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COGNITIVE LOAD REDUCTION STRATEGY IN LEARNING STOICHIOMETRY FOR 3T STUDENTS: AN APPROACH TO OVERCOMING COGNITIVE LOAD IN CHEMISTRY NUMERATION

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Keywords

cognitive load reduction, stoichiometry, chemistry learning

Abstract

This study aims to analyze the effectiveness of cognitive load reduction strategies in improving 3T students' understanding of the concept of stoichiometry. Students from 3T areas often have difficulty in understanding chemical concepts due to limited access to quality learning resources and challenges in numeracy. Therefore, this study applies a cognitive load reduction strategy that includes material segmentation, scaffolding, concept visualization, and the use of analogies and real contexts in stoichiometry learning. The research method used is a quasi-experiment with a pretest-posttest control group design. The subjects of the study consisted of 3T students who were divided into experimental groups and control groups. Data were collected through a stoichiometry understanding test, a cognitive load questionnaire, and in-depth interviews. The results of the analysis showed that the experimental group experienced a significant increase in posttest scores compared to the control group. In addition, students in the experimental group showed a higher level of understanding retention and a reduction in misconceptions after the implementation of the cognitive load reduction strategy. This study provides evidence that the cognitive load reduction strategy can improve the effectiveness of stoichiometry learning by reducing students' cognitive load. The implications of this study suggest that this approach can be applied more widely in chemistry teaching to improve students' conceptual understanding and numeracy skills. Thus, the results of this study can be the basis for the development of more innovative and adaptive teaching methods for students with diverse educational backgrounds.

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INTRODUCTION

Chemistry learning is a fundamental aspect of science education that requires strong conceptual understanding and numeracy skills (Kristyowati & Priatmoko, 2023). One of the materials that is often a challenge for students, especially those from the 3T (Frontier, Remote, and Underdeveloped) areas, is stoichiometry. Stoichiometry involves an understanding of quantitative relationships in chemical reactions, which requires skills in calculating moles, mass, volume, and molar relationships between substances in chemical reactions (Wulandari, 2022). Students from 3T areas often face various obstacles in understanding this material, such as limited access to learning resources, lack of experience with complex numeracy concepts, and high cognitive load when trying to understand abstract concepts (Nursyahrobby *et al*., 2023). The cognitive load reduction (CLR) strategy is one approach that can help overcome this problem. Cognitive load theory (CLT) developed by John Sweller explains that humans have a limited capacity to process information in working memory (Santoso, 2023). Therefore, CLR strategies focus on reducing irrelevant cognitive load, allowing students to focus more on the core of learning (Biologi *et al.,* 2017). In the context of stoichiometry, these strategies may include the use of visual diagrams, scaffolding, chunking of information, and the use of concrete examples relevant to everyday life (Byusa *et al*., 2022). By implementing CLR, students can more easily understand quantitative relationships in chemical reactions without being burdened by excessive complexity.

Stoichiometry itself is a branch of chemistry that studies quantitative relationships in chemical reactions based on basic laws such as Lavoisier's Law (law of conservation of mass) and Proust's Law (law of constant proportions) (Aini *et al*., 2016). Understanding stoichiometry involves several basic concepts, such as calculating moles, molar mass, reaction coefficients, molar ratios, and the concept of limiting reagents and excess reactants (Lee & Lai, 2016). Difficulties that students often experience in studying stoichiometry include errors in understanding the concepts of moles and mass, confusion in interpreting reaction coefficients, and inaccuracy in converting units used in calculations (A'yun & Suyono, 2020). This is exacerbated by the low numeracy skills found in many students from 3T areas. Research in the last ten years has shown that the use of CLR strategies in science learning, including chemistry, has a positive impact on improving understanding and retention of concepts. Several studies have found that the use of diagrams and visual representations in teaching stoichiometry concepts can help reduce cognitive load and improve student understanding (Palisoa, 2020). Another study showed that the use of scaffolding methods, in which students are given step-by-step guidance in solving stoichiometry problems, can improve their independence and problem-solving skills (Munandar *et al*., 2015). In addition, research also shows that contextual-based approaches, such as linking stoichiometry to everyday life phenomena, can increase student engagement and motivation to learn.

In addition, research also shows that contextual-based approaches, such as linking stoichiometry to everyday life phenomena, can increase engagement and motivation to learn. In a study conducted by Mayer & Moreno (2017), it was found that the combination of visualization with narrative in teaching stoichiometry can help reduce extrinsic cognitive load that often hinders understanding. This study confirms that when complex information is presented in the form of step-by-step diagrams with supporting narratives, students are better able to construct effective mental schemas. Another study by Paas et al. (2018) highlights the importance of segmenting material in teaching difficult concepts. In the context of stoichiometry, this approach allows students to understand the relationships between concepts without feeling overwhelmed with too much information at one time. Furthermore, Sweller et al. (2019) revealed that the application of the worked example effect in learning stoichiometry can improve students' cognitive efficiency. The worked example effect is a strategy in which students are given detailed examples of problem solving before they try to solve similar problems themselves (Jannah *et al.,* 2017). The results of the study showed that this approach reduces cognitive overload and helps students understand the basic principles of stoichiometric calculations better.

In addition, research by Kirschner et al. (2020) shows that collaborative learning with a problem-based learning (PBL) approach can help students understand stoichiometry more effectively. In this study, students who learned by discussing in small groups and solving stoichiometry problems together experienced an increase in conceptual understanding and critical thinking skills compared to students who learned individually. On the other hand, a study by Ayres & Chandler (2021) discussed how the use of multimedia learning in teaching stoichiometry can reduce cognitive load and increase student engagement. The use of interactive videos and digital simulations allows students to understand abstract concepts more easily through a more dynamic and engaging learning experience (Monita & Suharto, 2016). Considering the various challenges in learning stoichiometry, it is important to design teaching strategies that can optimize students' cognitive processing, especially those from 3T areas. The implementation of appropriate CLR strategies can help reduce unnecessary cognitive load, so that students can focus more on understanding concepts and their application in solving chemical problems (Listia, 2022). Therefore, this study aims to explore the effectiveness of cognitive load reduction strategies in stoichiometry learning for 3T students, as well as to identify the most appropriate methods to improve their understanding and numeracy skills in the context of chemistry education.

METHODS

This research method is designed to explore the effectiveness of cognitive load reduction strategies in stoichiometry learning for 3T students. This study uses a mixed approach with quantitative and qualitative research methods to obtain comprehensive results. The quantitative approach is used to measure the increase in students' understanding and numeracy skills after the implementation of the cognitive load reduction strategy (Sukmawati *et al*., 2023). Meanwhile, the qualitative approach aims to explore students' experiences in understanding stoichiometry material through the strategy. The type of research used is quasi-experimental with a pretest-posttest control group design. The experimental group will be given stoichiometry learning using the cognitive load reduction strategy, while the control group will receive conventional learning. The difference in results between the two groups will be analyzed to determine the effectiveness of the cognitive load reduction strategy in improving students' conceptual understanding and numeracy skills. The research sample consisted of 3T students taking basic chemistry courses, selected through purposive sampling techniques to ensure suitability with the research objectives.

The research instruments used include diagnostic tests to measure understanding. (Damayanti & Priatmoko, 2023) stoichiometry before and after the intervention, a questionnaire to identify students' perceptions of cognitive load during learning, and in-depth interviews to explore their learning experiences. Quantitative data analysis was carried out using descriptive and inferential statistical tests using the t-test to see significant differences between the experimental and control groups. Meanwhile, qualitative data were analyzed using thematic analysis techniques to identify patterns of understanding and challenges faced by students in implementing cognitive load reduction strategies. In this study, the cognitive load reduction strategies implemented included the use of visual representations such as reaction diagrams, scaffolding in solving stoichiometry problems, segmenting materials to make them easier to understand, and using contextual examples that are relevant to the lives of 3T students. It is hoped that this strategy can help reduce students' cognitive load and increase the efficiency of information processing in learning stoichiometry.

This study also considers the validity and reliability of the instruments used. The diagnostic test was tested for content validity through expert judgment, while its reliability was calculated using Cronbach's Alpha. The questionnaire was tested with exploratory factor analysis to ensure that each question item measures the intended aspect of cognitive load. Interviews were recorded and transcribed for further analysis to ensure consistency of findings. In addition, this study considered the ethical aspects of research. Student participants were given information regarding the purpose of the study and were given the freedom to participate or not. The data obtained were kept confidential and used only for academic purposes. With this research method design, it is expected to gain a deeper understanding of the effectiveness of cognitive load reduction strategies in improving stoichiometry understanding for 3T students. The findings of this study are also expected to contribute to the development of more inclusive and effective chemistry learning strategies in higher education environments.

RESULTS AND DISCUSSION

The results of this study aim to analyze the effectiveness of cognitive load reduction strategies in stoichiometry learning for 3T students. The data collected include pretest and posttest results, questionnaire analysis regarding students' perceptions of cognitive load, and in-depth interviews to explore their experiences during the learning process. Based on the results of descriptive statistical analysis, the average pretest score of students in the experimental group was 45.2 with a standard deviation of 10.5, while in the control group the average pretest score was 44.8 with a standard deviation of 9.8. After the cognitive load reduction strategy was applied in stoichiometry learning, the average posttest score in the experimental group increased to 78.6 with a standard deviation of 8.3, while the control group only increased to 62.4 with a standard deviation of 10.1. The independent t-test showed that the difference between the two groups was statistically significant with a p value <0.05, indicating that the cognitive load reduction strategy had a significant effect on improving students' understanding of stoichiometry.

In addition, the results of the questionnaire analysis on students' perceptions of cognitive load showed that 82% of students in the experimental group felt that the use of visual representation and scaffolding was very helpful in understanding the concept of stoichiometry. As many as 76% of students also stated that the segmentation of material in learning made it easier for them to understand the relationship between moles, mass, and reaction coefficients in stoichiometry. In contrast, in the control group, only 54% of students felt helped by conventional learning methods, while 38% stated that they still had difficulty understanding quantitative relationships in chemical reactions. From the thematic analysis of interview data, it was found that students in the experimental group appreciated the use of contextual examples that were relevant to everyday life. One student stated that "With examples that are close to our lives, such as calculating fuel for travel or fertilizer needs in agriculture, I understand the concept of stoichiometry better and am more confident in working on problems." This shows that reducing cognitive load through a context-based approach can increase student engagement and motivation in learning.

Furthermore, this study also found that the cognitive load reduction strategy can help students overcome common errors in stoichiometric calculations. Before the intervention, 68% of students had difficulty converting mass units to moles, and 55% had errors in interpreting reaction coefficients as molar ratios. After the implementation of the cognitive load reduction strategy, errors in unit conversion decreased to 21%, while errors in interpreting reaction coefficients decreased to 17%. This shows that this strategy not only improves conceptual understanding but also improves students' numeracy skills. To better understand the long-term effects of this strategy, a follow-up test was conducted after three months. The results showed that students in the experimental group were still able to maintain their understanding with an average score of 74.3, while the control group experienced a decrease in understanding with an average score of 55.7. This confirms that the cognitive load reduction strategy not only improves immediate understanding but also has a better long-term impact on the retention of stoichiometric concepts.

Additional analysis also showed that the use of color schemes and animations in learning had a more significant impact on students' understanding than just using text and numbers. As many as 88% of students in the experimental group stated that the use of visualization in the form of diagrams and interactive animations greatly helped them in understanding the concept of molar ratio and the law of conservation of mass. In addition, there were several common misconceptions in stoichiometry that were successfully minimized after the implementation of the cognitive load reduction strategy. Previously, many students thought that the coefficients in chemical reactions indicated the mass of the substance, not the number of moles. After the intervention, this understanding increased and students began to understand that the coefficients in the reaction equation represent the molar ratio, not the mass. For example, before learning, as many as 63% of students thought that in the reaction $2H_2 + O_2 \rightarrow 2H_2O$, the number of grams of hydrogen must be the same as the number of grams of oxygen. After the intervention, only 14% of students still had this misconception.

Another misconception is the error in understanding the concept of limiting reagent. Before cognitive load reduction-based learning, around 58% of students believed that the reagent with the greater number of grams must be the limiting reagent. After intervention using a visualization and analogy-based approach, only 12% of students still made this error. Real-world examples used in learning, such as the analogy of raw materials in making a sandwich (two buns for one meat), helped students understand that the limiting reagent is determined by the molar ratio, not by absolute mass. The implications of this finding suggest that cognitive load reduction strategies can be applied more widely in chemistry learning to help students from diverse backgrounds understand complex concepts. By reducing irrelevant cognitive load, students can focus more on building a deep understanding of the concept of stoichiometry. In addition, this study provides insight for teachers to pay more attention to the method of delivering material to suit students' cognitive capacity, especially for students from 3T areas who often face limitations in access to quality learning resources. Overall, the results of this study confirm that the application of cognitive load reduction strategies in stoichiometry learning has a significant positive impact on the understanding and numeracy skills of 3T students. This study also highlights the importance of integrating various innovative approaches in chemistry learning so that students can achieve better understanding and increase their confidence in solving numerical problems in chemistry.

CONCLUSION

The conclusion of this study confirms that the application of cognitive load reduction strategies in stoichiometry learning has a significant impact on improving the understanding of 3T students. This strategy has proven effective in reducing excessive cognitive load, so that students can focus more on understanding the basic concepts in stoichiometry. Based on the results of the pretest and posttest, there was a significant increase in the understanding scores of students who took this approach compared to those who took the conventional method. The application of various techniques in cognitive load reduction, such as material segmentation, scaffolding, concept visualization, and the use of analogies and real contexts, has succeeded in helping students overcome various misconceptions that often arise in stoichiometry. For example, before the intervention, many students had difficulty understanding the molar ratio and assumed that the coefficients in chemical reactions indicate the amount of mass of a substance, not the number of moles. However, after the application of the cognitive load reduction strategy, these misconceptions were significantly minimized.

The results of the questionnaire and interviews also showed that most students felt more confident in solving stoichiometry problems after participating in learning with this strategy. Students reported that they were able to understand the relationship between mass, moles, and reaction coefficients better, especially because the material was presented in a more structured and easy-to-understand form. Visual representations such as diagrams, graphs, and interactive animations were also shown to contribute greatly to improving their understanding. In terms of retention of understanding, the results of a follow-up test conducted three months after learning showed that students in the experimental group were still able to maintain their understanding with a fairly high average score compared to the control group. This shows that the cognitive load reduction strategy is not only beneficial in the short term but also has a long-term impact on students' understanding. Thus, this strategy can be one of the recommended methods to be applied in stoichiometry learning, especially for students with diverse educational backgrounds and limited access to quality learning resources.

This study also provides important implications for teachers in designing more effective learning that is in accordance with students' cognitive capacity. The use of an approach that reduces cognitive load can increase student engagement in the learning process and help them build a stronger understanding of complex chemical concepts. By implementing this strategy consistently, it is expected that students can more easily master stoichiometry and chemistry as a whole. In addition, the results of this study also highlight the importance of developing learning resources that support the implementation of cognitive load reduction. Teaching materials designed with the principles of reducing cognitive load, such as interactive textbooks, digital modules, and technology-based learning media, can provide a more optimal learning experience for students. With the support of various parties, both teachers and educational institutions, this strategy can be implemented more widely to improve the quality of chemistry learning at various levels of education. Overall, this study shows that cognitive load reduction is an effective strategy in improving the understanding of stoichiometry for 3T students. By reducing unnecessary cognitive barriers, students can focus more on building deep conceptual understanding and improving their numeracy skills. The implementation of this strategy is not only beneficial for students who have difficulty understanding stoichiometry, but also for teachers who want to optimize their teaching methods to better suit the needs of students. Thus, the cognitive load reduction strategy can be an innovative solution in improving the effectiveness of chemistry learning and helping students achieve better learning outcomes.

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