making process as they answered questions during the assessment (Wolcott, & Lobczowski, 2021).

More studies showed that asking students to give reasons for responses improved performance on a test reading comprehension (Ward, & Traweek, 1993). The study of thinking aloud and verbal protocols have a long tradition in psychology. The thinking-aloud method was heavily criticized by behaviorists, as they assumed cognitive processes, such as memory, could not be studied scientifically. As Watson (1925) expressed, "*The behaviorist never uses the term memory. He believes that it has no place in an objective psychology*" (p.177) (Güss, 2018). The thinking-aloud method became popular again after the influence of behaviorism diminished in mainstream psychology and cognitive psychology became the dominant paradigm. Newell and Simon (1972), for example, asked participants to think aloud while solving particular problems (Güss, 2018). According to Bandura (1986), three key steps constitute self-regulation, i.e., self-observations, self-judgements, and self-reactions (Bai, 2018). First, learners keep track of specific aspects of their own learning. Second, they judge their own learning based on a standard. Third, they react and adjust their self-regulated learning experiences should they perceive their learning as unsuccessful. These key processes point to the importance of individual learners' role in their learning. Although young children may experience a different rate of development in think-management, according to Vygotsky's The Zone of Proximal Development (ZPD) theory, we find that young students should acquire most of the learning strategies related to the academic context through the step-by-step guidance and guidance of learning from teachers in the early stage.

The strategy of writing down thoughts and arguments contains all the advantages of the think- aloud strategy, with the difference that, firstly, by writing down thoughts, others are not

<sup>1</sup> zone of proximal development

bothered by the speaker's voice. Secondly, by writing, learner's thoughts are recorded and none of its components are forgotten, thirdly, writing down thoughts and arguments causes more focus and order in the mental and intellectual learners' activities.

Many articles have appeared reporting the positive effects of metacognitive training on reading comprehension but rarely experimental study has been done on the use of written think-aloud strategy for mathematical assessment.

Despite the realization that conceptual understanding of mathematics is critical to mathematical development, most math instruction, particularly for students continues to stress rote learning of math facts and procedures (Rosenzweig, Krawec, & Montague, 2011). Various factors in learning mathematics, such as differences in language usage between math and natural language, and incorrect or incomplete mental models cause difficulty and mistakes in problem solving. Mayer (1985) To solve math problems, students must be able to represent the problem, develop a solution path, and execute the solution (Rosenzweig, Krawec, & Montague, 2011). Mayer (1985) Several cognitive processes and metacognitive strategies (e.g., visualization, estimation, self-questioning) are integral to problem representation and execution underlie successful problem solving (Rosenzweig, Krawec, & Montague, 2011). Problem representation, generally speaking, is a combination of concrete representations and something written. Teachers must convey the meaning of mathematics as an integral part of students' everyday lives, on the other hand, ask the students to write their thoughts while solving math problems so that their misunderstandings are revealed.

One part of understanding mathematics is developing mathematical arguments and proofs (Tristani, & Nusantara, 2021). Mathematical argumentation aims to reveal the truth of conclusion making (Aberdein, 2005). Tristani and Nusantara (2021) argue that reasoning activities may occur in either dialogue or non-dialogue. Writing is an essential skill for learning and expressing what students know (Bai, 2018). It is vital to understand how students produce their solutions and writing so that teachers can know how to teach students effectively-conscious and deliberate use of Such strategies is to aid achieve automatically, self-regulation and correct understanding is developed. Using the Written think-aloud method is also associated with some concerns. For example, elementary school children may find Written think- aloud very demanding due to their verbalization skills, concentration, or reactivity (Merchie, & Van Keer, 2014). In addition, the influence of culture on individuals' learning cannot be Denied (Sommers, 2018). Furthermore, the role of the teacher or educator in developing or guiding reasoning in the students is crucial (Sylvia, 2019).

In order to provide deeper learning of mathematics, we used the method of assessment to learning, and in order to understand the cognitive process of students learning, we used the written think-aloud strategy. Written think- aloud makes it possible for the teacher to provide the most appropriate feedback and guidance to the student by being aware of the cognitive process, arguments and the problem -solving process. Therefore, the question of the current research is, what effect does assessment of mathematics in students using the written think-aloud protocol have on academic achievement?

## **2. Literature Review**

The think-aloud protocol has been used in various researches. In many educational researches as an effective strategy for learning (e. g., Merchie, E. and H. Van Keer,2014; Nakakoji Y, Wilson R,2020; Wolcott, M.D. and N.G. Lobczowski,2021; Rogiers A. et al., 2020 ) and in some psychological researches as an effective factor related to self-regulation (e. g. , Whitehead, A. E., et al., 2018) and in some as an elicitation tool (e. g. , Cohen, 2011; Gu, Hu, & Zhang, 2005; Altalhi F, Altalhi A, Magliah Z et al.,2021). Think-aloud protocols are considered the best method for collecting data on students' self-regulated learning experiences. (Bai, 2018).

Fernandez and Jamet (2017) documented some benefits of think-aloud protocols, e. g., identifying cognitive and meta cognitive processes which are regarded as effective self-

regulated learning strategies. Since the publication of Ericsson and Chase's work, thinking aloud has been recognized as an acceptable and even essential method in the study of human cognition. These sources of data can influence the design of future research, provide a deeper understanding of how an intervention, technology, or measurement makes an impact. The purpose of this study is to investigate the effect of writing thoughts while solving math problems on students' math performance. In fact, we want to know what is the causes of the students' right or wrong answers? Since assessment is done for learning and assessment as learning, this research examines the effect of using the protocol of writing thoughts and arguments in non-mathematical and non-formula language in assessing students' academic achievement.

In conclusion, the written think-aloud strategy is a useful tool that can significantly improve math performance among students. Through its implementation, students are given the opportunity to reflect on their thought processes as they work through complex problems, which can lead to increased understanding and improved problem-solving skills. While further research is necessary to investigate the long-term effects of this strategy, it is evident that it has the potential to positively impact math education and the academic success of students. Therefore, teachers should consider utilizing this strategy in their classrooms to enhance the learning experience for their students.

### **3. Method**

The purpose of the WTA is to ask the participant to think aloud as a means to capture the problem-solving process. Written think aloud means the learners should share their thoughts during an activity or task; most importantly, the researcher has the participant focus on what they are thinking (Gu, 2014).

At the start of a WTA, the researcher provided an example to show the participants how to think aloud and write in their own words the thoughts and reasoning that come to their mind while solving math problems. Then allowed them to practice on a similar task. The researcher required from the learners to apply previously learned skills. Then the participants solved the problems, while writing their thoughts. For effective WTAs, participants must be offered an opportunity to practice, as thinking aloud is something that may not come naturally. Practice helps thinking aloud to become more automatic, which allows participants to focus on task (Gu, 2014). The task must be of enough complexity, difficulty, or novelty to evoke the necessity of metacognitive ability Ward, & Traweck, 1993).

When subjects are simply instructed to verbalize or write the information they attended to, the structure of the process for performing the main task is not changed. Rather, they only ask subjects to explain their thought processes and reasons for their behavior in light of prior information relevant to the current problem.

Variables such as age, motivation, anxiety, self-disclosure and verbal ability are all correlated with the ability to express and express thoughts and may increase its effect. Therefore, the selection sample was tried to be homogeneous in these respects.

#### ***Participants***

The statistical population of the present study included the fifth-grade students of Hejrat school (n=60) in 1400-1401 academic year. The statistical sample was 32 students who participated in math classes in person (16 students from the fifth grade A and 16 students from the fifth grade B) in this plan. Participated who were selected by available sampling method. The assignment of subjects was done non-randomly and according to class grouping. Class A was selected as the control group and Class B as the experimental group.

We adopted a written think-aloud protocol to collect data and document the cognitive processes used in mathematics problem-solving tasks. These students were then assigned to one of two conditions: An experimental group used a written think-aloud technique during solving a mathematic problem; the control group did not use the think-aloud technique. Inclusion criterion included ages 10-12 years, the ability to write thinking and Self-disclosure ability.

**Method of execution**

The type of the present research was quasi-experimental and a pretest-post test design was used with a control group.

First, we took a pre-test from both control and experimental groups to get the basic level. Then we taught and evaluated chapter 6 of the math book. Formative assessment in the control group was done in a routine way, but in the experimental group, the students had to fully explain in non-mathematical and non-formulaic language the process of reaching the answer instead of the final answer to the problem.

Finally, a post-performance exam consisting of ten open-ended questions selected. The subjects were tested in a quiet room at school lasting approximately 45 min. Rather than investigating whether the learners solved a problem or not, our focus was on the process of student reasoning while solving problems.

**4. Findings**

Our research question was What is the effect of written think aloud strategy on the students' success in solving math problems?

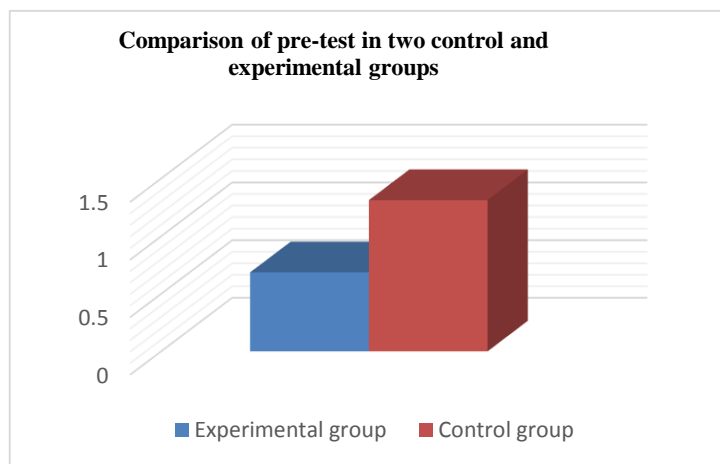
Descriptive and Inferential statistics were used to analyze the collected data. In order to describe the data, indicators such as average and standard deviation were used (Table 1 and Chart 1); and in order to analyze the data and compare the averages of the two groups, the t-test (Table 2, Diagram 2) and the non-parametric, covariance analysis test (Table 3, Diagram 3) were used; The data was analyzed by SPSS 22.

*Table 1. Comparison of pre-test in two control and experimental groups\**

Pre-test	N	Mean	Std. Deviation	Std. Error Mean
Experimental group	16	.6875	.81394	.20349
Control group	16	1.3125	2.72565	.68141

\* t-test

According to table1, there is no significant difference between the average of the control group and the experimental group in pre-test.



*Figure 1. Comparison of pre-test in two control and experimental groups*

*Table 2. Comparison of post-test in two control and experimental groups\**

Post-test	N	Mean	Std. Deviation	Std. Error Mean
Experimental group	16	19.3750	7.08637	1.77159
Control group	16	13.8125	6.34790	1.58697

\* t-test

According to table2, there is a significant difference between the average of the control group and the experimental group in the post-test. Therefore, the null hypothesis is rejected and it can be concluded that the use of the written think-aloud strategy in the math assessment of students affected their math success.

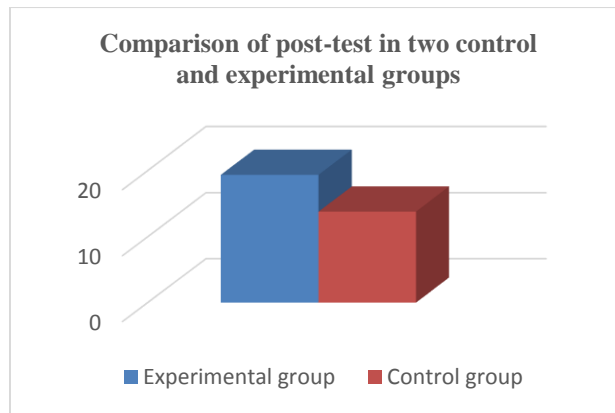


Figure 2. Comparison of post-test in two control and experimental groups

In order to check the results, covariance analysis test was used

Table 3. Comparison of post-test in two control and experimental groups\*

Variable	sum of squares	df	F	(p-value)
Width from the origin	1102.175	1	502.786	0.000
pre-exam	529.713	1	483.284	0.000
Grouping	514.911	31	469.780	0.000
error	25.210	32		
Total	255162			

According to table 3, the test showed that the difference in the average scores of students in the control and experimental groups is significant ( $p \leq 0.0000$ ). , covariance analysis showed that the use of the written think-aloud strategy in the math assessment of students affected their math success.

## 5. Discussion

The study was conducted with the aim of investigating the effect of written think-aloud strategy (WTA) on students` math performance among 5th grade students of Hejrat School in Arak city.

According to this research, addition of a written think-aloud protocol to the math learning has several benefits. The current research showed that the use of the written think-aloud strategy in the math assessment of students affected their math success, also suggests that young students are able to perform think-aloud and write down their thought processes with sufficient training.

This evidence is in line with findings from other studies (Contreras Villamiza et al., 2023; Pan et al., 2023; Alhejaili, Wharrad, & Windle, 2022; Wolcott & Lobczowski, 2021; Nakakoji, Wilson, 2020; Rogiers et al., 2020; Wan, Tor, & Hudson, 2020; Fuchs et al., 2019; Power, Lemay, & Cooke, 2017; Vandeveldel et al., 2015; Merchie, E. and H. Van Keer, 2014; Gu et al. 2005).

Contreras Villamiza et al. (2023) Recently, in a study entitled “ Construction of a strategy to evaluate the clinical reasoning of internal medicine residents through the use of the Script

Concordance Test plus Written Think Aloud” found The SCT<sup>2</sup>-WTA<sup>3</sup> was perceived as complementary and valuable as a formative assessment.

Wan, Tor, & Hudson (2020) Think-aloud is an exceptionally valuable methodology for SCT approval research, particularly in social occasion proof for reaction process legitimacy in this various decision evaluation design.

Alhejaili, Wharrad, & Windle (2022) has shown that Think-Aloud research methods are a reliable source of information about the psychological mechanisms and knowledge structures that underpin human problem-solving activities in relation to specific tasks, such as problem solving, reading, writing, research on second language learning, counseling, business, and human-computer interactions, etc.

Metacognitive strategies are higher-order executive abilities, which enable learners to inspect their learning, efforts, success, and future learning directions. By using metacognitive strategies, learners exercise conscious management and control over their own learning process. They set up their learning goals, work out procedures for reaching their goals, and evaluate whether their goals have been reached (Bai,2018). They also display their superiority in metacognitive awareness through their use of various monitoring strategies (Bai,2018). Ericsson and Simon (1993) have put together various studies on verbal reports in Western countries and have shown that it is a quite reliable and valid method that might in turn influence and redirect their problem solving or trigger new thought processes (reactive effects of verbal protocols) (Hayes, 1986).

However, this conclusion should be treated with caution. There may be a task difference with regard to the students’ use of writing strategies (Bai, 2018). The question whether this method can provide a complete picture of the cognitive processes that are considered during the performance of tasks is controversial.

Learning to solve problems requires the coordination and mastery of numerous complex skills. An understanding of the complexity of strategic processing has tempered the enthusiasm and recommendations of metacognition for understanding problem-solving. We must examine precisely how metacognition interacts with strategic knowledge and application. Children's strategic processing may require systematic prompting in addition to training until the processes become automatic. The teacher can offer fresh perspectives on how strategy instruction in schools can be evaluated and carried out. The teacher may play a crucial role in examining how metacognitive processes interact with other intricate problem-solving processes in order to translate metacognition from theory to practice. The written think-aloud procedure may be useful for teachers interested in determining specific areas of weakness in students’ processing skills, different types of errors, and strategies used during problem-solving. As an alternative to solving problems Process-oriented measures, as opposed to assessment methods that rely on standardized tests and emphasis on the final answer to the problem, can give useful insights into the cognitive and metacognitive strategies used by learners, which can help with strategy training for problem-solving interventions.

The written think-aloud technique described here can be used by a teacher, assistant, or peer tutor as an intervention in the classroom as well as a tool for teachers to formative assess students' problem-solving abilities. These tasks are difficult, especially for students who struggle to learn mathematics. As a result, effective intervention is essential. Good reading comprehension skills and more advanced reading comprehension strategies are linked to written think-aloud skills (Fuchs et al., 2019).

## **6. Conclusion**

It is deduced that writing think- aloud can tap into information that cannot be analyzed by other methods alone, explaining the differences or accessing the nuances usually not revealed through other forms of data gathering. These methods will assist teachers in developing a more

<sup>2</sup> Script Concordance Test

<sup>3</sup> Written Think Aloud

transparent comprehension of the mathematical concepts and help students foster deeper connections within the mathematics curriculum.

Primary school students are able to write their thinking processes during problem-solving with proper training. In addition, by writing think-aloud about what is happening in their minds, students can better monitor and self-regulate their own learning of math. It also helps teachers to be aware of the cognitive processes that occur in students' minds during problem-solving. By being aware of what is going on in the minds of students, teachers can well discover their knowledge defects and misunderstandings (detecting question misinterpretation) and provide the necessary guidance in a timely and sufficient manner in order to solve their shortcomings and defects.

This is an effective method to discover the cognitive errors of the learners, and increase the accuracy of the teacher's feedback. Giving quick and timely feedback by the teacher improves the thinking process and, as a result, succeeds in solving math problems. On the other hand, after using a written think-aloud method, students can gain powerful and timely knowledge of mathematical reasoning by addressing such misconceptions in face-to-face discussions. Educators can also use this to improve ambiguous questions to avoid students' confusion and misinterpretation. Accordingly, teachers should employ writing down thinking and arguing as a useful tool to find out the math self-regulated strategies.

Some limitations of the present study were:

First, there were only 32 students' written think-aloud protocols in this study. Larger sample size may lead to other different findings.

second, the teacher of the experimental group was different from the teacher of the control group. Therefore, the teaching method of the teachers can affect the results of the experiment.

Third, our sampling was not random, so the generalization of the results is limited.

Fourth, some cognitive process are not active in working memory and cannot be verbalized. Wilson (1994) Some psychological processes do not reach consciousness or are automatic processes that cannot be verbalized (Güss, 2018).

Fifth, the limitation is sometimes a participant may experience various thoughts, but may not have the time to write all of them and, therefore, will be required to select what to report.

Also, the learning task used in this study was oriented toward preparing for a test. It is however shown that students modify their strategy used to fit different tasks or purposes and that especially the purpose of test preparation is linked to more effortful learning (Rogiers, Merchie, & Van Keer, 2020).

### ***Suggestions***

A large target population should be selected and random sampling should be done so that the research results are reliable and can be generalized to similar communities.

Considering the vital role of focusing on solving problems and writing down thinking in students' learning and mathematical success, future research should investigate the extent and degree of change in students' self-regulation according to this strategy through longitudinal research.

Another important area of impact is within decision-making and problem-solving research. In this profession, this could include research about diagnostic reasoning, educational problem-solving processes, and mapping how learners identify and resolve misconceptions in their knowledge.

The development and evaluation of these cognitive models can inform how educators create educational interventions and learning activities that best support the construction of knowledge based on these cognitive models. For instance, a cognitive model could be constructed to how students typically solve a problem and the factors that influence them. We can identify common errors that a learner may commit in this task and provide support or prompting that can help minimize these issues.

The teachers should realize that students may experience differences in their developmental levels in writing. We also recommend that thinking aloud should be introduced to young students in the early years of their mathematics education as it is a gradual developmental process over time. This task in this research was considered for the math test. More variables or strategies could be investigated in depth in future research.

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### **Declaration of Competing Interest**

The author declares that he has no competing financial interests or known personal relationships that would influence the report presented in this article.

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