



Research article

A strategy based on fun learning for developing deep understanding of mathematics and reducing cognitive load among middle school students

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Abstract: This study examined the effectiveness of a teaching strategy based on fun learning in developing students' deep understanding of mathematical problems and reducing their cognitive load at the intermediate school level. It also explored the relationship between students' deep understanding of mathematical problems and their level of cognitive load. The study used a quasi-experimental design, with a sample of 68 seventh-grade students in Saudi Arabia. The research instruments consisted of a mathematics achievement test, a test measuring deep understanding skills in mathematical problems, and a cognitive load scale. The results showed statistically significant differences in mean scores between the experimental and control groups in the post-administration of the mathematics achievement and deep understanding skills tests in mathematical problems, with the differences in favor of the experimental group. The findings also revealed statistically significant differences in the post-administration of the cognitive load scale, with lower scores among the experimental group. This indicates that students in the experimental group experienced a lower level of cognitive load than their peers in the control group. In addition, the results showed a statistically significant negative correlation between students' deep understanding skills in mathematical problems and their level of cognitive load. Based on these findings, the study recommends integrating fun learning-based teaching strategies into mathematics teacher preparation and professional development programs. This may help present mathematics in more interactive and engaging learning contexts, support students' deep understanding, and reduce sources of cognitive load associated with learning mathematical concepts and solving mathematical problems.

Keywords: fun learning, deep understanding, mathematical problems, cognitive load, mathematics, middle school

1. Introduction

Mathematics is an academic field that requires learners to use different levels of thinking, given its nature as a discipline built on concepts, relationships, symbols, representations, and problems. Learning mathematics is not limited to memorizing rules or applying computational procedures. Rather, it involves the construction of meaning, understanding relationships, interpreting mathematical situations, and choosing appropriate strategies for problem solving. For this reason, teaching mathematics requires instructional approaches and strategies that help learners move beyond surface-level processing toward deeper understanding. Such approaches can support students' ability to interpret mathematical ideas and apply them in new situations [1]. The intermediate school stage is particularly important in this regard. This stage represents a developmental and educational phase in which learners gradually move from concrete thinking to more abstract and organized forms of reasoning. During this stage, students' abilities to analyze, compare, infer, formulate hypotheses, and make decisions continue to develop. They also become more capable of dealing with problems in a conscious and systematic way. Cherukunnath and Singh [2] indicated that the intermediate stage contributes to developing students' personal development and enhancing their mental and cognitive abilities through the knowledge, experiences, and educational activities it provides.

From this perspective, the concept of deep understanding has received increasing attention in the literature on education and mathematics teaching, as it is considered one of the central goals of effective learning [3]. Deep understanding is not simply about remembering or recalling information. It refers to learners' ability to connect prior knowledge with new experiences, recognize relationships among ideas, provide justified explanations, ask meaningful questions, and use what they have learned in new situations. Several educational orientations have emphasized the importance of moving from knowledge-transmission teaching toward teaching for understanding, so that learning becomes more lasting and more applicable [4]. In mathematics education, understanding and analyzing mathematical problems are essential components in building mathematical knowledge. The National Council of Teachers of Mathematics [5] has emphasized problem solving as a fundamental standard in mathematics learning. Problem solving involves analyzing the mathematical situation, identifying the given information and relationships, developing a solution plan, implementing the plan, and evaluating whether the solution is reasonable. Working with mathematical problems also gives learners opportunities to practice different types of thinking, including critical thinking, analytical thinking, decision-making, and mathematical justification.

Deep understanding of mathematical problems is closely related to learners' ability to go beyond direct procedural solutions. It involves interpreting the structure of the problem, generating alternative solutions, selecting the most appropriate method, and justifying the steps taken [6]. In general, deep understanding can be defined as a set of interconnected abilities that develop through reflection, questioning, inquiry, discussion, and the use of ideas in different situations [7]. In mathematics, deep understanding is linked to learners' ability to connect new information with what already exists in their cognitive structure, which helps them reach logical solutions to mathematical problems. This is reflected in several dimensions, including generative thinking, questioning,

explanation, and decision-making. Despite the importance of deep understanding in learning mathematics, some studies indicate that students, particularly at the intermediate stage, may show weaknesses in this area [8]. These weaknesses may appear in students' limited ability to ask in-depth questions during learning, provide appropriate explanations and conclusions, transform mathematical concepts and generalizations from one form to another, generate different alternatives when solving problems, or justify their choice of solution method. Such difficulties can be reflected in students' mathematical achievement and in their ability to deal with mathematical problems flexibly and with understanding.

At the same time, weak deep understanding of mathematical problems may be associated with a high level of cognitive load during learning and problem-solving. Cognitive load refers to the amount of mental effort imposed on working memory while processing information and performing instructional tasks [9]. Since working memory has a limited capacity, presenting information in a dense or poorly organized way, or using teaching methods that do not consider the nature of the mathematical task, may increase cognitive load in a way that hinders understanding, processing, and the construction of cognitive schemas. Cognitive Load Theory emphasizes that learning becomes more effective when educational experiences are organized in a way that takes into account the limits of working memory [10]. This helps learners direct their mental effort toward processing essential information and constructing understanding. In mathematical problem solving, sources of cognitive load may stem from difficult terminology, the number of solution steps, weak links among mathematical representations, or teaching methods that rely on rote instruction and memorization rather than on understanding and active practice. Therefore, reducing cognitive load does not mean oversimplifying mathematics or weakening its nature. Rather, it means organizing mathematics learning in a way that helps learners process information more clearly and coherently.

In light of this, there is a need for teaching strategies that make mathematics learning more interactive and more connected to learners' experiences, while also supporting deep understanding and reducing cognitive load. Fun learning is one instructional approach that may help achieve this purpose. It is based on the use of educational activities and tasks that stimulate learners' interest, increase their participation, and support their learning through practice, educational games, puzzles, inquiry-based activities, and mathematical situations that encourage thinking [11]. Fun learning does not mean turning learning into mere entertainment. Instead, it involves creating a positive learning environment that helps learners engage effectively in learning and reduces the boredom and frustration that may accompany mathematics learning when traditional methods are used. Its significance in mathematics education comes from the opportunities it gives learners to interact with concepts and problems through active learning contexts [1]. It encourages discussion, questioning, testing solutions, and exchanging ideas. Moreover, varying educational activities and presenting content in an engaging way may help distribute cognitive effort more appropriately. This can reduce the concentration of cognitive load on memorization and recall, leaving more room for understanding, interpretation, and the construction of relationships [12]. In this sense, fun learning can be viewed as an instructional approach that integrates both cognitive and affective dimensions in mathematics learning.

Although some previous studies (e.g., [13–16]) have addressed fun learning in mathematics teaching and examined its effect on different learning outcomes, a review of the relevant literature indicates a need for further research on the effectiveness of a teaching strategy based on fun learning in developing deep understanding of mathematical problems while also reducing cognitive load

among intermediate school students. The research gap lies in the limited number of studies that have combined these two variables—deep understanding of mathematical problems and cognitive load—within an experimental design targeting seventh-grade students in mathematics education in Saudi Arabia.

The focus on seventh-grade students was not only a matter of sampling convenience but was also connected to the educational and curricular context of mathematics learning in Saudi Arabia. In the Saudi intermediate-stage mathematics curriculum, seventh grade represents an important transitional point in which students begin to deal more extensively with abstract mathematical relationships, measurement, geometric representation, and two- and three-dimensional figures. These topics require students to connect symbolic, verbal, and visual information, analyze mathematical situations, and move beyond direct procedural application. The selected unit, *Measurement: Two-Dimensional and Three-Dimensional Figures*, includes concepts and tasks that are closely related to mathematical problem solving, interpretation, reasoning, and the management of cognitive effort. For this reason, seventh grade was considered an appropriate educational level for examining the effectiveness of a fun learning-based strategy in developing deep understanding of mathematical problems and reducing cognitive load.

To strengthen the research problem, the researcher conducted an exploratory study on a sample of 27 seventh-grade students who were not part of the final study sample. The exploratory study used an initial test to measure selected skills involved in the deep understanding of mathematical problems and a scale to measure the level of cognitive load. The results showed that 21 students, representing 77.8%, scored below half of the total score on the deep understanding skills test, indicating a noticeable weakness in their performance in these skills. The results also showed that 19 students, representing 70.4%, obtained high scores on the cognitive load scale, indicating an elevated level of cognitive load while learning mathematics and solving mathematical problems.

Based on these preliminary findings, the significance of the present study lies in its attempt to propose a fun learning-based strategy for teaching mathematics and to measure its effectiveness in developing deep understanding skills in mathematical problems and reducing cognitive load among intermediate school students. The study also contributes to presenting an instructional treatment that combines the improvement of mathematical understanding with the organization of the cognitive effort exerted during learning. This may benefit mathematics teachers, curriculum developers, and teacher preparation programs. Accordingly, the present study was guided by the following main question:

What is the effectiveness of a fun learning-based teaching strategy in improving seventh-grade students' mathematics learning outcomes, represented by mathematical achievement, deep understanding of mathematical problems, and cognitive load, and what is the relationship between deep understanding and cognitive load?

To address this main question, the study pursued the following objectives:

1. To identify the deep understanding skills in mathematical problems that are appropriate for seventh-grade students.
2. To design a teaching strategy based on fun learning for teaching the unit *Measurement: Two-Dimensional and Three-Dimensional Figures*.
3. To examine the effectiveness of the fun learning-based strategy in developing students' mathematical achievement.

4. To examine the effectiveness of the fun learning–based strategy in developing students’ deep understanding skills in mathematical problems.
5. To examine the effectiveness of the fun learning–based strategy in reducing students’ cognitive load.
6. To determine the nature and direction of the relationship between deep understanding skills in mathematical problems and cognitive load.

These outcomes were examined together because they represent interrelated dimensions of mathematics learning. Mathematical achievement reflects students’ mastery of the targeted content, deep understanding reflects their ability to interpret, justify, question, and generate solutions, while cognitive load reflects the mental effort required to process mathematical tasks. A fun learning–based strategy was expected to support achievement and deep understanding by increasing engagement, organizing learning experiences, and reducing unnecessary cognitive burden during problem solving.

2. Theoretical framework and literature review

2.1. Fun learning in mathematics

Fun learning is an instructional approach that aims to make the learning situation more engaging and interactive by using structured educational activities that capture learners’ interest, increase their participation, and support their learning in a positive classroom environment [17]. Fun learning does not mean turning education into entertainment that lacks academic purpose. Rather, it uses enjoyment to motivate learning and support knowledge construction and skill development, especially in subjects that some learners may find abstract or difficult, such as mathematics. Definitions of fun learning vary among the literature. Bukit et al. [18] defined it as a set of educational activities or games used in specific instructional situations, helping to transform the learning situation and its content into flexible and enjoyable learning experiences in which learners participate in some of its components. Fun learning is also viewed as the acquisition of knowledge and skills through methods that provide learners with enjoyment and positive learning experiences, increase their motivation and participation in learning processes, support affective aspects, and positively influence their cognitive development [19]. Okasha [20] described it as a meaningful, contextual, constructivist, and active instructional approach that takes learners’ psychological development into account and presents content through educational activities or games in an enjoyable and stimulating atmosphere. Kokarida et al. [21], meanwhile, considered it one of the innovative educational methods that helps present important information in an organized and purposeful way while enhancing learners’ sense of happiness and desire to learn. In light of these definitions, fun learning in mathematics can be understood as an instructional approach based on designing active and engaging learning experiences that include activities, games, puzzles, and mathematical situations that stimulate thinking. These experiences help break the routine of learning and allow learners to interact with mathematical concepts and problems in a more positive and effective way. This approach is particularly important in mathematics teaching, as learning mathematics often requires students to process abstract concepts, connect symbolic, visual, and verbal representations, and engage in continuous problem-solving practice. Therefore, integrating enjoyment into mathematics learning may help reduce feelings of boredom or anxiety and enhance both cognitive and affective engagement in the learning situation.

Fun learning is based on several principles that help explain its nature and its role in improving the quality of learning. One of the most important of these principles is the flow experience, a state in which the learner becomes mentally and emotionally immersed in the learning task, combining enjoyment with deep concentration. In this state, the learner does not simply take part in the activity at a surface level but becomes actively engaged in the cognitive processing of what is being learned [22]. This is consistent with the constructivist perspective, which emphasizes the central role of the learner in constructing knowledge. However, fun learning adds an affective dimension that helps maintain attention and participation. Another principle related to fun learning is the experience economy, which suggests that the more organized and engaging the educational experience is for the learner, the greater its potential to produce better learning outcomes with relatively less time and effort [23]. Learning experiences that are designed to be enjoyable and meaningful may help learners understand and retain knowledge more effectively than traditional experiences that mainly focus on reception or repetition. Fun learning is also linked to the principle of curiosity. Engaging activities and thought-provoking situations encourage learners to search for answers, explore relationships, and address knowledge gaps that emerge during learning [24]. The emotional effect is another central principle in fun learning. Learners' emotions and attitudes toward a school subject may influence their level of participation and achievement [25]. When the learning situation is designed in a way that includes moderate challenge, peer interaction, and a sense of accomplishment, it may reduce withdrawal or frustration and increase learners' acceptance of the subject. Closely related to this is intrinsic motivation, through which fun learning activates learners' internal motivation through meaningful activities and educational experiences that provide a sense of achievement and enjoyment, rather than relying only on external motivation such as grades or rewards [26].

Several studies have examined the use of fun learning in mathematics education. Shmakov and Hannula [27] investigated the effect of using humor to make mathematics more enjoyable and to develop learners' emotional and mathematical thinking. The findings indicated that the appropriate use of humor in mathematics teaching can help create a positive classroom environment and support the development of mathematical thinking within a context that learners find more acceptable. This study shows that enjoyment is not separate from the cognitive dimension; rather, it can serve as a supportive entry point for thinking and engagement with mathematical content. Himmawan and Juandi [28] conducted a systematic literature review (SLR) on the effect of game-based mathematics learning. Their study analyzed a number of primary studies published in databases including Google Scholar and ERIC. The findings showed that games used in mathematics learning can be classified into traditional and modern games, and that both types can contribute to improving learning quality, increasing student activity, and enhancing indicators of learning efficiency. This finding confirms the importance of educational games as one practical application of fun learning in mathematics, provided that they are designed in light of clear educational objectives. In the same context, Mustafa et al. [29] examined the effect of fun learning methods on seventh-grade students' interest in learning mathematics. The study was based on the observation that students' interest in learning mathematics tends to decline, especially when they encounter difficult topics or tasks that require cognitive effort. The researchers used a questionnaire and an observation checklist to collect data. The results showed that employing fun learning methods increased students' interest and activity during mathematics learning. The significance of this study lies in its relevance to the age group targeted in the present research and in its specific focus on seventh-grade students.

Ardani et al. [30] examined the extent to which game-based entertainment learning media were

used in mathematics education among a sample of first-year intermediate students. The results indicated that these media were highly practical and easy to use. They also contributed to improving cognitive and affective performance, supporting both individual and collaborative learning, and providing opportunities for learning across different times and places. This study highlights the importance of game-based educational media not only as a way to attract attention but also as tools that can support self-directed and collaborative mathematics learning. Pulungan and Marpaung [31] focused on helping teachers overcome students' low interest in learning mathematics through the use of enjoyable instructional media, such as mathematical manipulatives and puzzle straw activities. The findings showed that students became more enthusiastic about learning mathematics, particularly in geometry topics, as the media helped them explore geometric concepts directly. The study also contributed to raising teachers' awareness of the importance of enjoyable instructional media in mathematics teaching.

Taken together, previous studies indicate that fun learning in mathematics has often been associated with improving motivation, increasing participation, developing interest, and enhancing certain aspects of cognitive performance. Some studies have also focused on educational games, interactive media, humor, and hands-on activities as practical applications of this approach. However, most of these studies have examined fun learning mainly in relation to achievement, interest, or participation. Further research is needed to examine the link between fun learning and the development of deep understanding of mathematical problems on the one hand, and the reduction of cognitive load on the other, particularly among intermediate school students.

2.2. Deep understanding of mathematical problems

Deep understanding is a central construct in contemporary educational literature. Effective learning is no longer measured only by learners' ability to remember or reproduce information. Rather, it is also reflected in their ability to use knowledge, connect it to new contexts, interpret it, critique it, and apply it in problem solving [32]. Therefore, education that is limited to acquiring and recalling knowledge, without enabling learners to benefit from it in new situations, remains limited in its impact on the development of thinking and decision-making abilities. Theoretical perspectives on deep understanding vary. Fenwick et al. [33] defined it as the learner's ability to perceive concepts and their associated meanings, retrieve them when needed, and build meaningful connections among different concepts within the cognitive structure. Uesaka et al. [34] viewed deep understanding as the critical examination of new ideas and facts, their integration into the cognitive structure, the construction of multiple relationships among them, the provision of varied explanations for a problem, and the generation of new solutions. Ali and Al Kadhimi [7] indicated that deep understanding includes subprocesses of thinking such as concept formation, principle formation, and comprehension, which are processes associated with learners' characteristics, experiences, and the learning environment in which they learn.

In mathematics, deep understanding is especially important because learning mathematics is not based only on memorizing rules or following algorithms. It requires grasping the conceptual structure of the mathematical situation, understanding relationships among data, connecting different representations, and justifying solution steps [35]. A learner who has deep understanding of a mathematical problem can analyze it, identify what is known and what is required, retrieve relevant prior knowledge, generate more than one possible solution path, and evaluate the correctness and

reasonableness of the solution. In this sense, deep understanding provides a basis for moving from procedural performance to justified mathematical thinking. Deep understanding cannot be verified through traditional tests that focus only on the final answer or on recalling information. Instead, it requires performance indicators that reveal the learner's ability to interpret ideas, ask questions, generate solutions, and make decisions [36]. Accordingly, some literature (e.g., [37–39]) has identified a set of skills that indicate deep understanding, most notably generative thinking, interpretation, and questioning. Generative thinking includes skills such as fluency of ideas, flexibility, hypothesis formulation, and prediction in light of mathematical data [37]. Interpretation refers to the learner's ability to assign logical meaning to results or relationships based on prior knowledge or on the properties of the mathematical problem [38]. Questioning, meanwhile, reflects the learner's ability to produce questions at different levels, moving beyond recall toward application, analysis, synthesis, and evaluation [39].

Several studies have examined deep understanding in mathematics and its relationship with different educational and cognitive variables. Abdelshafy [40] aimed to identify deep understanding and its relationship with deductive thinking among ninth-grade students in mathematics. The study sample consisted of 400 female students. The researcher used one test to measure deep understanding and another to measure deductive reasoning. The findings showed that students' levels in the deep understanding test and the deductive reasoning test were good and revealed a positive correlation between the two variables. This finding suggests that deep understanding is associated with learners' ability to reason and construct logical relationships, which are important skills in mathematics learning. Otaify et al. [41] examined the effect of using the probing thinking model in addressing geometric misconceptions and developing skills among first-year intermediate students. The study used a quasi-experimental design with two groups: experimental and control. The sample consisted of 80 students. The study instruments included a teacher's guide, a student booklet, a deep understanding skills test, and a tool for detecting geometric misconceptions. The results showed that the probing thinking model significantly developed deep understanding skills and identifying geometric misconceptions and their causes among students. The importance of this study lies in the way it connects deep understanding with geometry learning and with learners' ability to distinguish conceptual and inferential errors.

In the same context, Hathal and Dhari [42] aimed to identify the extent to which second-stage students possessed deep understanding skills and how these skills were related to their ability to solve mathematical problems. The researchers used the descriptive method and developed two tests: one to measure deep understanding skills and another to measure the ability to solve mathematical problems. The sample consisted of 100 male and female students. The findings showed that students possessed a good level of deep understanding skills and a good ability to solve mathematical problems. The results also revealed a positive correlation between deep understanding skills and mathematical problem-solving ability. This finding supports the assumption that deep understanding is an important requirement for solving mathematical problems effectively. Mohamed and Salhah [43] measured the effectiveness of a proposed strategy in developing levels of mathematical depth of knowledge and deep understanding in mathematics among primary school students. The study adopted an experimental design with two groups: experimental and control. Its instruments included a test of mathematical depth of knowledge levels and a test of deep understanding. The findings revealed statistically significant differences in favor of the experimental group in the post-administration, indicating the effectiveness of the proposed strategy in developing levels of

depth of knowledge and deep understanding in mathematics. The results also showed a strong positive correlation between depth of knowledge levels and deep understanding, as well as the continued effect of the strategy in the follow-up administration.

Overall, these studies indicate that deep understanding in mathematics is associated with higher-order cognitive skills, such as reasoning, problem solving, detecting misconceptions, and interpreting relationships. They also confirm that developing deep understanding requires teaching strategies that go beyond presenting information and instead engage learners in analysis, interpretation, questioning, and the generation of alternatives. Indeed, while several studies have focused on the relationship between deep understanding and cognitive variables such as reasoning or depth of knowledge, there remains a need to examine the effectiveness of interactive and affective instructional approaches, such as fun learning, in developing deep understanding of mathematical problems, particularly among intermediate school students.

2.3. Cognitive load in mathematics

Cognitive load is an important concept in cognitive psychology and instructional design because it is directly related to how learners process information during learning and problem-solving activities. Cognitive load refers to the amount of mental effort imposed on working memory while performing a particular instructional task [44]. Since working memory has a limited capacity, increasing the amount of information or presenting it in an inappropriate way may confuse learners, weaken their ability to understand and organize information, and hinder the construction of cognitive schemas. Definitions of cognitive load vary among the literature. Van Merriënboer et al. [45] defined it as the load imposed on working memory during learning and problem-solving activities. Mayer and Moreno [46] viewed it as the amount of working memory required by a problem-solving task. Sweller [47] defined it as the amount of mental effort imposed on working memory as a result of performance demands in a task that includes a certain amount of information. All these definitions emphasize that cognitive load is related to the limits of learners' mental processing and to the way the instructional task is designed and presented.

Cognitive load is particularly important in mathematics education because solving mathematical problems often requires learners to process several elements at the same time [48]. These elements may include understanding the wording of the problem, identifying the given information, retrieving appropriate rules or concepts, selecting a solution plan, carrying out procedures, and verifying the result. When these components are not organized in a way that considers learners' abilities and prior experiences, the load imposed on working memory may increase. This, in turn, may weaken understanding and limit learners' ability to process the problem effectively.

Cognitive load theory, as developed by Sweller et al. [49], identifies three main types of cognitive load. The first is intrinsic cognitive load, which refers to the amount of processing required to understand the learning content itself. It is influenced by the difficulty of the content, the number of interacting elements within it, and the learner's level of prior knowledge. The greater the interaction among the elements of the mathematical task, and the lower the learner's prior experience, the higher the intrinsic load. This type of load can be managed by organizing tasks gradually, segmenting content, and providing appropriate examples that take learners' levels into account. The second type is extraneous cognitive load, which is associated with the way information is presented, the design of instructional materials, and the teaching strategies used. This type of load arises when

information is presented in a distracting or disorganized manner, or when the task includes additional elements that do not serve learning. Extraneous load is highly modifiable. It can be reduced by improving instructional design, clarifying instructions, organizing visual and verbal representations, and removing unnecessary information. The third type is germane cognitive load, which is associated with useful cognitive processing that contributes to the construction of cognitive schemas and the development of understanding. Unlike extraneous load, this type is considered positive when mental effort is directed toward understanding relationships, organizing knowledge, and constructing meaning. Therefore, Cognitive Load Theory does not aim to reduce all forms of load. Rather, it seeks to minimize unnecessary load, regulate intrinsic load, and enhance the cognitive effort directed toward meaningful learning.

Cognitive Load Theory is based on several cognitive assumptions. One of the most prominent is the assumption of active processing, which emphasizes that learners process information by attending to the information presented, mentally organizing it into a coherent structure, and then linking it to prior knowledge [50]. The theory is also based on the dual-channel assumption, which suggests that information is processed through two main channels: the auditory–verbal channel and the visual–spatial channel [51]. This means that designing instruction in a way that integrates verbal and visual representations can help distribute cognitive processing and reduce pressure on working memory.

In light of this theory, the literature has proposed a set of instructional principles that can be used to reduce cognitive load during mathematics learning and problem solving. One of these is the modality principle, which involves presenting information through integrated visual and verbal representations so that processing is distributed between the visual and auditory channels [52]. Another important principle is the split-attention principle, which emphasizes the need to integrate related sources of information rather than distribute them across different locations, so that learners do not have to spend additional effort searching for and linking sources [53]. Another key principle is the worked-examples principle, in which learners are presented with a solved example that illustrates the thinking steps and procedures needed for a solution, rather than being asked to solve the entire problem independently at an early stage of learning [54]. This helps reduce extraneous load caused by unguided searching for solution steps. Closely related to this is the completion principle, which presents learners with a partially solved problem and asks them to complete it, thereby directing their attention to important steps without overloading working memory [52]. The redundancy principle also contributes to reducing extraneous load by removing information or representations that do not add new meaning or that repeat content in a way that may distract learners' attention [9].

Several studies have examined cognitive load in mathematics education. Gillmor et al. [55] investigated the effect of research-based strategies on reducing extraneous cognitive load caused by the wording of mathematics test items among intermediate school students. The findings showed that reducing cognitive load in test items—through simplifying wording, highlighting important information, organizing visual elements, and removing unnecessary content—improved students' performance and reduced test anxiety. This study confirms that cognitive load may be related not only to the mathematical content itself, but also to the way the question or task is presented. Yung and Paas [56] examined the effect of visual representations on achievement and cognitive load in mathematics among primary school students. The study compared a group that learned mathematics using visual representations with another group that learned without them. The findings showed that the use of visual representations improved achievement and reduced cognitive load. This result

supports the importance of visual representations in organizing mathematical information and facilitating its processing, particularly when concepts or relationships are abstract. Gupta and Zheng [48] examined the interaction among prior knowledge level, type of worked example, and task difficulty in improving performance and reducing cognitive load during mathematical problem solving. The results showed that learners with high prior knowledge benefited more from incomplete worked examples, whereas learners with low prior knowledge benefited from fully worked examples. This finding indicates the importance of aligning the type of instructional support with learners' prior experience. In other words, an instructional strategy is not inherently effective in all situations; rather, its effectiveness is influenced by learners' characteristics and the nature of the task.

The foregoing discussion indicates that cognitive load is an important factor in mathematics learning and that reducing unnecessary sources of load can help learners direct their mental effort toward understanding and knowledge construction. The studies also confirm that the design of the mathematical task, the way information is presented, the use of visual representations, and the employment of fully or partially worked examples can all influence the level of cognitive load. However, most studies have focused on instructional design principles, visual representations, or worked examples, while there remains a need to examine the effectiveness of broader instructional strategies, such as fun learning, in reducing cognitive load during mathematics learning and problem solving.

The literature review shows that fun learning is a promising instructional approach in mathematics education because it provides a more interactive learning environment, offers opportunities to increase learners' participation, stimulates their interest, and motivates them to engage positively in mathematical activities. The literature also shows that deep understanding of mathematical problems is a fundamental goal in mathematics education, as it is associated with learners' ability to analyze, interpret, ask questions, generate solutions, and make decisions. By contrast, cognitive load appears as one of the factors that may hinder understanding and learning when task demands exceed the capacity of learners' working memory.

Although some studies have examined fun learning in mathematics (e.g., [28–31]), and others have addressed deep understanding or cognitive load (e.g., [40–43,48]), the literature indicates that few studies have combined these three variables within a single framework, particularly at the intermediate school stage. Most studies on fun learning have focused on interest, motivation, achievement, or learning quality. Studies on deep understanding have often focused on its relationship with reasoning, problem solving, or depth of knowledge. Similarly, studies on cognitive load have frequently emphasized task design, visual representations, or worked examples. Thus, the research gap relates to the need to investigate the effectiveness of a strategy based on fun learning in simultaneously developing deep understanding of mathematical problems and reducing cognitive load among intermediate school students. Accordingly, the present study seeks to contribute to addressing this gap by developing a teaching strategy based on fun learning and measuring its effectiveness in developing deep understanding skills in mathematical problems and reducing cognitive load among seventh-grade students. The significance of this study stems from its integration of the cognitive dimension represented by deep understanding, the cognitive-regulatory dimension associated with cognitive load, and the affective-motivational dimension on which fun learning is based. In doing so, the study offers a more integrated instructional treatment for mathematics learning at the intermediate school stage.

3. Methodology

The present study examined the effectiveness of a teaching strategy based on fun learning in developing academic achievement and deep understanding of mathematical problems, as well as in reducing cognitive load among intermediate school students. The study used a quasi-experimental design with two groups: an experimental group taught using the fun learning-based strategy, and a control group taught through the conventional teaching method. In the control condition, the teacher followed the textbook sequence and explained the content using the textbook and blackboard only. No additional visual aids, alternative scaffolding, manipulatives, tangible teaching tools, games, activity booklets, or other supplementary materials were provided. The only visual representations available to students were the figures printed in the textbook. To reduce the possible influence of teacher-related differences on the results, the same mathematics teacher taught both the experimental and control groups during the implementation period. The research instruments were administered to both groups before and after the intervention. The pre-administration was used to verify the equivalence of the two groups in the dependent variables before implementing the experimental treatment. The post-administration was then used to measure the effect of the independent variable, namely the fun learning-based strategy, on the dependent variables: academic achievement, deep understanding skills in mathematical problems, and level of cognitive load.

3.1. Research population and sample

The research population comprised seventh-grade students in the Eastern Province of Saudi Arabia. The study sample was limited to seventh-grade students at one school in Dammam. The school was selected because its administration cooperated with the researcher and approved the implementation of the research experiment. The sample consisted of 68 students distributed across two classes. One class was assigned as the experimental group, with 35 students, while the other class served as the control group, with 33 students. Before the experiment began, the equivalence of the two groups was verified through the pre-administration of the research instruments.

3.2. Research procedures

The research followed a set of systematic procedures. The process began with analyzing the content of Unit 9 in the seventh-grade mathematics textbook for the second semester, entitled *Measurement: Two-Dimensional and Three-Dimensional Figures*. This analysis aimed to identify the concepts, generalizations, and skills included in the unit. These results were then used to develop the research materials and instruments, particularly the teacher's guide, the student activity booklet, the achievement test, and the test of deep understanding skills in mathematical problems. Subsequently, a list of deep understanding skills in mathematical problems appropriate for seventh-grade students was prepared. The fun learning-based teaching strategy was then developed. Based on this strategy, the teacher's guide and the student activity booklet were designed. The measurement instruments were also prepared, namely the achievement test, the test of deep understanding skills in mathematical problems, and the cognitive load scale. Before being used in the main implementation, these instruments underwent validity and reliability procedures.

3.2.1. Content analysis of the unit

Content analysis was used as a systematic procedure to provide an accurate and organized description of the content of the targeted instructional unit. The analysis focused on Unit 9, *Measurement: Two-Dimensional and Three-Dimensional Figures*, from the seventh-grade mathematics textbook for the second semester of the 2025/2026 academic year. The purpose of the analysis was to identify the mathematical concepts, generalizations, and skills included in the unit, so that they could be used in preparing the teacher's guide, the student activity booklet, and the achievement test. The analysis sample was limited to Unit 9. Concepts, generalization, and skill were adopted as the units of analysis, whether they appeared in activities, drills, examples, exercises, or mathematical problems.

The analysis resulted in the identification of 14 concepts, 25 generalizations, and 29 mathematical skills. To verify the validity of the analysis, the analysis tool was presented to a group of experts and specialists, and their comments were taken into consideration when modifying the tool. The reliability of the analysis was verified using the reanalysis method. The unit was reanalyzed three weeks after the first analysis, and the agreement coefficient was calculated using Holsti's formula, as shown in Table 1. The reliability coefficient for the content analysis of the unit was 0.92, which is a high value and indicates the consistency and reliability of the analysis results [57].

Table 1. Holsti reliability coefficient for the content analysis of the unit.

Unit of analysis	First analysis	Second analysis	Agreements	Reliability
Concepts	15	14	14	0.96
Generalizations	25	26	25	0.98
Skills	29	33	29	0.93
Total	69	73	65	0.92

3.2.2. Preparing the list of deep understanding skills in mathematical problems

A list of deep understanding skills in mathematical problems was prepared to achieve the first research objective, which focuses on identifying the skills that should be developed among seventh-grade students. The list aimed to determine the main skills and subskills appropriate to the nature of the educational stage, as well as the behavioral performance indicators associated with each skill. The list was prepared based on the objectives of the mathematics curriculum, the characteristics of seventh-grade students, and the educational literature related to deep understanding in mathematics. The initial version of the list included four main skills: generative thinking, questioning, interpretation, and decision-making. These skills included 24 sub-skills distributed as follows: 15 sub-skills for generative thinking, 3 sub-skills for questioning, 3 sub-skills for interpretation, and 3 sub-skills for decision-making.

To verify the validity of the list, it was presented to five jury members specializing in curricula and methods of teaching mathematics. They were asked to provide their opinions on the suitability of the skills for seventh-grade students, the relevance of the performance indicators to the main skills and subskills, and the accuracy of the linguistic and scientific formulation. In light of the jury members' comments, the necessary modifications were made. The final version of the list consisted of 20 behavioral performances distributed across the main skills, with 11 sub-skills for generative thinking and 3 sub-skills for each of questioning, interpretation, and decision-making.

3.2.3. Developing the fun learning–based strategy

The fun learning–based strategy was developed in light of the theoretical foundations and characteristics of fun learning, as well as relevant literature on its use in mathematics education. When developing the strategy, attention was given to combining learners’ cognitive activation and motivation, a positive classroom environment, and enjoyable mathematical activities that help students understand mathematical problems and reduce the cognitive load associated with them.

The strategy consisted of five interrelated stages. The first stage was questioning and activation, in which students are prepared for the lesson topic through thought-provoking questions and varied mathematical representations. These help students recall prior knowledge, attract their attention, and build cognitive and affective readiness for learning. This stage is based on the principles of emotional effect and intrinsic motivation. The second stage is participation, in which the teacher engages students in constructing the general framework of the learning experience through enjoyable mathematical tasks and activities. These activities take into account students’ experiences and abilities and provide them with active practice related to the lesson topic. This was followed by the stage of cooperation and communication, which focuses on group work, classroom organization, and the distribution of tasks among group members. This stage helps students discover mathematical relationships, discuss solutions, exchange ideas, and solve mathematical problems in more than one way. The fourth stage is academic and life applications, in which students apply what they have learned in relevant mathematical situations and real-life contexts. This enhances the transfer of learning and connects mathematical concepts to students’ lived experiences. This stage is grounded in the principles of flow experience, curiosity, emotional effect, and intrinsic motivation. The strategy concludes with the evaluation and reinforcement stage. This stage involves diversifying assessment methods, including pre-assessment, formative assessment, summative assessment, and self-assessment. It also includes providing feedback that helps learners improve their performance and strengthen their sense of achievement.

Within this strategy, the teacher’s role shifted from being a transmitter of information to a facilitator, guide, and organizer of learning experiences. The teacher prepares a classroom environment based on respect and friendliness, uses varied teaching methods, selects activities that stimulate students’ curiosity, and provides constructive feedback. The student, in turn, takes on a more active role through initiative, participation in answering questions, group work, collaboration with peers, and self-performance assessment based on the ideas and solutions reached.

3.2.4. Preparation of the teacher’s guide

The teacher’s guide was prepared as a procedural guide for teaching the unit *Measurement: Two-Dimensional and Three-Dimensional Figures* according to the fun learning–based strategy. The guide aimed to help mathematics teachers implement the strategy in an organized way and use activities and tasks in a manner aligned with the unit objectives and the characteristics of seventh-grade students. The guide included a general introduction, the objectives for using the guide, its theoretical foundations, the stages of the fun learning–based strategy, the objectives of teaching the unit, the time allocation and teaching procedures for the nine unit lessons, and the proposed detailed teaching procedures for each lesson. It also included directions for teachers on managing activities, organizing classroom interaction, and providing assessment and feedback.

To verify the validity of the guide, it was presented to four jury members specializing in mathematics education. They were asked to provide their opinions on its suitability for mathematics teachers, its appropriateness for the characteristics of intermediate school students, the clarity and measurability of the behavioral objectives, the appropriateness of the number of class periods, and the linguistic and scientific accuracy of the teaching procedures. Based on the jury members' comments, the necessary modifications were made, and the guide was prepared in its final form.

3.2.5. Preparation of the student activity booklet

The student activity booklet was prepared according to the fun learning-based strategy to help students in the experimental group learn the topics of the *Measurement* unit through a variety of activities and worksheets. The booklet was designed to help develop deep understanding skills in mathematical problems, particularly generative thinking, questioning, interpretation, and decision-making, while also helping reduce the level of cognitive load associated with solving mathematical problems. The booklet included graded and varied activities that took into account individual differences among students in achievement level. It also helped students engage with mathematical concepts and skills through enjoyable and meaningful learning situations. When the activities were prepared, attention was given to reducing indicators of cognitive load, such as mental load, effort load, temporal demand load, performance load, and frustration load.

The activity booklet was presented to four jury members specializing in mathematics education to verify the suitability of the activities, tasks, and worksheets for the objectives and topic of the study, as well as the accuracy of the wording and clarity of the instructions. In light of the jury members' opinions and suggestions, the required modifications were made, and the booklet was prepared in its final form.

3.3. Research instruments

The present study relied on three main instruments for data collection: the achievement test, the test of deep understanding skills in mathematical problems, and the cognitive load scale. These instruments were developed in light of the research objectives, the content of the instructional unit, and the dependent variables. They then underwent validity and reliability procedures before being administered to the main research sample.

3.3.1. The achievement test

The achievement test was prepared to measure the seventh-grade students' achievement in the learning outcomes included in the unit *Measurement: Two-Dimensional and Three-Dimensional Figures*. A table of specifications was used to ensure that the test represented the unit content and its instructional objectives and was balanced across topics and Bloom's cognitive levels. In its final form, the test consisted of 40 items, including 15 multiple-choice questions, 15 completion items, and 10 constructed-response questions. The items were distributed across six cognitive levels: remembering, understanding, application, analysis, synthesis, and evaluation. The total score of the test was 60 points: 15 points were allocated to multiple-choice questions, 15 points to completion items, and 30 points to constructed-response questions, with three points assigned to each essay question and distributed across the correct solution steps.

To verify the validity of the test, its initial version was presented to six experts specializing in

mathematics education. They were asked to provide their opinions on the accuracy of the linguistic formulation, the suitability of the items for students' level, and the extent to which the questions were aligned with the objectives and content. The jury members' comments were taken into consideration when preparing the final version of the test. The test was also administered to a pilot sample of 30 students from outside the main research sample in order to calculate test reliability, as shown in Table 2, as well as facility, difficulty, and discrimination indices.

Table 2. Reliability coefficients of the achievement test.

Test components	Split-half reliability	Cronbach's alpha
Remembering	0.75	0.76
Understanding	0.82	0.89
Application	0.72	0.73
Analysis	0.82	0.72
Synthesis	0.85	0.77
Evaluation	0.76	0.86
Test as a whole	0.89	0.85

Reliability was examined using Cronbach's alpha as the main indicator of internal consistency. Split-half reliability was also calculated as an additional check because the test included different item formats. Table 2 shows that the reliability coefficient using Cronbach's alpha was 0.85, while the split-half reliability coefficient was 0.89. These values indicate that the test had a high degree of reliability [58].

Item analysis was conducted according to Classical Test Theory. The facility index was calculated as the proportion of students who answered each item correctly, while the difficulty index was calculated as the complementary value. The facility index ranged between 0.32 and 0.75, while the difficulty index ranged between 0.25 and 0.68, which are educationally acceptable values. The mean facility index for the test as a whole was 0.57, while the mean difficulty index was 0.43. The discrimination index ranged between 0.19 and 0.25, indicating that the test items were able to discriminate between different levels of student performance [59].

3.3.2. The test of deep understanding skills in mathematical problems

The test of deep understanding skills in mathematical problems was prepared to measure the extent to which seventh-grade students demonstrated these skills as one of the outcomes of using the fun learning-based strategy. The construction of the test was based on relevant literature on deep understanding in mathematics. Four main skills were identified: generative thinking, questioning, interpretation, and decision-making. The skill of generative thinking included five sub-skills: fluency, flexibility, prediction in light of given data, hypothesis formulation, and error identification. The test consisted of 20 varied constructed-response questions designed to measure students' ability to analyze mathematical problems, interpret relationships, generate solutions, ask questions, and make appropriate decisions in the context of problem solving. The total possible score for the test was 80 points. The score was distributed across the four main skills as follows: 35 points for generative thinking, 15 points for interpretation, 15 points for questioning, and 15 points for decision-making.

To verify the validity of the test, it was presented to five jury members specializing in

mathematics education. They were asked to provide their opinions on the linguistic and scientific formulation of the items, the suitability of the number and difficulty level of the questions for seventh-grade students, and the clarity of the test instructions. Based on their comments, the necessary modifications were made. To verify the reliability of the test, as shown in Table 3, it was administered to a pilot sample of 30 students from outside the main research sample.

Table 3. Reliability coefficients of the test of deep understanding skills in mathematical problems.

Deep understanding skills	Split-half reliability	Cronbach's alpha
Generative thinking	0.76	0.83
Interpretation	0.89	0.79
Questioning	0.73	0.74
Decision-making	0.82	0.76
Test as a whole	0.85	0.76

Table 3 shows that the reliability coefficient for the test as a whole using Cronbach's alpha was 0.76, while the split-half reliability coefficient was 0.85. This indicates that the test had an acceptable degree of reliability and was suitable for administration in its final form [58].

3.3.3. The cognitive load scale

The cognitive load scale was prepared to identify the level of cognitive load among seventh-grade students during mathematics learning; this was one of the dependent variables in the study. The construction of the scale was based on literature related to Cognitive Load Theory. Six dimensions were identified for the scale: mental load, physical load, temporal demand load, effort load, achieved performance load, and frustration load. Table 4 presents the scale dimensions and the number of statements for each dimension.

Table 4. Dimensions of the cognitive load scale.

Scale dimensions	Statements	Positive statements	Negative statements	Number of statements
Mental load	1, 7, 13, 19, 25, 31, 37	3	4	7
Physical load	2, 8, 14, 20, 26, 32	3	3	6
Temporal pressure load	3, 9, 15, 21, 27, 33, 38	3	4	7
Effort load	4, 10, 16, 22, 28, 34, 39	3	4	7
Achieved performance load	5, 11, 17, 23, 29, 35	4	2	6
Frustration load	6, 12, 18, 24, 36, 30, 40	4	3	7
Total	-	20	20	40

Table 4 shows that the scale consisted of 40 statements, including 20 positive and 20 negative statements, according to a three-point Likert scale, with the response options being as follows: always, sometimes, and never. Scores for positive statements were assigned in the order 3, 2, and 1, while scores for negative statements were reversed in the order 1, 2, and 3.

To verify the validity of the scale, it was presented to five jury members specializing in

mathematics education and four jury members specializing in psychology. They were asked to provide their opinions on the suitability of the statements for the dimensions to which they belonged, the clarity of the wording, and the appropriateness of the scale for students' level. The jury members' comments were taken into consideration when preparing the final version of the scale. The reliability of the scale, as shown in Table 5, was verified by administering it to a pilot sample of 30 students from outside the main sample.

Table 5. Reliability coefficients of the cognitive load scale.

Scale dimensions	Split-half reliability	Cronbach's alpha
Mental load	0.76	0.83
Physical load	0.89	0.79
Temporal pressure load	0.73	0.74
Effort load	0.82	0.76
Achieved performance load	0.83	0.81
Frustration load	0.80	0.85
Scale as a whole	0.82	0.86

Table 5 indicates that Cronbach's alpha coefficient for the scale as a whole was 0.86, while the split-half reliability coefficient was 0.82. These two values indicate that the scale had a high degree of reliability [58].

Before conducting the independent-samples t-tests, the assumptions of normality and homogeneity of variance were examined. The Shapiro–Wilk test was used to assess normality because the sample size in each group was below 50 students. Levene's test was used to examine the homogeneity of variance between the experimental and control groups. As shown in Table 6, all Shapiro–Wilk and Levene's test p-values were greater than 0.05, indicating that the assumptions required for using the independent-samples t-test were met.

Table 6. Results of normality and homogeneity of variance tests.

Variable	Group	Shapiro–Wilk	Levene's test	Decision
Achievement test	Experimental	0.980	0.810	Assumptions met
	Control	0.935		
Deep understanding test	Experimental	0.332	0.786	Assumptions met
	Control	0.229		
Cognitive load scale	Experimental	0.222	0.746	Assumptions met
	Control	0.182		

3.4. Pre-administration of the research instruments

Before implementing the experimental treatment, the research instruments were administered to students in both the experimental and control groups to verify the equivalence of the two groups in the dependent variables. The pre-administration instruments included the achievement test, the test of deep understanding skills in mathematical problems, and the cognitive load scale. The independent samples t-test was used to determine the significance of differences between the mean scores of the two groups in the pre-administration, as shown in Tables 7, 8, and 9.

Table 7. Results of the pre-administration of the achievement test.

Components	Group	N	Mean	SD	df	t	p
Remembering	Control	33	1.24	0.67	66	0.13	0.899
	Experimental	35	1.26	0.63			
Understanding	Control	33	2.43	1.63	66	0.51	0.609
	Experimental	35	2.62	1.42			
Application	Control	33	8.38	2.78	66	0.51	0.612
	Experimental	35	8.73	2.88			
Analysis	Control	33	6.26	3.56	66	0.01	0.990
	Experimental	35	6.25	2.95			
Synthesis	Control	33	3.10	2.01	66	0.07	0.948
	Experimental	35	3.14	2.90			
Evaluation	Control	33	1.28	1.28	66	0.38	0.706
	Experimental	35	1.40	1.33			
Whole	Control	33	22.69	4.8	66	0.56	0.581
	Experimental	35	23.42	5.94			

The results presented in Table 7, concerning the pre-administration of the achievement test, showed no statistically significant differences between the mean scores of the experimental and control groups. The t-value was 0.56 at a significance level of $p = 0.581$. This result indicates that the two groups were equivalent in mathematical achievement before the implementation of the strategy.

Table 8. Results of the pre-administration of the test of deep understanding skills.

Skills	Group	N	Mean	SD	df	t	p
Generative thinking	Control	33	15.72	1.85	66	0.46	0.646
	Experimental	35	15.93	1.9			
Interpretation	Control	33	5.69	1.22	66	0.36	0.721
	Experimental	35	5.84	2.09			
Questioning	Control	33	5.59	1.23	66	0.14	0.890
	Experimental	35	5.65	2.17			
Decision-making	Control	33	4.74	2.06	66	0.12	0.908
	Experimental	35	4.68	2.19			
Whole	Control	33	31.74	3.45	66	0.41	0.680
	Experimental	35	32.10	3.69			

The results presented in Table 8, related to the pre-administration of the test of deep understanding skills in mathematical problems, also showed no statistically significant differences between the mean scores of the two groups. The t-value was 0.41 at a significance level of $p = 0.680$. This indicates that the two groups were equivalent in deep understanding skills in mathematical problems before the beginning of the experiment.

Table 9. Results of the pre-administration of the cognitive load scale.

Dimensions	Group	N	Mean	SD	df	t	p
Mental load	Control	33	16.41	2.58	66	0.09	0.926
	Experimental	35	16.47	2.73			
Physical load	Control	33	14.30	2.26	66	0.06	0.956
	Experimental	35	14.27	2.21			
Temporal pressure load	Control	33	16.43	2.41	66	0.08	0.936
	Experimental	35	16.48	2.66			
Effort load	Control	33	16.45	2.60	66	0.38	0.703
	Experimental	35	16.20	2.78			
Achieved performance load	Control	33	14.26	2.29	66	0.21	0.838
	Experimental	35	14.37	2.12			
Frustration load	Control	33	16.33	2.78	66	0.09	0.932
	Experimental	35	16.39	3.00			
Whole	Control	33	94.20	7.37	66	0.01	0.991
	Experimental	35	94.18	7.83			

Regarding the cognitive load scale, the results presented in Table 9 showed no statistically significant differences between the mean scores of students in the experimental and control groups. The t-value was 0.01 at a significance level of $p = 0.991$. This result indicates that the two groups were equivalent in their level of cognitive load before the implementation of the experimental treatment.

Based on these results, it can be concluded that the experimental and control groups were equivalent in the three dependent variables before the intervention. This supports the soundness of the quasi-experimental design and strengthens the possibility of attributing any differences that may appear in the post-administration to the effect of the fun learning-based strategy.

4. Results and discussion

The present study aimed to examine the effectiveness of using a fun learning-based strategy in developing academic achievement and deep understanding of mathematical problems, as well as in reducing cognitive load among seventh-grade students. The study also sought to identify the nature of the correlational relationship between students' deep understanding skills in mathematical problems and their level of cognitive load.

4.1. Effectiveness of the strategy in developing mathematical achievement

To achieve the third research objective, which focuses on examining the effectiveness of the fun learning-based strategy in developing students' mathematical achievement, the null hypothesis was tested. This hypothesis stated that there were no statistically significant differences at the 0.05 level between the mean scores of students in the experimental and control groups in the post-administration of the achievement test. To verify this hypothesis, the independent samples t-test was used after confirming that its assumptions had been met. Table 10 presents the results of the test for the post-administration of the achievement test.

Table 10. Independent samples t-test results for the post-administration of the achievement test.

Test components	Group	N	Mean	SD	df	t	p
Remembering	Control	33	1.25	0.65	66	4.60	0.000***
	Experimental	35	1.88	0.47			
Understanding	Control	33	2.30	0.94	66	5.59	0.000***
	Experimental	35	3.50	0.83			
Application	Control	33	7.84	2.96	66	6.82	0.000***
	Experimental	35	12.93	3.18			
Analysis	Control	33	9.71	3.48	66	9.19	0.000***
	Experimental	35	17.95	3.89			
Synthesis	Control	33	5.56	2.24	66	5.56	0.000***
	Experimental	35	8.78	2.52			
Evaluation	Control	33	2.78	1.28	66	6.84	0.000***
	Experimental	35	5.10	1.50			
Test as a whole	Control	33	29.18	4.67	66	15.06	0.000***
	Experimental	35	49.43	6.25			

Note: ***p < 0.001

The results in Table 10 show statistically significant differences between the mean scores of students in the experimental and control groups in the post-administration of the achievement test, both as a whole and across its sub-levels: remembering, understanding, application, analysis, synthesis, and evaluation. These differences were in favor of the experimental group. The experimental group obtained a mean score of 49.43, with a standard deviation of 6.25. The t-value was 15.06, which is statistically significant at $p < 0.001$. Accordingly, the null hypothesis was rejected, and the alternative hypothesis was accepted. This indicates that the fun learning-based strategy had a positive effect on developing mathematical achievement among seventh-grade students. To determine the practical significance of this result, the effect size was calculated using eta squared (η^2). The value was 0.77, indicating a large and educationally meaningful effect size [60]. This means that a substantial proportion of the variance in post-achievement scores can be attributed to the use of the fun learning-based strategy.

The higher performance of the experimental group in mathematical achievement may be explained by the nature of the learning environment provided by the strategy. The strategy gave students wider opportunities to interact with the concepts, generalizations, and mathematical skills included in the unit *Measurement: Two-Dimensional and Three-Dimensional Figures* through varied and engaging activities, rather than limiting instruction to passive reception or traditional procedural solutions. The individual and group activities also helped increase students' participation, strengthen their independent learning, and improve their ability to understand concepts and apply them in different learning situations. This improvement may also be attributed to the positive classroom climate created by fun learning. The strategy encouraged students to interact with the teacher and their peers and reduced the anxiety often associated with dealing with mathematical problems. In addition, training students to read, analyze, and reformulate problems in their own language contributed to improving their understanding of the content and their performance on the achievement test. Continuous reinforcement and encouragement within a safe and flexible learning

environment also may have increased students' motivation and satisfaction with their performance, which was reflected in their academic achievement.

This result is consistent with previous studies that examined the effect of fun learning, games, and educational activities on developing mathematical achievement. These include the study by Kebritchi et al. [61], which indicated the effect of computerized educational games on the achievement of mathematical concepts; Lemonidis and Kaiafa's study [62], which examined the effect of the story strategy on mathematics achievement and learner motivation; and Alzhrani's study [63], which demonstrated the effectiveness of a strategy based on fun learning in developing immediate and delayed achievement and motivation toward learning mathematics.

4.2. Effectiveness of the strategy in developing deep understanding skills

To achieve the fourth research objective, which focuses on examining the effectiveness of the fun learning-based strategy in developing students' deep understanding skills in mathematical problem-solving, the null hypothesis was tested. This hypothesis stated that there were no statistically significant differences at the 0.05 level between the mean scores of students in the experimental and control groups in the post-administration of the test of deep understanding skills in mathematical problems. Table 11 presents the results of the independent samples t-test for the post-administration of the test of deep understanding skills in mathematical problems.

Table 11. t-test results for the post-administration of the test of deep understanding skills.

Skills	Group	N	Mean	SD	df	t	p
Generative thinking	Control	33	17.23	2.60	66	16.74	0.000***
	Experimental	35	28.46	2.91			
Interpretation	Control	33	6.91	2.09	66	9.52	0.000***
	Experimental	35	12.44	2.65			
Questioning	Control	33	7.13	2.26	66	8.79	0.000***
	Experimental	35	12.48	2.72			
Decision-making	Control	33	5.39	1.94	66	10.54	0.000***
	Experimental	35	11.31	2.62			
Test as a whole	Control	33	36.58	4.29	66	22.43	0.000***
	Experimental	35	64.69	5.87			

Note: ***p < 0.001

Table 11 shows statistically significant differences between the mean scores of students in the experimental and control groups in the post-administration of the test of deep understanding skills in mathematical problems, both as a whole and in its sub-skills: generative thinking, interpretation, questioning, and decision-making. These differences were in favor of the experimental group. The experimental group obtained a mean score of 64.69, with a standard deviation of 5.87. The t-value was 22.43, which is statistically significant at $p < 0.001$. This result indicates the effectiveness of the fun learning-based strategy in developing deep understanding skills in mathematical problems among seventh-grade students. The effect size, calculated using eta squared, was ($\eta^2 = 0.88$), indicating the strategy achieved a large and educationally meaningful effect in developing these skills.

This result can be interpreted in light of the structured opportunities provided by the strategy for processing mathematical problems in depth, rather than focusing only on reaching the final answer. Fun learning activities enabled students to read mathematical problems consciously, identify the given data and the required outcome, reformulate the problem in their own language, explore the relationships among its components, and then construct, implement, and evaluate solution plans. These steps represent the essence of deep understanding because they move learners from superficial engagement with the problem toward recognizing its structure, components, and governing relationships. The strategy also helped students practice generative thinking by generating multiple ideas and solutions for mathematical problems, formulating preliminary hypotheses for the solution, and identifying possible errors in the wording of the problem, the drawing, or the solution steps. Group work and varied activities provided opportunities for mathematical dialogue, questioning, and the exchange of explanations, which strengthened students' ability to construct mathematical meaning and justify their solution steps. Another factor that may explain this result is that the strategy was based on a clear problem-solving framework. This framework begins with the pre-solution stage, in which students are trained to analyze the problem elements and identify the given data and what is required. It then moves to the solution stage, where hypotheses are tested and solution steps are implemented. Finally, it reaches the post-solution stage, where students verify the correctness of the solution and propose similar problems or questions. This organized sequence helped develop interpretation and decision-making skills, as students became more capable of selecting and justifying the appropriate solution method.

This result is consistent with several studies that confirmed the effectiveness of enjoyable or active instructional approaches and activities in developing mathematical thinking and deep understanding. These include Matarazzo et al.'s study [64] on the effect of humor in making mathematics more enjoyable and developing mathematical thinking; Fontes et al.'s study [65] on the use of puzzles in developing critical thinking; Musdalifah et al.'s study [66] on fun learning and the acquisition of basic operations; Fouze and Amit's study [67] on educational games and the development of mathematical thinking; and Weijer-Bergsma and Ven's study [68], which examined the enjoyable mathematics approach in developing productive thinking and reducing cognitive load. The result is also consistent with other studies concerned with developing deep understanding in mathematics through various instructional strategies and models, such as the studies of Abdelshafy [40], Otaify et al. [41], Hathal and Dhari [42], and Mohamed and Salhah [43]. Collectively, these studies indicate that developing deep understanding requires instructional approaches that enable learners to analyze, interpret, question, and generate solutions, rather than limiting learning to memorization or the mechanical application of rules.

4.3. Effectiveness of the strategy in reducing cognitive load

To achieve the fifth research objective, which focuses on examining the effectiveness of the fun learning-based strategy in reducing students' cognitive load, the null hypothesis tested stated that there were no statistically significant differences at the 0.05 level between the mean scores of students in the experimental and control groups in the post-administration of the cognitive load scale. Table 12 presents the results of the independent samples t-test for the post-administration of the cognitive load scale.

Table 12. t-test results for the post-administration of the cognitive load scale.

Dimensions	Group	N	Mean	SD	df	t	p
Mental load	Control	33	14.80	3.31	66	6.95	0.000***
	Experimental	35	9.77	2.64			
Physical load	Control	33	13.05	2.72	66	6.73	0.000***
	Experimental	35	8.94	2.31			
Temporal pressure load	Control	33	14.45	3.29	66	6.03	0.000***
	Experimental	35	10.05	2.71			
Effort load	Control	33	14.87	3.26	66	6.60	0.000***
	Experimental	35	10.06	2.74			
Achieved performance load	Control	33	13.27	2.49	66	6.51	0.000***
	Experimental	35	9.27	2.57			
Frustration load	Control	33	14.73	2.89	66	7.12	0.000***
	Experimental	35	9.92	2.68			
Scale as a whole	Control	33	85.08	5.18	66	20.81	0.000***
	Experimental	35	58.00	5.53			

Note: ***p < 0.001

The results in Table 12 show statistically significant differences between the mean scores of students in the experimental and control groups in the post-administration of the cognitive load scale, both as a whole and in its sub-dimensions: mental load, physical load, temporal pressure load, effort load, achieved performance load, and frustration load. The difference was in favor of the control group in terms of the higher mean score. The control group obtained a mean score of 85.08, with a standard deviation of 5.18, and the t-value was 20.81, statistically significant at $p < 0.001$. Since a higher score on the scale indicates a higher level of cognitive load, this result means that students in the experimental group experienced a lower level of cognitive load than students in the control group. This finding demonstrates the effectiveness of the fun learning-based strategy in reducing cognitive load among seventh-grade students. The practical significance of the results was calculated using eta squared, which determines the proportion of variance in the dependent variable that can be attributed to the independent variable. The results indicated a large and educationally meaningful effect of using the fun learning-based strategy in reducing cognitive load ($\eta^2 = 0.87$).

The reduction in cognitive load among students in the experimental group may be explained by the clear organization and gradual presentation of mathematical tasks provided by the strategy. This organization helped students retrieve prior knowledge and connect it to new knowledge. From the perspective of Cognitive Load Theory, effective organization of content and tasks helps reduce pressure on working memory and enables learners to direct their mental effort toward understanding and constructing cognitive schemas, instead of becoming occupied with distracting or unnecessary elements. Fun learning activities also contributed to creating a more supportive and flexible classroom environment, especially when students were learning mathematical topics that may appear difficult or abstract. Diversifying activities, using problems graded by difficulty, and providing worked examples and guiding models helped reduce extraneous cognitive load that may result from traditional presentation methods or from dense and poorly organized information. The use of completion tasks, which provided students with a partial solution to continue building upon, may

also have reduced unnecessary effort and directed students' attention to the essential steps of the solution.

The reduction in cognitive load may also be attributed to the strategy's consideration of the principle of integration between visual and verbal processing. Some learning topics were presented through visual representations and organized verbal explanations, which contributed to distributing cognitive processing between the visual-spatial channel and the auditory-verbal channel. This type of organization helps reduce pressure on working memory, particularly in tasks that require understanding figures, measurements, and spatial relationships [69]. The affective environment associated with fun learning also seems to have played a role in reducing cognitive load. It helped reduce feelings of frustration and psychological pressure and increased students' sense of safety and confidence while solving problems. A student who participates in an encouraging classroom environment, receives continuous feedback, and is allowed to try and make mistakes without fear is more able to direct mental effort toward the learning task rather than becoming preoccupied with anxiety or fear of failure.

This result is consistent with several previous studies that confirmed the possibility of reducing cognitive load by improving learning design and using appropriate teaching strategies. These include Mayer and Moreno's study [46] on learning through visual representation, Surbakti et al.'s study [10] on instructional scaffolding, Krieglstein et al.'s study [70] on mind maps, and the studies of Buchner et al. [71] and Zhu et al. [72] on augmented reality. The result also aligns with Abdulalber's study [73], which demonstrated the effectiveness of the enjoyable mathematics approach in reducing cognitive load among intermediate school students.

4.4. The relationship between deep understanding skills in mathematical problems and cognitive load

To achieve the sixth research objective, which focuses on determining the nature and direction of the relationship between deep understanding skills in mathematical problem-solving and cognitive load, the null hypothesis tested stated that there was no statistically significant negative correlation between deep understanding skills in mathematical problems and cognitive load among seventh-grade students. To verify this, the Pearson correlation coefficient was calculated between the scores of students in the experimental group on the test of deep understanding skills in mathematical problems and their scores on the cognitive load scale.

The results revealed a moderate, statistically significant negative correlation between the two variables, with a correlation coefficient of $r = -0.467$, significant at the 0.05 level. This result indicates that the lower the level of cognitive load, the higher the level of deep understanding skills in mathematical problems, and vice versa. This finding is logical in light of the nature of deep understanding of mathematical problems. Deep understanding requires learners to attend to the elements of the problem, organize information, connect the given data to what is required, construct a solution plan, interpret the steps, and verify the correctness of the answer. All of these processes depend on the learner's ability to manage cognitive resources efficiently. When cognitive load exceeds the capacity of working memory, the learner's ability to analyze, interpret, and make decisions decreases, and the learner becomes more likely to rely on superficial processing or random attempts to solve the problem.

The negative relationship between the two variables can also be interpreted in light of the nature of the strategy used. Fun learning activities trained students to solve mathematical problems

according to a clear and organized framework. This framework begins with analyzing the problem and identifying the given data and requirements, then moves to proposing and testing hypotheses, and finally ends with verifying and evaluating the solution. This organization helped reduce unnecessary mental effort while also creating more cognitive space for practicing deep understanding skills, such as generative thinking, interpretation, questioning, and decision-making. This result also highlights the importance of addressing cognitive load when designing mathematics instruction, especially in topics related to measurements and two- and three-dimensional figures, which often require simultaneous visual, spatial, and symbolic processing. Reducing cognitive load does not mean lowering the level of mathematical challenge. Rather, it means organizing that challenge in a way that enables learners to build understanding gradually. Therefore, strategies that combine enjoyment, cognitive organization, and classroom interaction may be more capable of supporting deep understanding of mathematical problems.

This result is consistent with previous studies that have indicated an inverse relationship between cognitive load and achievement or cognitive performance in mathematics, such as the studies of Adeosun and Okonkwo [74], Bobis et al. [75], Kennedy and Romig [76], Singh [77], and Hussein [78]. These studies support the interpretation that high cognitive load may limit learners' ability to understand, analyze, and solve problems, whereas reducing and regulating cognitive load may improve mathematical performance and deepen understanding.

Overall, the results of the present study confirm that the fun learning-based strategy was effective in developing mathematical achievement and deep understanding skills in mathematical problems, as well as in reducing cognitive load among seventh-grade students. These results can be interpreted in light of the integration of three main dimensions within the strategy: the cognitive dimension, through organizing problem-solving steps and developing analysis and interpretation skills; the affective dimension, through providing an enjoyable and safe learning environment that reduces anxiety and frustration; and the interactive dimension, through offering opportunities for collaboration, dialogue, exchange of ideas, and active participation. The negative correlation between deep understanding and cognitive load also emphasizes the importance of designing learning situations that take into account the limits of working memory and help learners direct their mental effort toward constructing mathematical meaning, rather than becoming distracted by disorganized or irrelevant elements. Thus, the findings of this study support the use of fun learning in mathematics teaching, not only as an approach for improving students' motivation but also as an instructional strategy that can contribute to deepening understanding, regulating cognitive load, and improving the quality of mathematics learning.

5. Conclusions

The study found that a strategy based on fun learning helped seventh-grade students develop a deeper understanding of mathematical problems while also reducing their cognitive load. Students in the experimental group performed significantly better in both achievement and deep understanding skills. At the same time, the cognitive load results showed that students who learned through the fun learning strategy experienced a lower level of cognitive load. The study also found a moderate negative relationship between deep understanding and cognitive load, which suggests that when unnecessary mental effort is reduced, students may be better able to analyze mathematical problems and engage with them more deeply. These findings suggest that fun learning should not be seen simply as entertainment but as a teaching approach that can make learning more interactive,

organized, and meaningful. Based on these results, the study recommends integrating fun learning strategies into mathematics teacher preparation and professional development programs, enriching mathematics curricula with enjoyable and well-structured activities, and giving more attention to reducing cognitive load through gradual task sequencing, worked examples, guiding models, and clear visual and verbal representations. The study also recommends further research on fun learning and Cognitive Load Theory across different educational stages, particularly in relation to mathematical thinking, problem-solving difficulties, mathematics anxiety, sense of humor, higher-order thinking, and deep understanding.

5.1. Limitation

This study has several limitations. The sample included 68 seventh-grade students from one school and two intact classes, which limits generalizability and prevents the intervention effect from being separated fully from classroom-level influences. The same teacher taught both groups, creating possible expectancy bias and treatment spillover despite controlling for differences in teacher competence and practice. The intervention covered only the visual and spatial unit *Measurement: Two-Dimensional and Three-Dimensional Figures*, so the findings may not transfer to abstract topics such as algebra or probability. The lack of a delayed post-test also prevents conclusions about retention and makes it difficult to distinguish sustained learning from a novelty effect. Cognitive load was measured with a three-point self-report scale without behavioral or observational measures, which may have introduced response and social-desirability bias. The large effect sizes may reflect the controlled setting, homogeneous sample, focused unit, and close alignment between the intervention and outcome measures. Future studies should use larger samples, multiple schools, classes, and teachers, independent fidelity checks, delayed assessments, objective cognitive-load indicators, and mathematics topics with different representational demands.

Use of Generative-AI tools declaration

The author declares this manuscript was translated and edited using ChatGPT to enhance grammar and clarity. The author takes full responsibility for the content of the published work.

Conflict of interest

The author reports there are no competing interests to declare, no conflicts of interest, and no financial or non-financial interests.

Ethics declaration

This research was approved by the Ethics Committee of Imam Abdulrahman Bin Faisal University (IRB Number: 2026-15-0352) and conducted in compliance with the Declaration of Helsinki.

References

1. Vale, I. and Barbosa, A., Active learning strategies for an effective mathematics teaching and learning. *European Journal of Science and Mathematics Education*, 2023, 11(3): 573–588. <https://doi.org/10.30935/scimath/13135>

2. Cherukunnath, D. and Singh, A.P., Exploring cognitive processes of knowledge acquisition to upgrade academic practices. *Frontiers in psychology*, 2022, 13: 682628. <https://doi.org/10.3389/fpsyg.2022.682628>
3. Yang, Z., Yang, X., Wang, K., Zhang, Y., Pei, G. and Xu, B., The emergence of mathematical understanding: Connecting to the closest superordinate and convertible concepts. *Frontiers in psychology*, 2021, 12: 525493. <https://doi.org/10.3389/fpsyg.2021.525493>
4. Mockler, N., Curriculum integration in the twenty-first century: some reflections in the light of the Australian curriculum. *Curriculum Perspectives*, 2018, 38(2): 129–136. <https://doi.org/10.1007/s41297-018-0047-9>
5. National Council of Teachers of Mathematics (NCTM), *Catalyzing change in early childhood and elementary mathematics: Initiating critical conversations*, 2020, Reston, VA: NCTM.
6. Qetrani, S. and Achtaich, N., Evaluation of procedural and conceptual knowledge of mathematical functions: A case study from Morocco. *Journal on Mathematics Education*, 2022, 13(2): 211–238. <https://doi.org/10.22342/jme.v13i2.pp211-238>
7. Ali, I. and Al Kadhimi, H., Deep understanding skills and their relationship to mathematical modelling among fifth graders. *Turkish Journal of Computer and Mathematics Education*, 2021, 12(13): 3433–3443.
8. Ryan, V., Fitzmaurice, O. and O'Donoghue, J., A study of academic achievement in mathematics after the transition from primary to secondary education. *SN Social Sciences*, 2021, 1(7): 173. <https://doi.org/10.1007/s43545-021-00177-8>
9. De Jong, T., Cognitive load theory, educational research, and instructional design: some food for thought. *Instructional Science*, 2010, 38(2): 105–134. <https://doi.org/10.1007/s11251-009-9110-0>
10. Surbakti, R., Umboh, S.E., Pong, M. and Dara, S., Cognitive load theory: Implications for instructional design in digital classrooms. *International Journal of Educational Narratives*, 2024, 2(6): 483–493. <https://doi.org/10.70177/ijen.v2i6.1659>
11. Mokhtar, N., Xuan, L., Lokman, H. and Mat, N., Theory, literature review, and fun learning Method Effectiveness in teaching and learning. *International Journal of Social Science and Education Research Studies*, 2023, 3(08): 1738–1744. <https://doi.org/10.55677/ijssers/v03i8y2023-30>
12. Stiver, M., Naveed, A., Chilton, J. and Moyes, S., Gamifying anatomy outreach: An underexplored opportunity. *Anatomical Sciences Education*, 2025, 18(12): 1359–1372. <https://doi.org/10.1002/ase.70019>
13. Sundari, S. and Hertuti, A., Fun learning by applying competition and cooperation strategies through mathematical games. *Tekno - Pedagogi Jurnal Teknologi Pendidikan*, 2022, 12(1): 34–41. <https://doi.org/10.22437/teknopedagogi.v12i1.32509>
14. Rossi, M., Mathematics can be meaningful, easy and fun. *LUMAT International Journal on Math Science and Technology Education*, 2015, 3(7): 984–991. <https://doi.org/10.31129/lumat.v3i7.981>
15. Riley, N., Lubans, D., Holmes, K., Hansen, V., Gore, J. and Morgan, P., Movement-based mathematics: Enjoyment and engagement without compromising learning through the EASY minds program. *Eurasia Journal of Mathematics Science and Technology Education*, 2017, 13(6): 1653–1673. <https://doi.org/10.12973/eurasia.2017.00690a>

16. Yasin, A., Hamzah, M. and Mohamed, F., Fun Learning with "Magic Maths" for primary students: An action research. *Journal of Asian Vocational Education and Training*, 2017, 10: 88–102.
17. Fakhrunnisa, R., Karsiwan, W., Fajartriani, T., Kadfi, C. and Pelita, P., Fun learning innovation as an effective strategy in increasing students' learning engagement in non-formal education. *JUPE Jurnal Pendidikan Mandala*, 2025, 10(2): 112–120. <http://dx.doi.org/10.58258/jupe.v10i2.9061>
18. Bukit, S., Marcela, E. and Ernawati, E., Teacher's strategy to create fun learning in elementary school. *Journal Corner of Education Linguistics and Literature*, 2023, 2(3): 244–249. <https://doi.org/10.54012/jcell.v2i3.129>
19. Tisza, G., Zhu, S. and Markopoulos, P., Fun to enhance learning, motivation, self-efficacy, and intention to play in DGBL. In *Lecture notes in computer science*, 2021, 28–45. Springer, Cham. https://doi.org/10.1007/978-3-030-89394-1_3
20. Okasha, A., Non-digital game-based learning: A powerful tool to teach theories of architecture. *Journal of Engineering and Applied Science*, 2025, 72(1): 132. <https://doi.org/10.1186/s44147-025-00693-x>
21. Kokarida, P., Markopoulos, P. and Tisza, G., Fun beyond gamification: Universal elements to enhance children's learning. *Instructional Science*, 2026, 54(1): 30. <https://doi.org/10.1007/s11251-026-09780-9>
22. Kiili, K., De Freitas, S., Arnab, S. and Lainema, T., The design principles for flow experience in educational games. *Procedia Computer Science*, 2012, 15: 78–91. <https://doi.org/10.1016/j.procs.2012.10.060>
23. Kummanee, J., Nilsook, P., Piriya-surawong, P. and Wannapiroon, P., Digital learning ecosystem based on the STEAM Gamification concept to develop innovator characteristics of vocational learners. In *Lecture notes in networks and systems*, 2022, 695–706. Springer, Cham. https://doi.org/10.1007/978-3-031-26190-9_73
24. Tisza, G. and Markopoulos, P., FunQ: Measuring the fun experience of a learning activity with adolescents. *Current Psychology*, 2023, 42(3): 1936–1956. <https://doi.org/10.1007/s12144-021-01484-2>
25. Di Stasi, R., Esseily, R., Cerrotti, F. and Rat-Fischer, L., The impact of humor on infant social learning: Insights from social gaze, heart rate variability, and laughter. *Cognitive Development*, 2025, 74: 101575. <https://doi.org/10.1016/j.cogdev.2025.101575>
26. Momani, E.R., Make Them Create Their Fun to Enhance Perceived Learning Performance and Motivation: A Student-Created Gamification Strategy. *International Journal of Interdisciplinary Educational Studies*, 2026, 21(2): 151. <https://doi.org/10.18848/2327-011X/CGP/A260>
27. Shmakov, P. and Hannula, M., Humour as means to make mathematics enjoyable. In *the Sixth Congress of the European Society for Research in Mathematics Education*, 2010, 6: 144–153.
28. Himmawan, D. and Juandi, D., Games based learning in mathematics education: A systematic literature review. *Union: Jurnal Ilmiah Pendidikan Matematika*, 2023, 11(1): 41–50. <https://doi.org/10.30738/union.v11i1.13982>
29. Mustafa, S., Amaluddin, A., Nurhaeda, N., Sari, V. and Jannah, N., Fun learning method in effecting the students' interest learning mathematics. *Kreano Jurnal Matematika Kreatif-Inovatif*, 2023, 14(1): 12–27.

30. Ardani, R., Suwarno, M., Rezky, R. and Utari, T., Game-based edutainment media: How practical is it as a medium for learning mathematics? *AIP Conference Proceedings*, 2024, 3046(1): 020031. <https://doi.org/10.1063/5.0194544>
31. Pulungan, P. and Marpaung, A., Community service application of puzzle straw teaching aids in mathematics learning at coastal elementary school in silo baru village dusun x. *Center of Knowledge Jurnal Pendidikan Dan Pengabdian Masyarakat*, 2024, 6–13. <https://doi.org/10.51178/cok.v4i1.1767>
32. Esser, S., Lustig, C. and Haider, H., What triggers explicit awareness in implicit sequence learning? Implications from theories of consciousness. *Psychological research*, 2022, 86(5): 1442–1457. <https://doi.org/10.1007/s00426-021-01594-3>
33. Fenwick, L., Humphrey, S., Quinn, M. and Endicott, M., Developing deep understanding about language in undergraduate pre-service teacher programs through the application of knowledge. *Australian Journal of Teacher Education*, 2014, 39(1): 45–82. <http://dx.doi.org/10.14221/ajte.2014v39n1.4>
34. Uesaka, Y., Fukaya, T. and Ichikawa, S., Strategies for achieving deep understanding and improving learning skills: New approaches to instruction and lesson study in Japanese schools. *Cognition, metacognition and academic performance: An East Asian perspective*, 2017, 101–121. Routledge.
35. Tran, C., Smith, B. and Buschkuehl, M., Support of mathematical thinking through embodied cognition: Nondigital and digital approaches. *Cognitive research: principles and implications*, 2017, 2(1): 16. <https://doi.org/10.1186/s41235-017-0053-8>
36. Murphy, D., Little, J. and Bjork, E., The value of using tests in education as tools for Learning—Not just for assessment. *Educational Psychology Review*, 2023, 35(3): 89. <https://doi.org/10.1007/s10648-023-09808-3>
37. Sipahi, Y. and Bahar, A., Mathematical Creativity: A systematic review of definitions, frameworks, and assessment practices. *Education Sciences*, 2025, 15(10): 1348. <https://doi.org/10.3390/educsci15101348>
38. Sutiarto, S. and Rohmah, M., Analysis Problem Solving in Mathematical Using Theory Newman. *Eurasia Journal of Mathematics Science and Technology Education*, 2018, 14(2): 671–81. <https://doi.org/10.12973/ejmste/80630>
39. Bibi, W., Butt, M. and Reba, A., Relating Teachers' Questioning Techniques with Students' Learning within the Context of Bloom's Taxonomy. *FWU Journal of Social Sciences*, 2020, 14(1): 111.
40. Abdelshafy, M., Developing mathematics curricula in the light of knowledge economy standards to develop the deep mathematical understanding and curiosity epistemic of preparatory stage pupils. *Journal of Mathematics Education*, 2023, 26(6): 245–314. <https://doi.org/10.21608/armin.2023.328423>
41. Otaify, Z., Sayed, H. and Ibrahim, A., Using the probing reasoning model to address geometric fallacies and develop deep understanding skills among first-year middle school students. *Educational Journal for Adult Education*, 2023. <https://doi.org/10.21608/altc.2023.197405.1105>
42. HATHAL, T. and DHARI, H., Deep understanding skills of basic education students and their relationship to their ability to solve mathematical problems Murtadha. *Journal of the College of Basic Education*, 2023, 299. <https://doi.org/10.35950/cbej.v1iSI.10353>

43. Mohamed, E. and Salhah, R., The effectiveness of a proposed strategy based on the cognitive apprenticeship and Wheatley models to develop a depth of mathematical knowledge and a deep understanding in mathematics of primary school student. *Journal of Education-Sohag*, 2024, 119: 829–933. <https://doi.org/10.21608/edusohag.2024.347881>
44. Bannert, M., Managing cognitive load—recent trends in cognitive load theory. *Learning and Instruction*, 2002, 12(1): 139–46. [https://doi.org/10.1016/S0959-4752\(01\)00021-4](https://doi.org/10.1016/S0959-4752(01)00021-4)
45. Van Merriënboer, J., Kirschner, P. and Kester, L., Taking the load off a learner's mind: Instructional design for complex learning. *Educational Psychologist*, 2003, 38(1): 5–13. https://doi.org/10.1207/S15326985EP3801_2
46. Mayer, R. and Moreno, R., Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, 2003, 38(1): 43–52. https://doi.org/10.1207/S15326985EP3801_6
47. Sweller, J., Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review*, 2010, 22(2): 123–138. <https://doi.org/10.1007/s10648-010-9128-5>
48. Gupta, U. and Zheng, R., Cognitive load in solving mathematics problems: Validating the role of motivation and the interaction among prior knowledge, worked examples, and task difficulty. *European Journal of STEM Education*, 2020, 5(1): 5. <https://doi.org/10.20897/ejsteme/9252>
49. Sweller, J., Ayres, P. and Kalyuga, S., *Cognitive load theory*, 2011, Springer.
50. Sweller, J., The role of evolutionary psychology in our understanding of human cognition: Consequences for cognitive load theory and instructional procedures. *Educational Psychology Review*, 2022, 34(4): 2229–2241. <https://doi.org/10.1007/s10648-021-09647-0>
51. Castro-Alonso, J.C., Ayres, P. and Sweller, J., Instructional visualizations, cognitive load theory, and visuospatial processing. In *Visuospatial Processing for Education in Health and Natural Sciences*, 2019, 111–143. Springer International Publishing. https://doi.org/10.1007/978-3-030-20969-8_5
52. Martin, A., Ginns, P., Burns, E., Kennett, R., Munro-Smith, V., Collie, R., et al., Assessing instructional cognitive load in the context of students' psychological challenge and threat orientations: A multi-level latent profile analysis of students and classrooms. *Frontiers in psychology*, 2021, 12: 656994. <https://doi.org/10.3389/fpsyg.2021.656994>
53. Ayres, P. and Sweller, J., The split-attention principle in multimedia learning. *The Cambridge Handbook of Multimedia Learning*, 2021, 199–211. Cambridge: Cambridge University Press.
54. Ngu, B., Chen, O., Phan, H., Usop, H. and Anding, P., Can correct and incorrect worked examples supersede worked examples and problem-solving on learning linear equations? An examination from cognitive load and motivation perspectives. *Education Sciences*, 2025, 15(4): 504. <https://doi.org/10.3390/educsci15040504>
55. Gillmor, S., Poggio, J. and Embretson, S., Effects of reducing the cognitive load of mathematics test items on student performance. *Numeracy*, 2015, 8(1): 4. <https://doi.org/10.5038/1936-4660.8.1.4>
56. Yung, H. and Paas, G., Effects of computer-based visual representation on mathematics learning and cognitive load. *Journal of Educational Technology & Society*, 2015, 18(4): 70–77. <https://ro.uow.edu.au/sspapers/1941>
57. Mao, Y., Intercoder reliability techniques: Holsti method. *The sage encyclopedia of communication research methods*. 2017, 2: 741–743. SAGE Publications, Inc. <https://doi.org/10.4135/9781483381411.n258>

58. Setyaedhi, H., Comparative test of Cronbach's Alpha Reliability Coefficient, KR-20, KR-21, and Split-Half Method. *Journal of Education Research and Evaluation*, 2024, 8(1): 47–57. <https://doi.org/10.23887/jere.v8i1.68164>
59. Karim, S., Sudiro, S. and Sakinah, S., Utilizing test items analysis to examine the level of difficulty and discriminating power in a teacher-made test. *EduLite Journal of English Education Literature and Culture*, 2021, 6(2): 256–69. <https://doi.org/10.30659/e.6.2.256-269>
60. Cohen, J., *Statistical power analysis for the behavioral sciences*, 2nd ed. 1988, Routledge. <https://doi.org/10.4324/9780203771587>
61. Kebritchi, M., Hirumi, A. and Bai, H., The effects of modern mathematics computer games on mathematics achievement and class motivation. *Computers & Education*, 2010, 55(2): 427–443. <https://doi.org/10.1016/j.compedu.2010.02.007>
62. Lemonidis, C. and Kaiafa, I., The effect of using storytelling strategy on students' performance in fractions. *Journal of Education and Learning*, 2019, 8(2): 165–175. <https://doi.org/10.5539/jel.v8n2p165>
63. Alzhirani, B., A Proposed strategy based on fun learning to develop immediate and delayed achievement and motivation towards mathematics learning among primary school female students in the KSA. *Journal of Education-Al-Azhar*, 2022, 41(193): 59–106. <https://doi.org/10.21608/jsrep.2022.232939>
64. Matarazzo, K., Durik, A. and Delaney, M., The effect of humorous instructional materials on interest in a math task. *Motivation and Emotion*, 2010, 34(3): 293–305. <https://doi.org/10.1007/s11031-010-9178-5>
65. Fontes, M., Morgado, L., Pestana, P., Pedrosa, D. and Cravino, J., Viewing puzzles as two-faced: theoretical and practical implications for Puzzle-based Learning. *Thinking Skills and Creativity*, 2024, 52: 101470. <https://doi.org/10.1016/j.tsc.2024.101470>
66. Musdalifah, A., Irmayanti and Irawan, H., Guide to learning basic mathematics easy and fun for children. *Journal of Scientific Research, Education, and Technology (JSRET)*, 2022, 1(2): 58–61. <https://doi.org/10.58526/jsret.v1i2.9>
67. Fouze, A. and Amit, M., Development of Mathematical Thinking through Integration of Ethnomathematic Folklore Game in Math Instruction. *Eurasia Journal of Mathematics Science and Technology Education*, 2017, 14(2): 617–30. <https://doi.org/10.12973/ejmste/80626>
68. Weijer-Bergsma, E. and Ven, S., Why and for whom does personalizing math problems enhance performance? Testing the mediation of enjoyment and cognitive load at different ability levels. *Learning and Individual Differences*, 2021, 87: 101982. <https://doi.org/10.1016/j.lindif.2021.101982>
69. Chen, J., Li, Q., Tao, H., Xu, C., Gao, Y., Yang, J., et al., Audiovisual integration of simple stimuli: spatial congruency effects unaffected by working memory load. *Frontiers in Psychology*, 2025, 16: 1594306. <https://doi.org/10.3389/fpsyg.2025.1594306>
70. Krieglstein, F., Schneider, S., Beege, M. and Rey, G., How the design and complexity of concept maps influence cognitive learning processes. *Educational Technology Research and Development*, 2022, 70(1): 99–118. <https://doi.org/10.1007/s11423-022-10083-2>
71. Buchner, J., Buntins, K. and Kerres, M., The impact of augmented reality on cognitive load and performance: A systematic review. *Journal of Computer Assisted Learning*, 2022, 38(1): 285–303. <https://doi.org/10.1111/jcal.12617>

72. Zhu, X., Peng, K., Yu, S. and Wang, G., Can augmented reality technology reduce learners' cognitive load? A meta-analysis. *Smart Learning Environments*, 2026, 13(1): 9. <https://doi.org/10.1186/s40561-025-00429-7>
73. Abdulalber, A., Fun mathematics approach for developing productive thinking and reducing the level of cognitive burden among students of different achievement in the preparatory stage. *Faculty of Education Journal-Menofia*, 2021. <https://doi.org/10.21608/muja.2021.199941>
74. Adeosun, P. and Okonkwo, N., Cognitive load and test-taking skills as correlates of academic performance in mathematics of joint universities preliminary examinations board science students, University of Benin. *NIU Journal of Social Sciences*, 2024, 10(2): 107–13. <https://doi.org/10.58709/niujss.v10i2.1875>
75. Bobis, J., Sweller, J. and Cooper, M., Cognitive load effects in a primary-school geometry task. *Learning and Instruction*, 1993, 3(1): 1–21. [https://doi.org/10.1016/s0959-4752\(09\)80002-9](https://doi.org/10.1016/s0959-4752(09)80002-9)
76. Kennedy, M. and Romig, J., Cognitive load theory: An applied reintroduction for special and general educators. *Teaching Exceptional Children*, 2021, 56(6): 440–451. <https://doi.org/10.1177/00400599211048214>
77. Singh, J., Correlation between cognitive load, learning strategies, and academic success in STEM subjects. *International Journal for Research Publication and Seminar*, 2025, 16(4): 35–44. <https://doi.org/10.36676/jrps.v16.i4.319>
78. Hussein, R., Learning -educational design based on the cognitive burden strategy and its effect in primary school pupils achievement towards mathematics. *Sciental Journal of Education Humanities and Social Sciences*, 2026. <https://doi.org/10.62536/sjehss.2026.v4.i4.pp73-86>

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