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أثر دمج نظرية الحمل المعرفي في تدريس الرياضيات: دراسة قائمة على التصميم في صفوف المرحلة المتوسطة في العراق

م.م. زينب هادي فرحان
Zainab.hadi.1986@ec.edu.iq
المديرية العامة لتربية واسط

المستخلص:

يُعَدُّ تعلّم الرياضيات لدى طلبة المرحلة المتوسطة عمليةً معقّدة، ولا سيّما عند تناول موضوعات الجبر، لما تتطلّبه من توظيف الرموز والصيغ والإجراءات متعددة الخطوات. وفي السياق التعليمي العراقي، يُلاحظ تدنّي مستوى أداء الطلبة بشكل عام، مع انتشار الأخطاء الإجرائية، ويُعزى ذلك إلى اعتماد أساليب تدريس تقليدية لا تراعي حدود القدرات المعرفية للمتعلمين. هدفت هذه الدراسة إلى تقصّي أثر التدريس القائم على إرشادات نظرية الحمل المعرفي في الحدّ من الأخطاء لدى طلبة المرحلة المتوسطة في مادة الرياضيات. اعتمدت الدراسة منهج البحث القائم على التصميم، باستخدام تصميم شبه تجريبي لمجموعة واحدة باختبار قبلي/بعدي. وبلغت عيّنة الدراسة (٢٥) طالبة من الصف الثاني المتوسط في ثانوية النرجس للبنات بمحافظة واسط، العراق. وقد جرى تصميم وحدة تعليمية في التعابير والمعادلات الجبرية وفق مبادئ نظرية الحمل المعرفي، وتم تنفيذها على مدى أربعة أسابيع. شملت أدوات جمع البيانات اختبار تحصيلي في الرياضيات من إعداد الباحثة، وأداة لتحليل الأخطاء، إضافة إلى الملاحظة الصفّية. تم تحليل البيانات الكمية باستخدام الإحصاءات الوصفية، واختبار(t) ، وحجم الأثر، ومعامل الارتباط. وأظهرت نتائج الدراسة وجود أثر إحصائي دالّ في تحصيل الطالبات في الرياضيات بعد تطبيق الوحدة التعليمية($p<.001$) ، إلى جانب انخفاض ملحوظ في عدد الأخطاء الشائعة على مستوى موضوعات الجبر. كما لوحظ تحسّن في سرعة حلّ المشكلات وزيادة في مستوى التفاعل الصفي. وأشارت النتائج إلى وجود علاقة ارتباط إيجابية دالّة بين مستوى التفاعل الصفي والتحصيل في الاختبار البعدي. خلصت الدراسة إلى أنّ اعتماد عمليات تدريس قائمة على الأسس المعرفية يُعدّ عاملًا فاعلًا في تحقيق نتائج إيجابية في تحصيل طلبة المرحلة المتوسطة في مادة الرياضيات. كما تؤكد نتائج البحث على الأهمية البالغة لتبني أساليب التدريس القائمة على الإدراك المعرفي من أجل تحسين التحصيل الرياضي على المستوى الوطني في العراق.

الكلمات المفتاحية :نظرية الحمل المعرفي، التحصيل في الرياضيات، التعليم المتوسط، تدريس الجبر، تقليل الأخطاء.

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The Impact of Integrating Cognitive Load Theory into Mathematics Instruction: A Design-Based Study in Iraqi Middle School Classrooms

Asst. Lect. Zainab Hadi Farhan

Zainab.hadi.1986@ec.edu.iq

General Directorate of Education in Wasit

Abstract:

Mathematics learning among middle school students is very complicated, especially when it involves algebra, as it needs a combination of symbols, formulas, and multi-step procedures. Regarding the Iraqi educational setting, students' performance is generally very low, with many procedural mistakes, which is caused by traditional teaching methods that do not take into account the limitations of students' cognition. This research was designed to investigate the impact of mathematics teaching based on the guidelines of Cognitive Load Theory on reducing mistakes among middle school students. A design-based research approach with a one-group quasi-experiment pre-test/post-test approach was considered for the research. A total of 25 students from the second grade of the middle school, all of whom are female students from Al-Narjis Secondary School for Girls, Wasit Governorate, Iraq, participated in the research. An instructional unit on algebraic expressions and equations, based on cognitive load theory, was created and implemented over a period of four weeks. Data collection methods included a researcher-developed achievement test in mathematics, an error analysis tool, and classroom observation. Results of the quantitative data were analyzed using descriptive statistics, t-tests, effect size, and correlation. Results from this research indicate a significant statistical impact on the achievement of the participants in mathematics following the implementation of this instructional unit ($p<.001$), as well as a significant decrease in the number of common mistakes made at the level of algebra. Additionally, the participants realized faster problem-solving as well as greater classroom engagement. Greater classroom engagement of participants has a significant positive

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correlation to achievement at the second test. This research drew a conclusion indicating that a cognitively based instructional process is a powerful factor in impacting positive outcomes for the achievement of middle school mathematics. This research's findings place a great emphasis on cognitively based instructional processes to positively impact mathematics achievement at the national level of Iraq.

Keywords: Cognitive Load Theory, mathematics achievement, middle school education, algebra instruction, error reduction.

1. **Introduction**

1.1 Background of the Study

Mathematics has a very important place in school curricula because of its relevance to developing logical thinking and problem-solving skills. At the middle school level, the process of learning and teaching mathematics becomes a point of significant transitioning from basic computational mathematics to abstract areas like algebra, where a learner has to be cognizant of various symbols, formulas, and multi-step procedures simultaneously. All this becomes a very heavy cognitive load on a student and increases the chances of confusion and procedural errors.

Within the Iraqi educational system, mathematics is one of the subjects with constantly low levels of student attainment at the middle school stage. Reports and local studies have indicated that many students face difficulties in understanding algebraic concepts, reflected in the weak performance in achievement tests and examinations (Al-Jubouri, 2018; Ministry of Education, 2020). These challenges do not relate to the difficulty of content alone but are closely related to instructional practices that emphasize rote learning and repetitive procedures rather than conceptual understanding and cognitive organization of knowledge.

1.2 Mathematics Instruction in the Iraqi Context

Traditional methods of instruction are still predominant in math classes in Iraqi intermediate schools. These methods are typically manifested by direct instruction, a focus on the textbook, and a great deal of practice of similar problems without adequate attention to how students mentally process and differences in students (Al-Hilfi, 2017; Al-Zubaidi, 2019). Several researchers have cited that this approach to instruction results in students' cognitive overload, especially in complicated math problems (Al-Hilfi, 2017; Al-Zubaidi, 2019).

Moreover, the denseness of the mathematics curriculum and the need to cover the recommended topics in the limited teaching time could mean that the teacher has to focus on procedural teaching rather than meaningful teaching. This often results in students being able to solve the problems by rote, not fully understanding the concepts, thereby resulting in fluctuating performance results even in slightly altered versions of the tasks. This problem area has implications for teaching approaches that must be sensitive to the limitations of students' knowledge and must impact measurable mathematics achievement.

1.3 Cognitive Load Theory as an Instructional Framework

The Theory of Cognitive Load explains a scientific way of providing instruction based on the architecture of the human cognition system. The theory focuses on the capacity limits of the working memory and states that the effectiveness of learning is based on controls on the cognitive load introduced by the learning material. According to CLT theory, there are two kinds of cognitive loads: intrinsic and extraneous. The first one is associated with the inherent properties of the subject matter.

Poor structuring in mathematics education, especially in algebra, may impose extraneous cognitive load on students, thereby reducing their ability to process information effectively and lowering attainment. Based on CLT, the instruction aims to decrease unnecessary cognitive demands by

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organizing the content, using worked examples, sequencing tasks from simple to complex, and avoiding redundant information. Such principles meet the Iraqi classroom environment, where most students tackle cognitively demanding materials with little support from instruction.

1.4 Statement of the Problem

Despite the evidence of the effectiveness of CLT-based instructional strategies from international studies, their use in mathematics classes at middle schools in Iraq has been very limited. Studies carried out at a local level have shown poor mathematics results at middle schools, along with a high level of procedural and conceptual errors among algebraic expressions, especially at the middle school level (Al-Maliki, 2021; Al-Husseini, 2016).

The problem presented to be addressed by this research is that there is a mismatch between the demands of the mathematics concepts from a cognitive point of view and the instructional approaches that are typically followed in Iraqi schools. Poor achievement outcomes may be realized by instructional approaches that do not take into account the students' cognitive load. Thus, there is a need to have instructional approaches that address the management of the students' cognitive load to improve their achievement outcomes in mathematics.

1.5 Purpose of the Study

This study aims to develop and execute an instructional module for the subject of mathematics, according to the guidelines of Cognitive Load Theory. The study aims to determine the effect of the instructional procedure and module that is derived from Cognitive Load Theory on the learning outcomes of students in terms of their performance in a mathematics achievement test that is conducted before and after the procedure.

Using the principles of the CLT in the design of learning materials and activities in the classroom, the study will attempt to establish whether there is a statistically significant difference in the improved performance of the students in mathematics, as well as a reduction in common errors in algebra, in the Iraqi middle school environment.

1.6 Research Questions

The research questions for the study are:

1. What is the impact of CLT-based mathematical education on middle school students' performance in mathematics?
2. How much does instruction based on the Cognitive Load Theory reduce the occurrence of errors made by students on mathematical tasks?
3. What is the level of engagement and participation among students when they are taught mathematics based on the Cognitive Load Theory?

1.7 Significance of the Study

This research will be valuable, as it will be one of the few studies undertaken by Iraqis focusing on cognitive theory and its application to teaching mathematics in the classroom. With this in mind, the empirical findings regarding the impact of a CLT-based method of instruction on improved mathematics outcomes have several valuable implications.

The findings can benefit the movement for mathematics education reform in Iraqi middle schools by encouraging designs that work to minimize cognitive overload to facilitate correct and meaningful learning. This study is further justification for other studies to investigate applications of Cognitive Load Theory in various fields of learning in Iraqi educational settings.

2. Theoretical Framework

2.1 Learning Mathematics and Academic Achievement

Mathematical achievements can be referred to as the level of mastery that students attain in mathematics, as measured by techniques such as standardized tests or tests designed by instructors. In mid-level education, mathematical achievements involve not only procedures but also concept comprehension, logical thinking, and applications of rules learned to solve problems. Nonetheless, mathematical achievements still pose challenges to many learners around the world regarding algebraic mathematical achievements that involve coordinating several representations of problems to their solutions.

Research into the learning of mathematics suggests that poor achievement is related not only to the inherent difficulty of the mathematical content itself but also to the instructional approaches taken that are insensitive to how learners process information cognitively (Kirschner, Sweller, & Clark, 2006). Overloading the students' working memory by asking them to process too much information at any given time can result in confusion, superficial learning, and frequent errors. Consequently, improved mathematics achievement calls for instructional designs that take full account of the learners' cognitive capabilities and promote efficient construction of knowledge.

On the other hand, in the context of the Iraqi educational system, there have been a number of studies that revealed the poor performance of middle school students in the field of mathematics, and algebra and equations were at the forefront. The matter was attributed to the traditional teaching method used without a clear explanation (Al-Hilfi, 2017). The performance difficulties were found to be dependent on the design of instruction rather than the learners.

2.2 Cognitive Architecture and Working Memory

Cognitive Load Theory (CLT) is based on the premise of human cognitive architecture, specifically the idea of the limited capacity of working memory relative to the virtually unlimited capacity of long-term memory. Working memory is the part of cognitive processing that processes new information, though it can process only a limited amount of information if it is new (Sweller, 1988). Learning happens if new information is stored in the long-term memory as schemas, which decrease cognitive load when problem-solving.

Working memory becomes overloaded when instructional materials present too many interacting elements simultaneously, which leads to a failure of learning. This aspect is particularly relevant in mathematics because learners continuously have to process symbols, rules, procedures, and representations during the learning process. If appropriate instructional support does not take place, students will fail to integrate these elements into coherent schemas, leading to low achievement and unstable learning outcomes.

The CLT suggests that the teaching process must be structured in consideration of the limitations of the working memory, therefore controlling the level and type of cognitive load involved in the teaching process. The proposed theory has a strong basis to utilize in the teaching of mathematics to achieve better results by emphasizing the construction of the schema and minimizing the mental load.

2.3 Types of Cognitive Load

Cognitive Load Theory proposes that there are three different levels of cognitive load, which include intrinsic cognitive load, extraneous cognitive load, and germane cognitive load (Paas, Renkl, and Sweller, 2003).

Intrinsic cognitive load is the natural complexity of the task and the level of interactivity of the elements in the learning task. In math, for example, because of the abstract nature of many math concepts, such as algebraic manipulations and equation solving, the intrinsic cognitive load is high. Intrinsic cognitive load can never be reduced; however, it can be controlled through ordering the content from low to high and ensuring the foundation has been well-constructed.

Extraneous cognitive load is imposed by the presentation method of information, which has no connection with learning. Poorly designed teaching materials, ambiguous explanations, or dividing learners’ attention towards multiple sources of information can greatly influence extraneous cognitive load. High extraneous cognitive load has been found to decrease achievement in learning due to its contribution to the depletion of working memories that could otherwise be engaged in learning (Sweller et al., 2011).

Relevant cognitive load pertains to the cognitive processing of the construction and automatization of schemas. Good instructional practice aims at reducing extraneous cognitive load to optimum levels of germane cognitive load to achieve meaningful learning outcomes. In the context of mathematics education, it can be achieved through the use of worked examples, explanations, and practice.

2.4 Cognitive Load Theory and Mathematics Instruction

Learning mathematics is even more vulnerable to cognitive load. The level of abstraction and element interactivity for mathematics is very high. Solving algebra problems requires students to keep track of a set of rules to follow, as well as the procedures to follow in a certain order. These procedures can easily surpass working memory capacity if not properly sequenced.

Studies have confirmed that there are instructional approaches within the framework of CLT that can positively influence students' performance in mathematics. One of the most prevalent findings in the area is the effect of worked examples, which entail providing students with the step-by-step solution to a problem rather than expecting them to tackle a problem by themselves from the start (Atkinson et al., 2000). Worked examples are known to eliminate extraneous cognitive loads and help students concentrate more on the underlying concepts that result in better performance and lower mistake rates.

Another key principle to keep in mind is the split-attention effect. The split-attention effect occurs when the learners are compelled to allocate their attention to two or more sources of information, which should instead be integrated. For example, in the mathematical field, this typically occurs in textbooks where the information in text form is separated from the pictures and mathematical problems. Presenting information in space and time has been proven to increase the efficiency of learning (Chandler & Sweller, 1991).

The modality effect can also be applied when teaching mathematics. The simultaneous presentation of information through visual and auditory modalities can overcome cognitive overload and help in comprehension when describing complex operations (Mayer, 2009). The above points underscore the effectiveness of CLT on improving math outcomes.

2.5 Error Reduction and Cognitive Load

Errors in mathematics are a common indicator of cognitive overload and incomplete schema construction. Middle school students commonly commit procedural errors, such as incorrect manipulations of signs or inappropriate uses of algebraic rules, in cases when instructional explanations are not clear or when the explanation is cognitively demanding.

CLT postulates that the reduction of extraneous cognitive load will result in more accurate problem-solving since the resources of working memory will be liberated to monitor and detect errors. Research has demonstrated that students who learn through worked examples and guided practice make far fewer errors than those learning without such instruction through unguided problem-solving alone (Sweller et al., 2011).

Results by Al-Zubaidi (2019) in the Iraqi educational context revealed that a significant amount of algebraic mistakes made by secondary school students were due to confusion brought about by overloading of instructional explanations rather than due to a lack of effort or motivation. This goes toward addressing the assumption in managing cognitive load as part of error reduction and improving achievement.

2.6 Student Engagement and Cognitive Load

Engagement in class is also closely linked to the issue of cognitive load management. If the learning materials are very difficult, learners might end up getting frustrated, disengaged, or even avoiding learning. On the other hand, well-structured learning can greatly improve learner engagement.

CLT-based teaching encourages engagement by removing unnecessary complexity in learning. When students know what is expected of them, as long as they can process information effectively, there is a greater chance for them to engage actively in the learning process (Fredricks, Blumenfeld, & Paris, 2004). In a mathematics classroom, greater engagement leads to better outcomes in academics as well as better problem-solving skills.

2.7 Relevance of Cognitive Load Theory to the Iraqi Context

Despite the overwhelming empirical support for the use of CLT at the international level, the use of this approach in the Iraqi mathematics classroom is still minimal. The majority of studies undertaken in the country are still centered on traditional approaches to learning and instruction. The need for instructional approaches that incorporate students' cognitive ability, especially in subjects that involve a great deal of abstraction, such as Mathematics, was highlighted by Al-Hilfi (2017).

The application of the theory in the context of the Iraqi classroom addresses a range of concerns with achievement and mistakes made in mathematics. Through the optimization of lessons to minimize cognitive load and maximize the development of schema, teachers could improve the achievements of students.

3. Methodology

3.1 Research Design

The current study used a combination of the design-based research (DBR) approach and the quasi-experimental one-group pre-test/post-test design. Design-based research is mainly appropriate for educational studies that aim to bridge the gap between theory and classroom practice by designing, implementing, and evaluating instructional interventions in an authentic learning environment (Design-Based Research Collective, 2003; Anderson & Shattuck, 2012).

The pre-test and post-test design enabled the researcher to objectively determine the students' learning success achievement in mathematics, even before and after conducting the instruction. The design also correlates with the emphasis of the current research on quantifiable outcomes. Moreover, the design is capable of responding to the drawbacks in the instruction achievement effectiveness. The effectiveness is on measuring the truth and authenticity. The framework also enabled the researcher to enhance a set of CLT principles on instruction.

3.2 Research Context and Participants

The research was conducted in Al-Narjis Secondary School for Girls during the academic year 2024-2025, and it comes under the umbrella of the General Directorate of Education in Wasit Governorate, Iraq. The school follows the Iraqi national syllabus set by the Ministry of Education.

Respondents were 25 second-year middle school female students. Respondents were selected using purposive sampling, by which this class of students was representative of a typical class of middle school students taking mathematics in terms of the levels of their achievements. Purposive sampling is one of the common methods used in classroom studies, which this type of research method focuses on an in-depth exploration of a specific context in terms of how effectively a classroom setting impacts teaching effectiveness, as supported by Palinkas et al. 2015.

Before embarking on the data-gathering process, formal clearance was received from the Directorate of Education, while consent was sought from the school administration, pupils, and their parents. The requirements of confidentiality and voluntary participation, as ethically required in the research process, had been adhered to.

3.3 Instructional Intervention Design

The instructional intervention was a mathematics educational package designed following a teaching pattern postulated by Cognitive Load Theory. A critical area of mathematics education in the second year of schooling is algebraic expressions and equations, known to cause a high degree of intrinsic cognitive load. The instructional design was guided by the following CLT principles (Sweller, Ayres, & Kalyuga, 2011):

1. Minimization of unnecessary cognitive load through clear explanations, integrated representations, and elimination of redundancy.
2. Worked examples to illustrate how to solve problems systematically prior to independent problem-solving.
3. Fading of instructions by gradually reducing the level of instructional support as the students became comfortable with the material.
4. Modality optimization: the use of visual representations accompanied by teacher narration.

A lesson plan was designed with the help of a mathematics teacher to ensure that it achieves the goals of the curriculum. A lesson plan had a structure that included reviewing prerequisite knowledge, example solving, guided practice with feedback, and independent practice.

The intervention was conducted over a period of four weeks, with three 45-minute mathematics lessons per week, comprising twelve lessons altogether. During the period of the intervention, the researcher observed the classroom interactions and made notes on engagement and the pace of lessons.

3.4 Research Instruments

3.4.1 Mathematics Achievement Test

To enable the measurement of the students’ performance in mathematics, an achievement test developed by a researcher was designed in line with the curriculum content. The test contained items that covered the learning outcomes from the procedural fluency and understanding aspects.

The same test was used as a pre-test before the intervention, as well as the post-test afterwards, upon completion of the instructional unit. This is because the same content is used for the pre-test as well as for the post-test; therefore, accurate measurement is achieved.

The contents of the test were validated for their content validity by approaching two experts in the field of math education. The views of the experts not only aided in making the test clear and having levels of difficulty that respect the issue of learning goals, but also helped validate the contents of the test. The internal consistency reliability coefficient calculated by Cronbach's alpha was .82. This shows the internal consistency reliability coefficient with a significance level at .017.

3.4.2 Error Analysis Checklist

An error analysis checklist was designed based on the classification of error types that had been carried out among the students' written responses. The error types included sign error, operational error, rule misapplication error, and omission error. All the error types mentioned above have been supported by previous literature related to mathematical error analysis.

The checklist enabled comparisons to be done systematically in regard to error frequencies between both the pre-test and post-test, providing information on how CLT-based teaching affected students' accuracy.

3.4.3 Classroom Observation Protocol

A data recording format for observing levels of engagement of students based on factors of participation, response to tasks, and engagement with instructional activities was developed. The observations for recording data were all performed by the researcher personally in every single instructional session.

3.5 Data Collection Procedures

1. Pre-intervention phase. At this phase, students underwent pre-testing on their mathematics achievement.
2. Intervention phase: The instructional unit based on CLT was carried out for a period of four weeks.
3. Post-intervention stage: The students participated in a post-test, and their answers were examined for achievement and mistake patterns.

All the testing sessions were done in the classroom setting to minimize the variables that may affect performance.

3.6 Data Analysis

The quantitative data from the achievement tests were analyzed using the SPSS software package. Descriptive statistics, as well as the Paired-Samples T Test analysis, identified the differences between the pre-test and the post-test results as being statistically significant. Effect size measurement using Cohen's d rated the strength of the intervention effect based on the intervention implemented according to Cohen (1988).

The data on the rate of occurrence of errors were descriptively analyzed in order to examine changes in the types as well as the rate of occurrence of these types of errors before and post-intervention. Data generated from observation were employed in efforts to validate the quantitative findings.

3.7 Validity and Reliability

A number of methods have been used in order to improve the validity and reliability of the research. Content validity has been established using expert validation of the achievement test, and the use of tests of internal consistency has established reliability. A level of methodological triangulation has been provided using tests, errors, and observations in the classroom (Shenton, 2004).

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Even though the study was conducted in only one classroom, the use of a structured instructional design and a set of systematic data collection methodologies has helped to add to the credibility of the results.

3.8 Ethical Considerations

The ethical considerations were integral to the research process. The research was voluntary, and the students' identity was kept confidential. The data was used for research purposes and was aggregated.

4. Results

4.1 Introduction to the Results

This section presents the findings of the study based on quantitative and qualitative data that were collected to investigate how CLT-based instruction can improve mathematics achievement and reduce errors among middle school students. Results are organized to address each of the research questions and focus on quantifiable learning outcomes using assessment measured by a mathematics achievement test, systematic error analysis, and classroom observation data. All statistical analyses were done using SPSS, and the results are described using descriptive and inferential statistics.

4.2 Descriptive Statistics of Mathematics Achievement

In establishing a basis for comparison of their performance and achievement following the intervention, descriptive statistics were used for the pre-test and post-test results of the mathematics achievement test of the students. Table 1 below highlights the mean, standard deviations, and maximum and minimum scores of the pre-test and post-test results of the mathematics achievement test of the students.

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Table 1

Descriptive Statistics for Mathematics Achievement Test Scores (N = 25)

TEST	MEAN (M)	STANDARD DEVIATION (SD)	MINIMUM	MAXIMUM
PRE-TEST	52.40	10.23	35	70
POST-TEST	75.68	8.45	60	90

Referring to Table 1, it can be seen that the mean score of the post-test (M = 75.68) was significantly higher than the pre-test (M = 52.40). Moreover, the decrease in the standard deviation level from pre-test to post-test indicated a more uniform performance of the learners after the educational intervention.

4.3 Inferential Analysis of Achievement Scores

Referring to Table 1, it can be seen that the mean score of the post-test (M = 75.68) was significantly higher than the pre-test (M = 52.40). Moreover, the decrease in the standard deviation level from pre-test to post-test indicated a more uniform performance of the learners after the educational intervention.

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Table 2

Paired-Samples t-Test Results for Mathematics Achievement

TEST COMPARISON	MEAN DIFFERENCE	T-VALUE	DF	SIG. (P)
PRE-TEST – POST-TEST	-23.28	-13.82	24	< .001

The results showed a statistically significant difference between the pre-test and post-test scores, $t(24) = -13.82$, $p < .001$. This result shows that the instructional unit based on the CLT had a significant positive impact on students' performance in mathematics.

To determine the degree of the instructional effect, a value for Cohen's d was determined. The value for the effect size was $d = 2.76$, which is a very large effect size as determined by the criteria outlined by Cohen (1988). There was a significant and practical improvement in performance.

4.4 Analysis of Algebraic Error Reduction

In addition to the achievement scores, students' written responses were analyzed to determine if there was a change in the frequency and type of algebraic errors. The mathematical errors made by the students were classified into four categories: sign errors, operational errors, misapplication of rules, and omission errors. Table 3 presents the frequency of each error type in the pre-test and post-test.

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Table 3

Frequency of Algebraic Error Types in Pre-test and Post-test

ERROR TYPE	PRE-TEST FREQUENCY	POST-TEST FREQUENCY	REDUCTION (%)
SIGN ERRORS	34	8	76.5%
OPERATIONAL ERRORS	28	6	78.6%
MISAPPLICATION OF RULES	19	5	73.7%
OMISSION ERRORS	15	4	73.3%
TOTAL ERRORS	96	23	76.0%

The results show a significantly lower performance in all kinds of errors after treatment. Sign errors, the most frequent error type before treatment, were reduced by more than three-quarters. Overall, total errors were reduced by 76%, suggesting CLT-based instruction contributed to more accurate problem solving and better procedural control.

4.5 Response Time and Problem-Solving Efficiency

In investigating possible efficiencies in students' problem-solving abilities, data were collected on the average response time for algebra problem solutions on a four-week basis. The data is presented in Table 4, showing average response times for each week of experimentation.

Table 4

Mean Response Time for Solving Algebraic Problems (in Minutes)

WEEK	MEAN (M)	STANDARD DEVIATION (SD)
WEEK 1	7.4	1.1
WEEK 2	6.3	1.0
WEEK 3	5.0	0.8
WEEK 4	4.2	0.9

The results from the data also indicated a trend of steady decrease in the reaction time during the entire process of the treatment. The repeated measures ANOVA test result indicated a significant difference in the reaction time, $F(3, 72) = 142.56$, $p < 0.001$. The steady decrease in the reaction time reflects the increased fluency and automation of the schema, which was one of the proposed outcomes of the Cognitive Load Theory.

4.6 Relationship Between Engagement and Achievement

Data gathered from observations conducted in the classroom enabled the derivation of the engagement score of the students. The engagement score is measured based on the level of participation, task behavior, and responsiveness of the students to the instruction. Pearson correlation testing was used to find the correlation between the engagement score of the students and their performance during the post-test.

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Table 5

Correlation Between Student Engagement and Post-test Achievement

VARIABLES	R	SIG. (P)
ENGAGEMENT × ACHIEVEMENT	.69	< .001

The correlation coefficient of r = .69 speaks to a strong positive relationship between student engagement and mathematics achievement, thus showing that students in this study who were most actively engaged during instruction based on CLT generally had the highest post-test scores.

4.7 Qualitative Findings from Classroom Observations

Qualitative data from classrooms added depth to the context of results from quantitative studies. Outstanding themes included:

1. Clarity of Instructions: The students understood better when their instructions were based on worked examples.

2. Reduced Cognitive Overload: Fewer furrowed brows in the classroom as students worked out multi-step problems.

3. Willingness to Participate: Students asked more questions and demonstrated a disposition to engage in problem-independent solving.

From the above, it follows that CLT used in an instructional approach created a more supportive context for learning, through which both engagement and achievement came more easily.

5. Recommendations

On the basis of research findings, certain suggestions are being presented for educational practice and further research.

Based on the recommendations, it would therefore be advisable for a mathematics teacher in a middle school to employ teaching strategies anchored on the Cognitive Load Theory. These would involve the effective manipulation of worked examples, the hierarchical presentation of topics from simple to more complex matters, and the integration of visual and verbal statements. These would help alleviate cognitive load and lead to better performance among students on problem-solving exercises.

Secondly, curriculum developers and textbook authors should also consider applying principles of CLT to mathematics instruction. Textbooks that have fewer split-attention issues, less redundancy, and a better structure regarding providing examples would be suited to provide adequate support to cognitive processing, resulting in improved outcomes.

Third, mathematics teacher professional development programs should provide training in cognitive load management and instructional design. Understanding how students process information will better equip teachers to design effective instruction and lead to more durable learning gains in mathematics achievement.

Conclusion

This research focuses on evaluating whether mathematics teaching, based on the principles of the Theory of Cognitive Load Management, can benefit middle school students by reducing algebra errors and enhancing their mathematics outcomes. By taking a design science research and a quasi-experimental research method, this research attempts to fill a theoretical gap between cognitive psychology theory and instructional practice while still focusing on methodological rigor.

The findings revealed that the use of the CLT approach had a statistically significant and practically significant influence on student performance in mathematics. Students' scores after the test were higher and significantly different from the scores before the test, which supported the assumption that better learning outcomes may be attained through guidance using the learners' cognitive architecture. In addition, the finding that the number of joint errors in algebra had a great decline indicates the importance of the management of cognitive load in developing accuracy and stability in procedures, which are predominant in the subject of mathematics.

Apart from achievement and accuracy, the findings also revealed the benefits of problem-solving efficiency as well as engagement in the classroom. The point that there were lowered times to respond, as well as increased levels of participation, is an indication of the fact that the learners were able to process the information on the mathematical concept in class with efficiency and confidence. All these are driven by the assumption of the Cognitive Load Theory.

Overall, this study renders its support for Cognitive Load Theory as a powerful and applicable concept that can be used effectively for carrying forward mathematics education and performance positively for a section of students at the level of a middle school.

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