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Cognitive Load of Students in Chemistry Learning: A Survey of High School Students in Indonesia

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Abstract: This study aims to analyze the cognitive load of students in chemistry learning and categorize the results based on grade levels. The research was conducted in the form of a survey using a quantitative approach during the second semester of the 2023/2024 academic year. The sample was taken using simple random sampling technique and consisted of 600 students from 10 public high schools and 5 private high schools from DKI Jakarta, Banten, West Java, and South Sumatra Province. The instrument used was a cognitive load questionnaire to measure two aspects of cognitive load: mental load and mental effort. Data analysis was performed using descriptive statistics and one-way ANOVA test. The findings indicate that the overall cognitive load of students is in the moderate category (M = 23.29), suggesting that most students can process the learning materials. Mental load (M = 2.92) was found to be slightly higher than mental effort (M = 2.90), implying that students experience greater cognitive demands in understanding concepts than in performing tasks. Grade X students showed the highest cognitive load, likely due to their novice-level understanding of abstract chemical concepts. The results also highlight that cognitive load can be managed and maintained at a moderate level through appropriate instructional strategies and supportive learning environments.

Keywords: Chemistry; Cognitive load; Grade levels

Introduction

Chemistry is a science that studies the properties of matter, with elements and compounds playing a crucial role in chemical changes (Chang & Overby, 2011). Currently, chemistry continues to evolve and holds significant importance for life, the environment, and society (Chang, 2010). However, various studies in science education have found that students do not grasp the essence of chemistry learning (Milenković et al., 2014). Students perceive chemistry learning as conceptual and mathematical, abstract, and difficult to understand (Gafoor & Vevaremmal, 2012). One of the contributing factors to this difficulty is the high cognitive demand involved in understanding chemistry concepts. The complexity of the subject often requires students to process multiple pieces of interrelated information simultaneously, which can increase their cognitive load during learning.

As students' progress through their education from elementary to secondary school, there is an increase in homework, assessments, content coverage, material complexity, and difficulty level (Martin & Evans, 2018). This increase contributes to the interactivity of the elements being studied. The interactivity of elements becomes high when there are many interconnected components. For example, a student may be asked to analyze the reaction products of combustion by reviewing the relationships between fundamental chemical laws, reaction equations, and the concept of moles (Renkl & Atkinson, 2003).

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Everyone has a different and limited memory capacity, leading to variations in students' abilities to understand information during learning. A person with limited working memory capacity may struggle and feel overwhelmed when faced with a large amount of complex information (Lange & Costley, 2018; Skulmowski & Xu, 2022). The higher the interactivity of the elements and the more complex the material being studied, the greater the burden on the working memory that students must use to process information (Kala & Ayas, 2023; Skulmowski & Xu, 2022).

Working memory is related to cognitive load, defined as an individual's cognitive capacity to perform a task, learn, or solve a problem (Paas, 1992). Cognitive load is one aspect that influences the success of learning objectives. Chen & Huang (2020), in analyzing the relationship between cognitive load and learning outcomes, found a negative correlation between cognitive load and post-test results; lower cognitive load during the learning process leads to better post-test scores. Cognitive load reflects the pressure placed on working memory during learning, and heavy cognitive load can negatively affect task completion and reduce students' performance quality (Videla et al., 2021). Sweller et al. (1998) categorized cognitive load into two dimensions: task-based load (mental load) and learner-based load (mental effort).

Managing cognitive load can be achieved by reducing irrelevant factors and optimizing relevant ones in learning. Several factors can increase cognitive load when a person is working on specific tasks, including material complexity, poor instructional delivery, an unsuitable learning environment, and inappropriate learning design (Lange & Costley, 2018). Learning activities should encourage actions that minimize irrelevant processing or storage related to the learning task to avoid overloading working memory capacity (Sweller et al., 1998).

Chemistry learning, which is abstract and requires spatial abilities to visualize chemical models in three dimensions, can benefit from technology that aids in concept visualization, potentially reducing the cognitive load felt by students (Keller et al., 2021; Wu et al., 2022).

Based on this explanation, the purpose of this study is to analyze the cognitive load of students in chemistry learning and categorize the results by grade level. This research is important to determine the extent of cognitive load experienced by students during chemistry classes. The findings are expected to provide foundational information for selecting appropriate learning models and media, as well as creating learning environments that can reduce cognitive load to achieve successful learning outcomes.

Method

Study Design

The research was conducted in the form of a survey using a quantitative approach. Survey is a method of data collection focused on obtaining data, facts, beliefs, opinions, attitudes, motivations, and behaviors from specific individuals (Pinsonneault & Kraemer, 1993). In the context of this study, the survey was conducted to collect data related to students' cognitive load in chemistry learning.

Research Location and Subjects

The population in this study consists of high school students in the 2023/2024 academic year in the provinces of DKI Jakarta, Banten, West Java, and South Sumatra. The selection of these four provinces was based on several considerations, including existing collaborations with teachers at schools in these regions, ease of communication through the researcher's personal network, geographical proximity to the researcher's current location, which facilitates coordination, and the availability of adequate online learning infrastructure, enabling the data collection process to be conducted online.

Sample was selected using simple random sampling. Using this technique, a sample of 600 students from 10 public schools and 5 private schools was obtained. Before administering the questionnaire, the researcher obtained permission from subject teachers and consent for participation from students in accordance with ethical considerations in research. Participation was voluntary, and it was ensured that all collected data remained anonymous and were used solely for research purposes. Student privacy and data confidentiality were maintained by not including personal identifiers in data collection or reporting. The demographic characteristics of the sample are presented in Table 1.

Table 1. Sample demographic characteristics

Category	Type	Total participants	
		Total	Percentage (%)
School	Public schools	460	76.67
	Private school	140	23.33
	Total	600	100.00
Gender	Female	367	61.17
	Male	233	38.83
	Total	600	100.00
Age	14 Years old	28	4.67
	15 Years old	259	43.16
	16 Years old	141	23.50
	17 Years old	142	23.67
	18 Years old	28	4.67
	19 Years old	2	0.33
	Total	604	100.00

Category	Type	Total participants	
		Total	Percentage (%)
Grade	10	295	49.17
	11	115	19.17
	12	190	31.66
	Total	600	100.00

Research Instruments

The instrument used to measure students' cognitive load is a cognitive load questionnaire adapted from Hwang et al. (2013). The questionnaire contains 8 statements to measure two aspects of cognitive load, namely mental load and mental effort, using a 5-point Likert scale, where 1 = strongly disagree, 2 = disagree, 3 = undecided, 4 = agree, and 5 = strongly agree. The highest score is 40 points, with the lowest score being 8 points. Each item was mapped to specific sub aspects, as shown in Table 2.

Table 2. Distribution of the number of question items

Cognitive Load Aspect	Item Number	Total
Mental load	1, 2, 3, 4, 5	5
Mental effort	6, 7, 8	3

The instrument was adapted by translating it into Indonesian. To ensure the validity of the instrument, content validity was assessed from a linguistic perspective by testing the suitability of the instrument items with Indonesian language rules based on expert judgement. In this study, the language validators were two English teachers and one Indonesian language teacher. The researchers did not conduct reliability testing before collecting the main data. Therefore, the reliability of the instrument was tested retrospectively after the main data was collected using a relevant and similar sample. In this case, retrospective reliability used data from 30 tenth-grade high school students who completed the same instrument. The results showed a Cronbach's Alpha value of 0.845, indicating that the instrument has high reliability.

Data Collection Procedure

Data collection was conducted through a questionnaire distributed online via Google Forms and accessible to students. The questionnaire included instructions for completion on the first page. The questionnaire was completed after chemistry lessons under the supervision of chemistry teachers at each school. Completing the questionnaire took approximately 20 minutes.

Data Analysis

To figure out the overall cognitive load of students, we did a descriptive statistical analysis. Then cognitive load data was sorted into three categories: low (≤ 19), moderate (20–30), and high (≥ 30). Meanwhile, to find out the differences in cognitive load between classes, the data was analysed using one-way ANOVA.

Result and Discussion

Result

In this section, according to the research objectives, the results of the analysis of cognitive load regarding descriptive statistics and one-way ANOVA are presented as follows. Descriptive statistics (i.e., minimum and maximum scores, sum scores, mean scores, and standard deviations) for cognitive load are shown in Table 3.

Table 3. Descriptive statistics of students' cognitive load in chemistry learning

Aspect	Min	Max	Sum	Mean	SD
Mental load	5	25	8747	14.58	3.81
Mental effort	3	15	5226	8.71	2.259
Cognitive Load	8	40	13973	23.29	5.51

Table 3 shows that overall, student's cognitive load falls into moderate category (M = 23.29, SD = 5.51). Specifically, the mental load aspect shows a value of M = 14.58 with SD = 3.81. Meanwhile, the mental effort aspect shows a value M = 8.71 with SD = 2.259. To allow for fair comparison between mental load and mental effort, the mean scores were divided by the number of items in each subscale. The average per-item score for mental load was 2.92, while for mental effort was 2.90. This suggests that students perceived slightly higher mental load than mental effort during chemistry learning, although the difference was not very significant.

In response to the second research question, a one-way ANOVA was conducted to explain whether there were differences in students cognitive load between classes. However, before conducting the one-way ANOVA test, prerequisite tests were conducted, including normality and homogeneity tests. The results are as follows.

Table 4. Normality test result (Shapiro-Wilk)

Grade Level	N (respondents)	Sig. (p)	Interpretation
Grade X	295	0.053	Normal
Grade XI	115	0.200	Normal
Grade XII	190	0.279	Normal

Table 5. Homogeneity of variance test result (Levine's test)

Levine Statistic	df1	df2	Sig. (p)	Interpretation
0.290	2	597	0.748	homogeneous

The result of normality and homogeneity tests show sig. > 0.05, which can be interpreted as normal dan homogeneous data. These results indicate that the prerequisite tests have been met and can be followed by a one-way ANOVA test. The result of the one-way ANOVA test shown in Table 6.

Table 6. One-way ANOVA test result

Source of Variation	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	357.372	2	178.686	6.207	0.002
Within Groups	17185.902	597	28.787		
Total	17543.273	599			

A one-way ANOVA was conducted to examine whether there were statistically significant differences in students cognitive load across grade levels (grade X, XI, and XII). The result showed a significant difference in cognitive load among the three groups, F (2, 597) = 6.207, p = 0.002. This finding indicates that at least one grade level had a significant different mean cognitive load score compared to the others. Since a significant difference was found among the three grade levels, a follow up analysis was conducted using Tukey post hoc test to identify which specific groups differed. The results of the post hoc analysis is presented in Table 7.

Table 7. Post-Hoc test result (Tukey test)

(I) Grade	(J) Grade	Mean Difference (I-J)	Sig. (p)
Grade X	Grade XI	0.453	0.723
	Grade XII	1.746	0.001
Grade XI	Grade X	-0.453	0.723
	Grade XII	1.294	0.103
Grade XII	Grade X	-1.746	0.001
	Grade XII	-1.294	0.103

The post-hoc analysis using Tukey's test revealed that there were significant differences in cognitive load between grade X and Grade XII (p = 0.001). Meanwhile no significant difference was found between Grade X and Grade XI (p = 0.723). The mean difference between grade X and grade XII was 1.746. The positive sign indicates that there is a difference in the average cognitive load between grade X and grade XII of 1.746, where the average cognitive load of grade X is greater than grade XII. This indicates that grade X has the highest score of cognitive loads among all other grades.

Discussion

The purpose of this study was to analyse the cognitive load of students in chemistry learning and categories the results based on grade level. The sample in this study consisted of 600 students in grades X, XI, and XII from 10 public schools and 5 private schools in the provinces of DKI Jakarta, Banten, West Java, and South Sumatra. The results of the study indicate that the cognitive load of students in chemistry learning for all grade levels falls into the moderate category (M = 23.29). This finding indicates that despite the abstract and complex nature of chemistry material, most students are still able to manage the information received during learning. However, previous studies conducted by Herman & Yulis (2021), which specifically analysed students' cognitive load on salt hydrolysis and colligative properties of solutions, showed that students' cognitive load on these topics was high. The differences in research results may be due to several factors, such as the complexity and high level of interaction between materials (Nurwanda et al., 2020), learning media support (Azman & Johari, 2022; Gusti et al., 2023; Susanto et al., 2023) and the application of teaching methods aimed at reducing students' cognitive load (Damayanti & Putri, 2025; Mukarromah et al., 2022). The results of this study suggest that under certain conditions, students' cognitive load can be categorised as moderate by controlling related supporting factors.

Similarly, previous research at the junior high school level has suggested that reducing students' cognitive load may be an effective way to improve academic performance and foster a more optimal learning environment (Hidayat et al., 2025). These findings reinforce the importance of instructional strategies that are designed to align with students' cognitive capacities across different educational stages.

The aspects of cognitive load measured in this study were mental load and mental effort. The results showed that the mental load (M = 2.92) experienced by students in chemistry learning was greater than mental effort (M = 2.90). According to Wu et al. (2022), mental load represents the cognitive capacity required to process task complexity, while mental effort reflects the cognitive ability or resources allocated by learners to complete learning tasks. Based on this theory, the research findings indicate that in chemistry learning, the students' experience in processing new information is greater than their effort in completing the learning tasks assigned.

The highest score on the mental load aspect (M = 3.62) was found in the statement 'I have to work hard to answer the questions in the learning activities.' This statement indicates that students feel challenged in answering questions. This suggests that question-and-answer activities in chemistry learning can trigger mental load, especially if the questions require deep abstract and conceptual thinking. This results in line with research conducted by Rumasoreng (2021), which states that the greatest cognitive load on the intrinsic subdimension is when students are asked about the material taught. Meanwhile, in terms of mental effort, the highest score (M = 3.63) was found in the statement 'I need to work hard to complete the tasks or objectives in this learning activity'. This indicates that students still show commitment and sincerity in undergoing the learning process. Thus, it can be concluded that even though students experience considerable mental load, they still actively engage in mental effort to complete learning tasks.

Regarding grade level, the findings indicate that Grade X students have a higher cognitive load compared to Grade XI and XII students. This aligns with research conducted by Cardellini (2012), who stated that Grade 10 students tend to perceive atomic and molecular models as separate and concrete structures, which can lead to misunderstandings as they struggle to connect submicroscopic properties with particle characteristics. A novice learner experiences a higher intrinsic cognitive load compared to an expert (Skulmowski & Xu, 2022). This is supported by research conducted by Kurniawati et al. (2023) and Prayunisa & Mahariyanti (2022) which reported that some of the materials considered difficult for Grade X students include oxidation reduction, atomic structure, the periodic table of elements, and chemical bonding. Meanwhile, for advanced students, research conducted by Lu et al. (2022) and Matere et al. (2023) reported that advanced students have a better understanding of submicroscopic properties and particles as an integrated whole, enabling them to connect relationships between concepts to understand the learning tasks assigned. This can help them determine solutions and reduce their mental effort.

Conclusion

This study found that students' cognitive load in chemistry learning falls into the moderate category, suggesting that most students are able to manage the complexity and abstract nature of the subject matter. Among the two measured aspects—mental load and mental effort—mental load was slightly higher, indicating that students experience greater cognitive demands in understanding the material than in completing tasks. Nevertheless, students demonstrated strong commitment and engagement in the learning process. Furthermore, Grade X students experienced a higher cognitive load compared to those in Grades XI and XII. This can be attributed to their limited conceptual understanding, especially of submicroscopic representations. The level of cognitive load is influenced by various factors such as material complexity, the availability of learning media, and the instructional methods used. Therefore, managing these supporting factors is crucial to maintaining an optimal cognitive load during chemistry learning.

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Author Contributions
S.M.A., I., and A. devised this research and the main conceptual ideas; I. and A. designed the research design. S.M.A. carried out the experiment and analysis data. SMA conducted literature review and wrote the manuscript with support from I and A. The authors contributed to the final version of the manuscript.

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Conflicts of Interest
The funder had no role in the design, data collection, and analysis of this research. The authors were agreed with this manuscript.

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