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High school students' cognitive load on biology learning: A case study

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ABSTRACT

This study is aimed to analyze the cognitive load of high school students on biology learning. The method was used in this research is the survey method. The subjects of the study consisted of 179 students in grade X students consisting of 56 male students and 123 female students, 130 students in grade XI consisting of 37 male students and 93 female students, and 90 students in grade XII students consisting of 30 male students and 60 female students. The instrument in this study used a questionnaire cognitive load theory proposed by Meissner and Bogner about good learning design with a Likert scale. The results of research on high school students' cognitive load in biology revealed a medium average of 2.93, with GCL (3.29) ranking highest, followed by ICL (2.85) and ECL (2.66). The data processing results with the Kruskal Wallis test was showed that each factor has differences between ICL, ECL, and GCL. Thus, high school students still have a cognitive load when studying in class. The data processing results with the Mann U Whitney test to analyze the difference in cognitive load between male and female students was showed no significant difference between male and female students in cognitive load on biology learning.

INTRODUCTION

Cognitive load theory, which has evolved over the past three decades, is now a key tool for teachers to understand how curriculum and teaching materials affect students' academic performance. However, despite some more speculative evidence, the functioning of education requires the integration of cognitive and noncognitive processes (Feldon et al., 2019), building on this understanding, CLT is based on our understanding of human cognitive architecture and evolutionary psychology. According to this theory, complex information in learning situations reduces learners' memory for their work. In this context, CLT aims to explain how to use flexible working memory effectively for learning outcomes, defined as the construction and automatic extraction of knowledge from long-term memory. The first aspect of CLT is the interaction between working memory and long-term memory (Krieglstein et al., 2023). Moreover, the main goal of cognitive theory is to maximize student learning about complex cognitive tasks by reducing contemporary knowledge of how cognitive structures and functions are manipulated or how cognitive architecture becomes a tool for instructional (Pass & Van Merriënboer, 2020), CLT is based on the assumption of active learning, which requires students to be actively involved in knowledge construction. In other words, students are actively engaged in the process of thinking about relevant material and organizing it into a coherent structure integrated with knowledge previously (Jin et al., 2019).

Cognitive load can be defined as a multidimensional structure that stores mental load and mental energy. Both of the above constructs retain essential points in our understanding of cognitive behavior, although it is unclear how or even if they are related. For example, create a questionnaire that explicitly distinguishes between mental imagery and mental imagery. In general, it is assumed that mental exercises are supported by an active summary of the day that is present during learning. Therefore, to transmit knowledge to long-term memory and integrate it with previously acquired knowledge, students must become active learners by applying their cognitive summary to the learning activity in question. Educational materials can facilitate this process. On the other hand, learners adhere passively to characteristics found in learning materials, such as complexity and learning structure, which Krell describes (Krell, 2017) as a mental or task-related behavior.

As a result of this line of thinking, (Sweller et al., 2011) argue that mental health problems and psychological disorders should be viewed as two distinct constructs that are usually positively correlated. As stated earlier, cognitive decline stored in working memory is caused by learning tasks. Solving a task, that is, learning has been characterized by allocating and utilizing cognitive resources, suggesting that the amount of mental effort is a reliable estimate of a person's motivation to obtain new information. Instructional designs and procedures should encourage students to use available working memory summaries for efficient learning while maximizing capacity for information retrieval (Carpenter et al., 2020). To this end, CLT encapsulates design principles for teaching materials and procedures aimed at reducing information overload in working memory and reducing capacity for instructional procedures. Cognitive load increases when unnecessary tasks that hinder effective learning must be addressed. For example, a weak element in a learning environment can be an unnecessary cognitive summary. However, learning effectiveness can be increased if students have a threshold of prior knowledge specific to the subject matter. For this reason, cognitive learning is not always hindered by this kind of challenge. For this reason, the main objective of CLT is to identify cognitive deficits that present themselves as "the belief that learning experiences that produce learning outcomes can exceed the capacity of the learning system" (Krieglstein et al., 2022).

According to Paas and van Merriënboer (2020), cognitive load can be defined as a multidimensional structure that allows the load to perform specific tasks, such as modifying the cognitive architecture of the learning system. This construction has a subjective dimension that evaluates the interaction between tasks and individual characteristics as well as a subjective measurement that evaluates the basic concepts of mental, emotional, and occupational health. Task characteristics identified in CLT studies include task format, task complexity, multimedia use, time management, and learning speed. Relevant student characteristics include skill level, age, and spatial aptitude. Some of the observed interactions relate to people and task formats. This suggests that instruction that aligns tasks with specific goals or without specific goals in a disproportionate way improves the learning and transfer process for people who are long-term learners; skill level and task format showed that the learning outcomes observed for beginners were positively correlated with improvements in their spatial and cognitive abilities as well as multimedia use. This suggests that only learners with high spatial abilities can effectively utilize visual aids and correlate (Paas & Van Merrienboer, 2020).

The theory of cognitive bias was developed to explain the decline in cognitive arousal in education. This theory is based on the human cognitive architecture of information retrieval, where new information must first be retrieved from working memory before being stored in long-term memory. As per the main tenets of cognitive load theory, the capacity of memory to work is limited. As a result, learning objectives should focus on reducing working memory capacity rather than increasing it for learning outcomes (Anmarkrud et al., 2019).

Historically, CLT has defined three types of cognitive load. Here are the three components of cognitive load, intrinsic cognitive load (ICL), foreign cognitive load (ECL), and germane cognitive load (GCL). ICL deals with the difficulty of processing incoming information. This element collaborates with working memory to build cognitive schemes simultaneously. ECL is associated with the workload resulting from how learning is designed or how teaching materials are organized. Although not directly related to the development of cognitive schemes, this component stimulates working memory. Building cognitive schemes is GCL's responsibility. This element arises from the experience that students gain with ICL or ECL (Feldon et al., 2019). Measuring different types of cognitive load is crucial for researchers because it's a valid way to test why some learning materials are harder to learn than others. However, valid and reliable measurements are an ongoing challenge in CLT research. In this case, the measuring instrument must distinguish the type of cognitive load better to assess the effectiveness of certain designs and learning principles (Krieglstein et al., 2023).

High School students are in transition from adolescence to adulthood. Generally, the cognitive load of various subjects in high school is quite high. Learning strategies can affect the cognitive load of high school students. Teachers using learning strategies in the classroom must be appropriate because if they are not appropriate, students can have learning difficulties or be unable to devise knowledge schemes. Then there must be a reduction in CL, a reduction in CL will result in a better way for students to process learning information. The cognitive load will always be present and found in every learning. So far, biology learning is known as a subject that only adheres to rote memorization. Biology is often considered a rote subject. Where students just memorize biological materials. This makes students tend to feel heavy in studying biology. Learning strategies need to be applied in the learning process to facilitate students, especially biology lessons, by providing innovative and meaningful learning experiences. However, sometimes, students have difficulty digesting the various subjects they receive because they get too much information from each lesson. In this case, learning strategies that are by the characteristics of the material are needed in the learning process so that students can analyze the information conveyed by the teacher so that, in the end students do not use other heavy efforts to obtain the information they need. Such learning strategies can reduce the cognitive load of students due to the limited working memory factor of each individual (Janssen & Kirschner, 2020)

One of the biological materials that still causes cognitive load for students is the material of the plant world (Oktavian & Aldya, 2020). This material is very closely related to the classification of plants, which has a very high level of material complexity. It is said to be complex because this material is memorized, for example, memorizing scientific names and plant characteristics. Various efforts have been taken to reduce cognitive load in learning the plant world. One effort

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often studied about cognitive load is the learning strategies teachers use in teaching and learning activities.

So that students do not experience cognitive load in learning activities related to the load in processing information received, ECL relates to the load that arises due to the design of learning or the organization of teaching materials, and GCL relates to the load that arises in constructing cognitive schemes (Sweller, 2005). GCL is assessed about the natural cognitive load of students' reasoning abilities. Cognitive load is closely related to the memory activity of the human brain. Human brain memory is divided into two types, namely, long-term memory and short-term memory (De Jong, 2010). The ideal learning process is to reduce the three cognitive loads, as stated by Skulmowski & Xu (2022) to achieve the learning process, namely by managing intrinsic cognitive load and extraneous cognitive load so that it will reduce germane cognitive load. Because the three components of cognitive load are interconnected and cannot be seen one component of cognitive load alone. Moussa-Inaty et al. (2019) stated that the decrease in cognitive load is one of the reasons for students' modality effect or learning style.

Previous research focused more on methods and models, so the cognitive load analysis itself was incomplete (Hwang et al., 2013), Research on gender differences also in previous research is in the domain of other fields where no one has conducted research in biology studies (Yu, 2019). However, this study has novelty in the form of cognitive load research at the high school level and whether there are differences in cognitive load on sex in biology learning. This research will be the basis for further research because from this study, we have initial data or profiles available, then from this research data will be useful as an illustration of what strategies in the future can reduce CL.

Based on cognitive load theory, the complexity of information that students must learn affects cognitive load (Chen et al., 2018). The complexity of lesson information is related to the characteristics of the learning material. Based on the explanation above, research is needed to analyze the cognitive load of students in Biology learning and whether there are differences in cognitive load on gender.

METHODS

This study used survey methodology (Creswell & Creswell, 2017). The purpose of the survey is to collect data by asking respondents questions to obtain statistical data that accurately reflects the population under study (Fulton, 2018; Goodfellow, 2023). This research was conducted by sending online questionnaires to high school students using a Google Form that allows users to determine when and where questionnaires should be sent. Students are instructed to fill out forms precisely based on their understanding of biology lessons. Students are told that their beliefs do not negatively impact the evaluation of their academic performance. Supervision can be done using a computer or smartphone. Unlike traditional surveys that require pen and paper, online surveys provide various advantages, such as lower costs and easier implementation (Guterbock & Marcopulos, 2020).

The participants consisted of 399 students from classes X, XI, and XII at Senior High School, West Java, including 123 males and 276 females aged 12 to 18 years. They are divided into 6 different classes. The study was conducted by convenience sampling. An example of a sample population is shown in Table 1.

The instrument used in this study was a cognitive load questionnaire called the student cognitive load survey in biology Subjects. The survey collects students' responses regarding their perceptions of biology class. The questionnaire consists of three parts. The first section consists of questions regarding your name, age, gender, class, school name, hometown, and place of birth. The second part has a total of 15 statement items, which are divided into 5 questions to measure ICL (content or material difficulty), 5 questions to measure ECL (learning process difficulty), and 5 questions to measure GCL (Student Learning Outcomes). This questionnaire on Cognitive Load

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Theory (CTL) is a type of Likert scale modified by Krieglstein (2023). The third part of the instrument contains 3 open questions.

Table 1. Student sample population and gender ratio

	Participants		
Grade	**Male**	**Female**	**Sum**
X	56	123	179
XI	37	93	130
XII	30	60	90
Sum	123	276	399

The scale used in this study was the Likert scale, with five statements with five responses (strongly disagree, disagree, doubt, agree, and strongly agree). The revised version of the Cognitive Load Theory (CLT) scale includes item ratings for each component. The first factor is Intrinsic Cognitive Load (ICL), with a total of 5 items, the second factor is External Cognitive Load (ECL), with a total of 5 items; and the third factor is German Cognitive Load (GCL) with a total of 5 items. The data was analyzed by calculating the overall average of all ratings (1. 00-1. 50 = very low, 1. 51-2. 50 low, 2. 51-3. 50 mediums, 3. 51-4. 50 high, 4. 51-5.00 = very high) (Wang &; Shen, 2023). Also, for the Statistical Package for the Social Sciences (SPSS) v. 27.

RESULTS AND DISCUSSION

The results of measuring students' cognitive load in biology subjects mean this is a measure of student's ability to analyze information from teaching materials during the biology learning process, resulting in the following average scores (Figure 1).

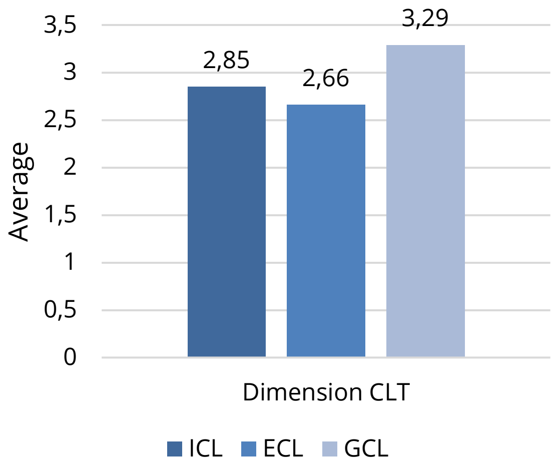

Figure 1. Cognitive load of high school students on biology learning

This study aims to analyze students' cognitive load in Biology learning in high school based on a cognitive load questionnaire survey. The results in Figure 1 show that the cognitive load of high school students in Biology learning has an average total score of 2.93 with the medium category with the aspect being the GCL factor has the highest average of 3.29, and the ECL factor has the lowest average of 2.66 and ICL of 2.85. The analysis of cognitive load aspects in biology learning reveals intriguing patterns. The German Cognitive Load (GCL) aspect demonstrates the highest average at 3.29, which can be attributed to its nature as an accumulation of Intrinsic Cognitive Load (ICL) and External Cognitive Load (ECL) factors. Conversely, the ECL aspect shows the lowest average, a finding that stems from observational results of biology learning processes

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in schools. These observations indicate that teachers often employ less varied delivery methods, frequently assigning writing tasks and relying heavily on lecture-style teaching. This approach persists despite the fact that students have varying attention spans and information absorption capacities. Furthermore, the lack of diverse teaching methods is compounded by an insufficient number of practice questions, potentially hindering students' ability to reinforce their learning. This combination of factors may explain the lower ECL scores and highlights areas for potential improvement in biology education methodologies.

Figure 1 explains that students can receive and process ICL information greater than mental effort in the form of ECL, students have ICL > ECL which can be interpreted that at that time the student's ability to receive and process information is higher than mental effort. So in this case, students do not have great difficulties because the learning strategies carried out by the teacher help students use cognitive abilities that are more than the use of mental effort. In addition, lower ECL is due to less functional learning strategies in assisting students to acquire and process information. Overall, there is a small cognitive load on high school students because students who can receive and process information are higher than students with high mental effort. This is by the statement De Jong (2010) that the load is said to be low if the ICL is low compared to the ECL. When the ICL result is high, the student's ECL will be low due to the student's effort in understanding small lessons and conversely, when the student's ICL is low, the student's ECL will be high because the student has to put a lot of effort into understanding the lesson the student is learning. A student's high ability to receive and process information may mean that a student's ability to process new information indicates an intrinsic load on low working memory or limited working memory capacity (Paas et al., 2004). Meanwhile, according to these data, ECL in students is smaller than the ability to Receive and Process ICL Information. Low ECL describes the cognitive processes of students that focus on understanding the material being taught using their reasoning and imparting the knowledge they already have.

The results of the study are supported by open-question data as follows:

Q1: What are your difficulties in studying Biology?
A1: I think the way of teaching biology teachers is difficult to understand and the intonation of speech is too fast to explain
A2: It is difficult to memorize parts of the structure of living things
A3: I have difficulty memorizing the names of scientific names present in the material.

Based on students' opinion 1, the difficulty in studying biology is related to teaching methods and explanations that are too fast, while student opinion 2 has difficulty memorizing parts of the structure of living things and student opinion 3 has difficulty memorizing scientific names. This is their difficulty in studying biology.

Q2: What were your difficulties during the Biology learning process at school?
A1: Very much writing
A2: Sometimes, it's hard to concentrate if you're just listening to the material. I have to work on questions to understand better
A3: Many theories lack practice

Based on student 1's opinion that the learning process is very monotonous and less varied, students answered that the teacher in delivering the material often writes on the blackboard, while student 2's opinion is often scattered or unable to absorb all the information conveyed because the teacher delivers the material only by speaking and based on student 3's opinion in presenting biology learning has minimal practice.

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Q3: What is the reason you strive to understand Biology learning well?
A1: Because I want to know things related to living things, such as the presence of bacteria, it turns out that there are bad bacteria in these bacteria, and some are useful
A2: because biology is a compulsory subject, and I want high grades
A3: To know about this learning and how it can also be applied daily

Based on the opinions of Student 1, who wants to know the usefulness of living things, and the opinions of Student 2 because of compulsory lessons and wants high grades, and the opinions of Student 3, who wants to know and apply them in daily life. CLT (Cognitive Load Theory) is divided into three factors: Cognitive Intelligent Loud (ICL), Extraneous Cognitive Loud (ECL), and Germane Cognitive Loud (GCL). Each factor consists of a different number of statements. The profile of students' cognitive load in Biology learning in high school is based on the Cognitive Load questionnaire survey on each factor ICL in Table 2.

Table 2. Descriptive statistics for participants cognitive load score in ICL factors

Items	N	Mean	SD
ICL1	399	2.84	0.65
ICL2	399	2.56	0.77
ICL3	399	2.71	0.77
ICL4	399	2.96	0.83
ICL5	399	3.17	0.81
Average		2.85	0.77

Table 2 shows the mean and standard deviation of students' ICL against Biology learning in Cognitive load according to ICL factors. Table 2 shows that the mean ICL is 2.85 this value is in the medium category (Wang & Shen, 2023). It is observed that ICL 4 and ICL 5 are above average. High school students state that biology material includes a lot of complicated information and without prior knowledge, new information related to biological material will be difficult to understand.

Items as codes SE1, SE2, and SE3 were found to be below the ICL item average. High school students feel that biology material is difficult, they have difficulty understanding biological material, they have difficulty understanding biological material through explanation, and studying biological material is very complicated. The profile of students' cognitive load on Biology learning in high school is based on the Cognitive Load questionnaire survey on each factor ECL in Table 3.

Table 3. Descriptive statistics for participants' cognitive load score in ECL factor

Item	N	Mean	SD
ECL1	399	2.93	0.79
ECL2	399	2.67	0.76
ECL3	399	2.41	0.82
ECL4	399	2.66	0.77
ECL5	399	2.61	0.76
Average		2.66	0.78

Data on table 3 shows the mean and standard deviation of students' ECL against Biology learning in Cognitive Load according to ECL factors. Table 3 shows that the average ECL is 2.66 this value is in the medium category (Wang & Shen, 2023). It is observed that ECL 1 and ECL 2 are above average. High school students stated that the difficulty in getting a general (complete) picture of the structure of biology subject matter was slightly overcome, along with the design of learning materials that were not so difficult in connecting relationships between information in biological materials.

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Items such as codes SE3, SE4, and SE5 were found to be below the average ICL item. High school students feel less comfortable with the learning design (way of teaching) applied by the teacher, the learning design applied to biology subjects makes it difficult to find appropriate (relevant) information quickly and because of the learning design applied to biology subjects, and it is less possible to concentrate on the learning material. The profile of students' cognitive load in Biology learning in high school is based on the Cognitive Load questionnaire survey on each factor GCL in Table 4.

Table 4. Descriptive statistics for participants cognitive load score in GCL factors

Item	N	Mean	SD
GCL1	399	3.12	0.56
GCL2	399	3.98	0.73
GCL3	399	3.01	0.61
GCL4	399	3.27	0.63
GCL5	399	3.1	0.61
Average		3.29	0.63

Table 4 shows the mean and standard deviation of GCL students against Biology learning in Cognitive Load by GCL factor. Table 4 shows that the average GCL is 3.29 this value is in the medium category (Wang & Shen, 2023). It was observed that GCL 2 was above average. High school students stated that they tried hard to understand biology learning materials because GCL code 1, GCL3 4, and GCL5 were found to be below the average GCL item. High school students find it difficult to actively reflect on learning outcomes in biology subjects and find it difficult to be able to understand biology learning material thoroughly, As well as difficulties to be able to develop existing knowledge with biology learning materials and difficulties to be able to apply the knowledge obtained through learning materials quickly and accurately, the results of data processing for average ranking results will be shown in Table 5.

Table 5. Kruskal-Wallis test results (average rating) for cognitive load score participants Ranks

N	Mean Rank
399	541.87
399	428.10
399	827.03
1197	

Table 5 shows the average ranking results for each factor. It is observed that GCL is ranked highest, ECL is ranked lowest, and ICL is ranked middle.The results of the Kruskal-Wallis Test (significant difference) for the Cognitive Load score will be shown in Table 6.

Table 6. Kruskal-Wallis test results (significant difference) for participants' cognitive load score

	Skor_Tot
Kruskal-Wallis H	286.800
df	2
Asymp. Sig.	.000
a. Kruskal Wallis Test	
b. Grouping Variable: CLT	

Table 6 shows the results of the Kruskal-Wallis test, showing significant differences between types based on ICL, ECL, and GCL. The table indicates the value (Asymp. Sig).<0.05 This means that there is a noticeable difference between ICL, ECL, and GCL from each of the factors. In this section, it will be discussed that from the data and findings above, a learning strategy is needed to reduce cognitive load on ECL, this is because the process of delivering effective and efficient material, in addition to ICL that rises, of course, GCL will also increase. In addition, it is also necessary to understand that students' cognitive load is not only related to school but outside of school. Students also have a cognitive load, which will also contribute to their memory capacity. Therefore, a teacher must have creativity in determining methods, models, and approaches to determining treatment in the classroom.

Related findings Research Question 2: "Are there differences in cognitive load between male and female high school students on biology learning?" The results of the Mann U Whitney statistical test are shown in Table 7.

Table 7. Uji Mann-Whitney U

	Skor_Total
Mann-Whitney U	16451.500
Wilcoxon W	54677.500
With	-.493
Asymp. Sig. (2-tailed)	.622
a. Grouping Variable: Gender	

Based on the output of the Mann U Whitney test above, it is known that the value of Asymp. The (2-tailed) mark of 0.622 is greater than the probability value of 0.05. Therefore, as a basis for making decisions on the Mann U Whitney test above, it can be concluded that there is no significant difference between men and women in cognitive load on biology learning, this is in line with research (Yohanes & Yusuf, 2021) which states Problem-Solving always involves cognitive abilities (Cognitive Load) that can be traced or viewed from the cognitive map of learners. In the cognitive map there is a cognitive load that leads to being able to solve problems and did not show real differences and negative relationships (correlations) between variables between male and female students.

However, this contrasts previous research stating that students of different sexes have different physical, psychological, and learning characteristics, so gender differences affect cognitive load. Cognitive load can be divided into two types: positive cognitive load and negative cognitive load. Typically, positive cognitive load results in good learning performance while negative cognitive load results in poor learning performance. Therefore, we use cognitive load theory to define learning efficiency as an incremental impact of learning performance and cognitive load. The results showed that the boys had a much lower cognitive load. The boys' learning performance was also better, although the difference did not reach significance. In addition, the efficiency of learning for male students is significantly higher (Chen et al., 2021).

Other studies have also shown that Female students have a higher cognitive load (Hwang et al., 2013) Significant gender differences in cognitive load found that men had significantly less cognitive load when learning English through mobile learning platforms (Yu, 2019). This may be due to the same total cognitive load on the student difficulty in the material and the absence of prior knowledge.

CONCLUSION

The results of research on the cognitive load profile of students in Biology learning showed that the average total was 2.93 with the medium category with the highest aspect value, namely the highest GCL with an average of 3.29 with the medium category, then ICL 2.85 with the medium category and ECL 2.66 with the medium category, then there was no significant difference between men and women in cognitive load on biology learning. Thus, high school students still have a cognitive load when studying in class. This study is useful to see an overview of how the cognitive load of students in Biology learning can also be a reference for Biology teachers to improve

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learning and teaching in Biology. In future research, researchers may have to provide solutions or suggestions to improve the teaching and learning process to reduce students' cognitive load, especially in secondary schools, including methods, media, and teaching and learning strategies in Biology.

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Authors' Note

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