JURNAL UPI

Indonesian Journal of Teaching in Science

IJOTIS

Journal homepage: http://ejournal.upi.edu/index.php/ IJOTIS/

Analyzing Junior High School Students' Cognitive Load in A Science Subject: A Case Study

Aulia Nurhamidah Hidayat [1], Nanang Winarno [1,], Ratih Mega Ayu Afifah [2], Nur Jahan Ahmad [3]*

[1]Universitas Pendidikan Indonesia, Bandung, Indonesia
[2] Universitas Negeri Malang, Indonesia
[3] Univesiti Sains Malaysia, Malaysia
*Correspondence: E-mail: nanang_winarno@upi.edu

ABSTRACT

This study examined the cognitive load experienced by junior high school students in science disciplines. This study used a survey methodology. The study utilized a questionnaire consisting of 15 items to assess three aspects of cognitive load: intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL), measured using a 5-point Likert scale. The study included 500 students from grades VII, VIII, and IX in junior high schools in West Java and DKI Jakarta, Indonesia. Data components ICL, ECL, and GCL in cognitive load instruments were processed in Microsoft Excel to calculate percentages, average scores, and scores. Statistical tests were conducted to compare cognitive load across different grade levels. The study revealed that the average scores for cognitive load components ICL (2.92) and ECL (2.83) exceeded that of GCL (2.73), indicating that students experience a high level of cognitive load while learning science. Differences in the cognitive load component were observed at each grade level. Grade 9 students encounter high ICL and ECL, while students in grades 7 and 8 suffer high ECL. These results validate the need to focus on learning design, particularly when presenting intricate scientific content. Emphasizing the reduction of cognitive load, particularly from the ECL factor, may be a way to enhance student performance and establish an optimal learning environment.

ARTICLE INFO

Article History:
Submitted/Received 15 Aug 2024
First Revised 25 Sep 2024
Accepted 18 Nov 2024
First Available online on 19 Nov 2024
Publication Date 01 Mar 2025

Keyword:
Cognitive load,
Extraneous Cognitive Load, Germane Cognitive Load,
Intrinsic Cognitive Load,
Science learning.

1. INTRODUCTION

Education is the basis for the formation of future generations. As part of the learning process, Natural Science (IPA) subjects at the Junior High School (SMP) level have a crucial role in students' cognitive development as part of the learning process. Student engagement in the teaching-learning process is complex, involving various factors, including understanding, memory, and problem-solving skills. Cognitive load, which measures the mental load on the mind throughout a task, is crucial in assessing learning efficiency (Sweller, 1994).

Cognitive load is the mental work required for processing information by an individual's mind (Paas *et al*., 2003). It is important to explore how students respond to their learning assignments and how this cognitive load might be transformed into a profound understanding. Research indicates that junior high school students frequently experience significant cognitive strain in science disciplines, which is impacted by the difficulty of the content and the instructional methods used (Kalyuga *et al*., 2003).

Intrinsic Cognitive Load (ICL) refers to the mental effort required to digest new information, which is influenced by existing concepts or prior knowledge. Intrinsic load refers to the cognitive processing needed to accomplish a learning assignment, which is affected by the complexity of the subject matter that students need to recall simultaneously (Kennedy & Romig, 2024). Learning tasks can be simplified to decrease intrinsic load or improve students' existing knowledge and skills (Kennedy & Romig, 2024). The intrinsic load on each student differs based on their prior knowledge and willingness to learn. Intrinsic Cognitive Load refers to the capacity to acquire and process information from students during the learning process (de Jong, 2010). Deficient design of educational resources can lead to students experiencing a high level of cognitive load (Chu, 2014; Curum & Khedo, 2021). For example, providing overly intricate content, including excess concepts and facts that do not align with the learning goals, and employing uncommon terminology (Kennedy & Romig, 2024). This can have a negative effect on students' internal challenges. Increased task complexity leads to a higher level of intrinsic cognitive load on students.

Extraneous processing refers to any cognitive processes that do not contribute to achieving learning goals. Educators must manage the extraneous cognitive load (ECL) caused by learning approaches or strategies (Kennedy & Romig, 2024). Students may experience difficulties when they need to combine information from several sources spread out in different locations or periods or when they need to search for information to fulfill a learning objective, leading to information overload (Kennedy & Romig, 2024). Cognitive load is linked to the capacity of working memory to keep a particular amount of knowledge and carry out a particular number of activities (Hong *et al*., 2017). Task performance can lead to the cognitive overload of working memory resources due to the amount of information and interactions processed by individuals (Paas *et al*., 2003; Hong *et al*., 2017). Everyone has a limited working memory capacity, causing processed information to disappear within seconds unless reinforced through repetition (van Merriënboer and Sweller, 2010). This will impact the relevant germane cognitive load related to creating cognitive frameworks from the newest data stored in long-term memory or information already possessed by students.

Previous research studies have examined the cognitive load of students. In a study on cognitive load by Rahmat *et al*. (2014), data was collected through description questions of varying complexity to assess ICL, subjective statement questionnaires on mental load in understanding learning for ECL, and a reasoned multiple-choice test for germane cognitive load (GCL). Further studies revealed that complexity worksheets were utilized to measure ICL,

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6101 e- ISSN 2776-6152

questionnaires with subjective research scales were used for ECL, and learning achievement through examinations was employed for GCL (Rahmat *et al*., 2017). Both studies assessed the elements of cognitive load to measure the cognitive load level experienced by students or college students.

An update was provided regarding instruments used to measure cognitive load, including ICL, ECL, and GCL. The study by Klepsch and Seufert (2020) utilized questionnaires to measure different aspects of cognitive load, including intrinsic cognitive load, extrinsic cognitive load, and germane cognitive load, to analyze variations in difficulty, design, and learning improvement. Further reports (Sabilla (2019); Jiang and Kalyuga (2020), Ratnasari (2023), and Santoso (2023)) have shown an improvement in the measurement of cognitive load. Cognitive load is assessed through a questionnaire that includes a subjective rating scale measuring instrument. The instrument consists of statements that assess the difficulty of teaching material of ICL, the difficulty of processing learning activities of ECL, and activities related to exploring learning activities of GCL. The study's findings indicate that cognitive load can be classified as either high or low.

A new instrument was developed and validated to accurately measure the three categories of cognitive load through a series of empirical experiments. Krieglstein *et al*. (2023) conducted a series of research to measure three forms of cognitive load in experimental tasks using a questionnaire that has been constructed and validated by experts. The questionnaire demonstrates that different types of cognitive load can be assessed separately. No research accurately quantifies student's cognitive load according to their grade level or degree of education.

Previous studies emphasized the importance of assessing and examining cognitive load in learning. A comprehensive understanding of students' cognitive load can help teachers create more effective and efficient teaching strategies. Understanding students' cognitive load for science courses is crucial for improving learning quality and ensuring the learning approach aligns with students' cognitive requirements (Leahy *et al*., 2003).

Based on the importance of measuring cognitive load, this study was conducted to answer the following research questions: (i) How is the cognitive load of junior high school students in learning science materials?; (ii) Is there a difference in the cognitive load of students in grades 7, 8, and 9 in learning science material?.

2. METHODS

2.1. Research Design

This study utilizes a descriptive research design with a survey methodology. Survey research is a study that samples from a population and utilizes a questionnaire for data collecting. This study examines the cognitive load experienced by junior high school students when studying science courses through a questionnaire instrument. The questionnaire is distributed to participants online using the Google Form application, which may be viewed using a smartphone for easy accessibility by students.

2.2. Participant

The study included 500 students from grades VII, VIII, and IX at several junior high schools in Indonesia, specifically in the provinces of West Java and DKI Jakarta, during the first semester of the 2023/2024 school year. The research sample was selected using purposive sampling to target junior high school students with a background in science. The sample distribution is as follows: 163 respondents are in grade 7, 244 are in grade 8, and 93 are in grade 9. Below is data regarding the distribution of sample participants categorized by grade, gender, and region (province). The distribution of participants in this study is presented in **Table 1**.

Table 1. Research Participants' Frequency (n= 50).

Demographics	Total	Percentage
Grade		
7	163	32.60%
8	244	48.80%
9	93	18.60%
Gender		
Male	212	42.40%
Female	288	57.60%
Region (Province)		
Jawa Barat	245	49.00%
DKI Jakarta	255	51.00%

2.3 Research Instrument

The study instrument utilized was adapted from the cognitive load research instrument developed by Krieglstein *et al*. (2023). The questionnaire consists of 15 items with an overall reliability (*Cronbach alpha*) of 0.61. The ICL, ECL, and GCL instruments were assessed using a 5-point Likert scale where 1 represents "*Strongly agree*," 2 represents "*Agree*," 3 represents "*Neutral*," 4 represents "*Disagree*," and 5 represents "*Strongly disagree*." The questionnaire given to participants comprised 5 sections. The initial section included inquiries regarding respondents' information such as name, grade, age, school district of origin, and school province of origin. The second section contained 5 questions regarding ICL (complexity of scientific content). The third section had 5 questions regarding ECL (learning process). The fourth section contained 5 questions regarding GCL (long-term cognitive schema processing). The final section had three open-ended questions.

2.4. Data Analysis

Analyzed cognitive load instruments, ICL, ECL, and GCL, using Microsoft Excel to determine the percentage, average score, and score. To assess the cognitive load, the average score of each cognitive load component was calculated using Meissner and Bogner's (2013) theory as outlined in Rahmat and Hindriana's (2014) publication. An effective learning design can offer tasks that accomplish the optimum amount of ICL, decrease ECL, and enhance GCL.

A normality test was conducted using the Kolmogorov-Smirnov test in SPSS 25.0 to detect differences in students' cognitive load when studying science topics throughout grades 7, 8, and 9. If the data follows a normal distribution, parametric tests such as One Way ANOVA are conducted using SPSS 25.0. A non-parametric test, such as the Kruskal-Wallis test, is used if the data does not follow a normal distribution.

3. RESULTS AND DISCUSSION

3.1. Findings on Research Question (i): "How is the cognitive load of junior high school students in learning science materials?"

Figure 1 shows the average score of each cognitive load component for junior high school students learning science. Cognitive load components (ICL, ECL, and GCL) were assessed by a questionnaire utilizing a 5-point Likert scale. **Figure 1** shows that the average ICL score is 2.92, suggesting that the intrinsic cognitive load level is significantly higher than other cognitive

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6101 e- ISSN 2776-6152

load components. The average ECL score of 2.84 is slightly lower than the ICL, while the average GCL score of 2.73 is the lowest among the three components. Cognitive Load Components of Junior High School Students in Learning Science are presented in **Figure 1**.

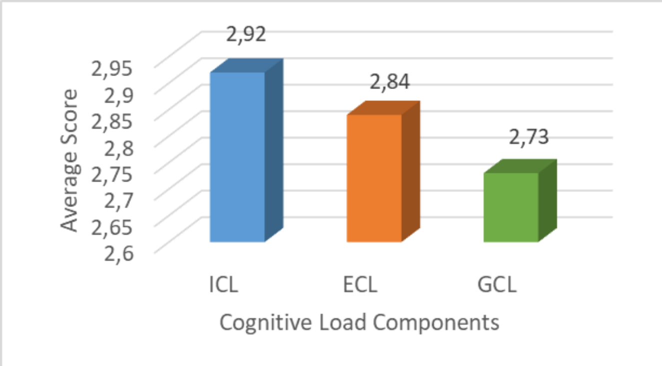

Figure 1. Cognitive load components of junior high school students in learning science.

Based on the cognitive load theory proposed by Meissner and Bogner (2013) as discussed in Rahmat and Hindriana's (2014), effective learning design should offer tasks that maintain an optimal level of ICL, decrease ECL, and increase GCL. According to this idea, cognitive load students can be identified when the ICL and ECL scores exceed the GCL scores. If the ICL and ECL are lower than the, then the learner is not experiencing cognitive load. According to the theory, the research findings in **Figure 1** indicate that the ICL and ECL scores exceed GCL, indicating that students had experienced cognitive load when learning science.

There are open-ended questions in this study that support the claim about students' opinions on difficulties experienced when studying science and problems related to the science learning process in school. Here are the responses from the students' opinions.

Question 1: What are your difficulties in learning science?

Student 1: *Finds science easy to learn, especially when dealing with materials that include complex calculations*.

Student 2: *Struggles with applying formulas to solve science problems due to the complex scientific terminology and many topics requiring logical thinking*.

Question 2: What are your difficulties during the science learning process at school?

Student 1: *Struggles to focus when studying science in an uncomfortable classroom environment with teachers who only provide theoretical explanations without practical demonstrations*.

Student 2: *Finds the learning environment uncomfortable, leading to a loss of concentration. The teacher's too much information delivery causes monotony, and the numerous writing assignments are overwhelming. Additionally, inadequate laboratory conditions result in a lack of tools and materials during practicum*.

Students' difficulties with understanding science are not only due to the subject matter but are also impacted by the learning environment, as indicated by student's opinions. Calculation formulas, scientific terminology, and reasoning in science are other factors that contribute to the complexity of students. Classroom environment and teacher interactions significantly affect student attentiveness when learning science.

The average scores of the cognitive load component of junior high school students in learning science consisting of ICL, ECL, and GCL factors are presented in tabular form, namely **Table 2** related to the ICL factor, **Table 3** related to the ECL factor, and **Table 4** related to the GCL factor. Average Score ICL (Intrinsic Cognitive Load) Component of Students in Studying Science is presented in **Table 2**.

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6101 e- ISSN 2776-6152

Table 2. Average Score ICL Component of Students in Studying Science.

Item	N	Average (*Mean*)	SD
ICL1	500	2.93	1.02
ICL2	500	3.11	1.12
ICL3	500	2.90	1.06
ICL4	500	2.96	1.13
ICL5	500	2.68	1.14
Average		2.92	1.09

Referring to **Table 2**, the ICL score has an average of 2.92. Items ICL1, ICL2, and ICL4 show above-average numbers, whilst items ICL3 and ICL5 show below-average numbers. Students claim that science content is not complex, but additional science-related information becomes easier to understand when they have prior knowledge. According to Kennedy and Romig (2024), the intrinsic load can be decreased by reducing learning tasks or increasing students' prior knowledge and abilities.

According to de Jong (2010), ICL in the learning process is defined as the capacity to receive and process student information. Students with low ICL are considered to have a high ability to receive and process information according to their perspective. The high average score of ICL in this study indicates that students can receive and process low-level information. Average Score ECL (Extraneous Cognitive Load) Component of Students in Studying Science is presented in **Table 3**.

Table 3. Average Score ECL Component of Students in Studying Science.

Item	N	Average (*Mean*)	SD
ECL1	500	2.68	0.98
ECL2	500	2.77	0.99
ECL3	500	3.08	1.27
ECL4	500	2.84	1.00
ECL5	500	2.83	1.09
Average		2.84	1.06

The average score for students' ECL in learning science is 2.84, as shown in **Table 3.** ECL1, ECL2, and ECL5 have an average below 2.84, while ECL3 and ECL4 show above-average scores. Students are uncomfortable with the teacher's learning design, affecting their ability to access important materials quickly. Consistent with Kennedy and Romig's (2024) opinion educators should be able to manage the additional cognitive load caused by the teaching method or strategy.

When a teacher presents an extensive amount of text on a screen and then verbally explains it, the extraneous cognitive load on the student increases due to the requirement to process conflicting information both visually (text) and audibly (voice). The student experiences higher levels of cognitive load due to being pulled in two different directions simultaneously. Students may experience cognitive load when they need to combine information from several sources located in different places or times or when they have to search for information to fulfill a learning objective, leading to overload (Kennedy & Romig, 2024). An optimal learning design should aim to preserve or increase the ICL while decreasing the ECL. Average Score GCL (German Cognitive Load) Component of Students in Studying Science is presented in **Table 4. Table 4** shows an average GCL score of 2.73, the lowest average among all the cognitive load components assessed. Items GCL1 and GCL2 have scores above the average, while items GCL3, GCL4, and GCL5 have scores equal to the average GCL score. This indicates that students still need to understand the science learning content

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6101 e- ISSN 2776-6152

thoroughly, have not enhanced their current knowledge with science information, and cannot apply the knowledge acquired through learning quickly and accurately.

Table 4. Average Score GCL Component of Students in Studying Science.

Item	N	Average (*Mean*)	SD
GCL1	500	2.73	0.90
GCL2	500	2.99	1.39
GCL3	500	2.64	0.89
GCL4	500	2.60	0.94
GCL5	500	2.68	0.86
Average		2.73	1.00

During the elaboration phase, students are encouraged to develop schemas by connecting new information with existing knowledge stored in long-term memory. GCL, as defined by Kennedy and Romig (2024), refers to the mental effort needed to structure received knowledge and integrate it into prior knowledge stored in long-term memory. In short, the load can be affected by students' motivation to study the topic and their background knowledge. Students with low GCL are not yet capable of constructing cognitive systems.

3.2. Findings on Research Question (ii): "Is there a difference in the cognitive load of students in grades 7, 8, and 9 in learning science material?"

The study examines the differences in the cognitive load of junior high school students in grades 7, 8, and 9 when learning science information. The following are investigated by descriptive analysis and the Kruskal-Wallis test because the data is not normally distributed, as presented in **Tables 5 to 7**.

Table 5 shows the mean cognitive load of students studying science in 7th (n=163), 8th (n = 244), and 9th (n = 93) grades. The overall class average was 2.89. Grades 7 and 8 had higher averages than grade 9. An examination of cognitive load components in Table 6 is required to compare students' cognitive load in grades 7, 8, and 9.

Table 5. Average Student Cognitive Load Scores Regarding Grades.

Class	N	Average (*Mean*)	SD
7	163	2.90	1.59
8	244	3.02	0.93
9	93	2.76	1.19
Average		2.89	1.24

Table 6 indicates that grade 8 has a lower average ICL score than grade 7 and grade 9. Additionally, grade 9 has a lower ECL score compared to grade 7 and grade 8. Grade 9 has the lowest average GCL score compared to grade 7 and grade 8.

Table 7 indicates that all components of cognitive load (ICL, ECL, and GCL) have a statistically significant difference in score between the three grade levels, with a significance level of 0.00 <0.05 (Asym. Sig.). Cognitive load analysis adapted from Rahmat and Hindriana (2014) suggests that effective learning design should aim to deliver tasks that accomplish the optimum amount of ICL, decrease ECL, and increase GCL. Grade 9 has a lower GCL score compared to ICL and ECL, indicating that grade 9 is experiencing a lower level of cognitive load due to ICL and ECL causes. The mean score of the ICL component is larger than the ECL component, suggesting that cognitive load from the difficulty of the subject matter of ICL may have a bigger impact than the learning process factor of ECL.

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6101 e- ISSN 2776-6152

Table 6. Results of Kruskal-Wallis Test Analysis (mean rank) Cognitive Load Component Score by Grade Level.

Cognitive Load Component	Grade	N	Mean Rank	Mean
ICL	Grade 7	163	227.07	13.88
	Grade 8	244	220.88	13.66
	Grade 9	93	369.28	18.23
	Total	500		
ECL	Grade 7	163	272.40	14.93
	Grade 8	244	277.74	14.96
	Grade 9	93	140.66	10.90
	Total	500		
GCL	Grade 7	163	277.05	16.66
	Grade 8	244	278.77	16.70
	Grade 9	93	129.80	11.60
	Total	500		

Table 7. Kruskal-Wallis Test Analysis Results (the significant difference) Students' Cognitive Load Score by Grade Level.

	ICL	ECL	GCL
Kruskal-Wallis H	78.021	66.646	80.622
df	2.000	2.000	2.000
Asymp. Sig.	0.000	0.000	0.000

The results indicate that 9th-grade students experienced a higher level of cognitive load due to the complexity of science subjects and the learning process. A specific approach is needed to enhance students' performance and cognitive load in this subject matter. That corresponds with a study by Anderson *et al*. (2004) that examined how age and cognitive load impact performance on science tasks that require problem-solving and analysis of complicated topics. The findings indicated that older persons are more likely to experience increased cognitive load, particularly when processing material that involves a thorough understanding of scientific concepts. Park and Reuter-Lorenz's (2009) study emphasizes cognitive transformations that might affect cognitive load in older individuals when engaging in problem-solving and decision-making learning activities.

Grades 7 and 8 have significantly higher ECL scores than ICL, causing students to feel mentally overwhelmed. In this scenario, there is a difference in the cognitive load experienced by students in grade 9 compared to grades 7 and 8. The difference is attributed to ECL variables, resulting from the incompatibility between the activities, processes, and teaching methods teachers apply to students' talents or interests. Factors such as task complexity, the volume of information offered, or the lack of student interaction in the learning context might increase ECL. According to Paas *et al*. (2003), external factors like instructional design, material delivery, and technology utilization may significantly affect students' effective cognitive load during the science learning process. This study highlights that ineffective learning design or complex presentation of material can lead to an unneeded cognitive load on students. Further research by Kalyuga (2011) found that the complexity of science learning materials affects ECL and can impact students' understanding. Complex materials may restrict students' capacity to efficiently process knowledge, leading to higher ECL.

These results confirm the need to focus on learning design, mainly when presenting complex scientific content. Enhanced learning outcomes can be attained by modifying the learning design to align with students' abilities, interests, and cognitive levels. Emphasizing

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6101 e- ISSN 2776-6152

the reduction of cognitive load, particularly from the ECL component, a strategy that helps improve student performance and establish a more efficient learning environment. A strategy outlined in the study is utilizing adapted multimedia. Transforming information into multimedia can reduce students' cognitive load, mainly when delivering complicated material clearly and in an orderly manner. Furthermore, text-based techniques that divide educational content into smaller, more manageable segments were also discovered to decrease cognitive load. Chandler and Sweller's (1991) research highlights that gradually delivering material with clear arrangement can assist students in managing their cognitive load.

4. CONCLUSION

Cognitive load components, including ICL, ECL, and GCL, were assessed using a questionnaire that utilized a 5-point Likert scale. The average cognitive load scores for ICL and ECL are 2.92 and 2.83, respectively, higher than GCL's score of 2.73. This indicates that students experience a cognitive load while learning science. The subject itself does not simply cause students difficulties with understanding science. However, it is also impacted by the learning environment, educators, and content of the learning materials, as indicated by the open-ended questions provided to students. The cognitive load component showed significant differences between grade levels, as determined by the Kruskal-Wallis analysis test (Asym. Sig.) 0.00 <0.05. Grade 9 students experience cognitive load due to high ICL and ECL, whereas in grades 7 and 8, it is caused by high ECL. Future studies can concentrate on gaining a thorough knowledge of how the increased cognitive load components of ICL and ECL affect student cognitive load in scientific learning.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6101 e- ISSN 2776-6152