MANAGING STUDENTS' COGNITIVE LOAD ON THE IMMUNE SYSTEM TOPIC THROUGH THE IMUNOPOLI BOARD GAME

PENGENDALIAN BEBAN KOGNITIF SISWA PADA PEMBELAJARAN SISTEM IMUN MELALUI BOARD GAME IMUNOPOLI

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Abstract

The complexity of immune system content may impose a high cognitive load if the instructional design fails to accommodate the limitations of working memory. This study aims to manage students' cognitive load and describe the correlations among cognitive load aspects in IMUNOPOLI board game-based learning. The study employed a quasi-experimental method with a non-equivalent control group post-test only design involving 60 Grade XI students from a senior high school in Bandung. The cognitive load aspects, including Intrinsic Cognitive Load (ICL), Extraneous Cognitive Load (ECL), and Germane Cognitive Load (GCL), were measured using a 10-item questionnaire. Data were analyzed using inferential statistics, correlation analysis, and effect size. The results showed a significant difference between the two groups and a moderate effect on ECL ($p = 0.047$; $d = 0.530$) during the second meeting. This finding indicates that IMUNOPOLI reduce students' ECL, particularly during the initial learning session. However, this effect was not consistent, as no significant differences were found in ICL, ECL during the fourth meeting, or GCL, while the correlations among the cognitive load aspects ranged from moderate to very weak. Future studies are recommended to extend the intervention duration, incorporate a pre-test, and combine subjective measures with students' learning outcomes.

Keywords: Cognitive load, board game, immune system, imunopoli

Abstrak

Kompleksitas materi sistem imun dapat menimbulkan beban kognitif yang tinggi apabila desain pembelajaran tidak mampu mengakomodasi keterbatasan memori kerja. Penelitian ini bertujuan untuk mengelola beban kognitif siswa dan mendeskripsikan korelasi antar aspek beban kognitif dalam pembelajaran berbasis board game IMUNOPOLI. Penelitian ini menggunakan metode kuasi eksperimen dengan desain non-equivalent control group post-test only yang melibatkan 60 siswa kelas XI dari salah satu SMA di Bandung. Aspek beban kognitif, yang meliputi Intrinsic Cognitive Load (ICL), Extraneous Cognitive Load (ECL), dan Germane Cognitive Load (GCL), diukur menggunakan kuesioner yang terdiri atas 10 item. Data dianalisis menggunakan statistik inferensial, analisis korelasi, dan effect size. Hasil penelitian menunjukkan adanya perbedaan yang signifikan antara kedua kelompok dengan pengaruh sedang pada aspek ECL ($p = 0,047$; $d = 0,530$) pada pertemuan kedua. Temuan ini menunjukkan bahwa IMUNOPOLI menurunkan ECL siswa, terutama pada pembelajaran awal. Namun, pengaruh tersebut belum konsisten, karena tidak ditemukan perbedaan yang signifikan pada ICL, ECL pada pertemuan keempat, maupun GCL, sedangkan korelasi antar aspek beban kognitif berkisar dari sedang hingga sangat lemah. Penelitian selanjutnya disarankan untuk memperpanjang durasi intervensi, menambahkan pre-test, serta mengombinasikan pengukuran subjektif dengan hasil belajar siswa.

***Kata kunci**: Beban kognitif, board game, sistem imun, imunopoli*

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Introduction

The complexity of immune system material is a challenge in learning it, both for teachers and high school students (Lewar et al., 2025), because immune system material is often considered boring and difficult to understand (Fakhriah et al., 2022). This complexity has an impact on the high Instrinsic Cognitive Load (ICL) of students due to the large amount of material that must be studied (Susanto et al., 2023). In addition to complexity, external factors such as the learning environment, teacher explanations, and the presentation of teaching materials also make it difficult for students to understand the immune system material (Klepsch & Seufert, 2020; Lewar et al., 2025). This affects the increase in students' Extraneous Cognitive Load (ECL) (Hidayat et al., 2025).

Learning should be adjusted to the limitations of the human cognitive system, especially working memory (Sweller, 2008). Cognitive load theory highlights the role of working memory limitations as an important factor that influences the success of a learning design (Sweller et al., 1998). This theory is divided into three aspects, namely intrinsic, extraneous, and germane cognitive load.

Intrinsic Cognitive Load (ICL) is the load that arises from the internal complexity of learning material, which is influenced by the combination between the characteristics of the material being studied and the students' level of ability (Sweller, 1994; Sweller et al., 1998). Extraneous Cognitive Load (ECL) emerges from cognitive activities that do not support the learning process and is typically triggered by ineffective instructional design (Sweller, 1994). Germane Cognitive Load (GCL) arises from cognitive activities that are deliberately designed to enhance learning outcomes by helping students construct new knowledge schemas (Sweller et al., 2011).

In fact, school-based learning has yet to adequately accommodate the management of students' cognitive load, particularly ECL. The use of digital learning media in the study conducted by Sari et al. (2020) indicated suboptimal ECL management, as students found it difficult to understand online learning. Another study also revealed that students tend to struggle with using digital learning media, even when their ECL is already in a good category (Lolang et al., 2023). This condition shows that some digital media are not able to control students' cognitive load (Yuniarti et al., 2023).

The limitations of learning methods and media in dealing with the complexity of the material encourage the birth of new approaches. One of them is game-based learning (GBL), which has the advantage of fostering intrinsic learning motivation through the introduction of various joyful elements in learning (Hartt et al., 2020). The integration of game elements into learning activities can trigger the activation of brain areas to become more intense, which in turn is related to increased working memory capacity and attention control (Kober et al., 2020).

Various studies on GBL have shown that learning through games is proven to provide a fun experience that is able to motivate students to actively engage in learning challenging topics (Barber et al., 2020; Rivard & Rivard, 2024). GBL can help develop a variety of cognitive abilities, such as remembering information, controlling emotions, thinking flexibly, planning and organizing tasks, resisting impulsive impulses, taking initiative, and self-managing (Pinedo et al., 2021). However, other findings show less consistent results, as shown in the results of Stiller & Schworm (2019) that the application of GBL does not necessarily reduce the students' cognitive load.

One of the non-digital applications of GBL is through the use of board games. Research on board games generally focuses on student engagement. A study by Tsai et al. (2021) shows that board game-based learning makes the learning process more active, engaging, and increases student engagement. Regular board game play can stimulate and re-influence brain structures specifically related to attentional control, working memory, and problem solving (Jung et al., 2018). With regard to cognitive outcomes, the findings of Mohamed et al. (2025) indicate that the use of board games can increase students' interest and understanding of difficult biological concepts.

Based on interviews conducted with teachers at the school where the research took place, the use of instructional methods and media was still dominated by the lecture method and books, although interactive learning activities were occasionally implemented once or twice. This has implications for inconsistent student learning outcomes, particularly in biology topics considered difficult. The tendency toward low learning outcomes in challenging material indicates ineffective management of students' cognitive load, largely attributed to the use of instructional methods and media that are insufficiently relevant.

This indicates that there is a gap between GBL, especially the application of board games to manage students' cognitive load. Therefore, this study aims to manage students' cognitive load and describe the correlation between cognitive load aspects in IMUNOPOLI board game-based learning. The IMUNOPOLI board game in this study was developed specifically as a training and learning tools based on cognitive psychology by integrating various concepts and mechanisms of the immune system into each component. The selection of the IMUNOPOLI board game as a solution for managing cognitive load is based on the premise that this board game presents complex immune system material in an interactive, contextual, and structured format, as evidenced by the inclusion of challenge cards containing questions arranged in levels of difficulty (easy, medium, and hard) which are expected to reduce students' ICL and ECL. The game mechanisms in IMUNOPOLI also expected to encourage students to actively construct new knowledge schemas, thereby enhancing GCL.

Methods

Research Design

The method used in this study is quasi experimental with a non-equivalent control group post-test only design. The use of this design aims to avoid biases, such as response shifts (changes in students' responses before and after learning) that can arise as a result of pre-testing (Leppink, 2020). This research design was chosen due to the characteristics of cognitive load variables, which tend to increase as learning progresses. Administering a pre-test before the treatment may introduce extraneous cognitive load that is not relevant to the study, thereby potentially biasing the collected data.

The research was carried out for two weeks (4 meetings) from January 19 to January 30, 2026 at one of the high schools in Bandung. The research design is presented in Table 1 as follows.

Table 1. Research Design

Groups	Treatment	*Posttest*
Experiment	X	O_1
Control	-	O_1

Description:

X : Intervention using IMUNOPOLI board game

O1: Posttest data collection (cognitive load questionnaire)

Participants

Participants in this study are 60 grade XI students who received Biology learning on immune system material. The sampling technique used in this study was convenience sampling, as it was adjusted to the conditions and availability of participants at the school. Participants were divided into two groups, control and experiment, with each group consists of 30 students. The control group carried out conventional learning, which is learning that is usually carried out in schools, especially in the subject of Biology. The experimental group received the board game-based learning treatment IMUNOPOLI. At the second and fourth meetings, the control group was given an assignment in the form of a Student Worksheet to strengthen their understanding of immune system material, while the experimental group practiced and improved the retention of immune system material using the IMUNOPOLI board game.

Instrument

The instrument used in this study is non-test instrument. The non-test instrument used was a student cognitive load questionnaire adapted from *Cognitive Load Questionnaire* by Leppink et al. (2013) and *Naive Rating Questionnaire* by Klepsch et al. (2017). In the cognitive load questionnaire, there are 10 items, consisting of 3 items to measure Instrinsic Cognitive Load (ICL), 4 items to measure Extraneous Cognitive Load (ECL), and 3 items to measure Germane Cognitive Load (GCL) in the form of subjective rating scale 1-9 statements processed into Google Form media. Secondary data in the form of interviews with students were collected to support the argument. The instrument guides are presented in Table 2 and Table 3.

Table 2. Cognitive Load Questionnaire Guidelines

No.	Indicator	Description	Item Number	Total Item
1.	Material complexity	The difficulty and complexity of the learning content presented to students	1*, 2*, 3*	3
2.	Clarity of instructions and explanations	The clarity of the instructional design, systematic organization, and presentation of the learning materials provided to students	4*, 5*, 6*, 7*	4
3.	Improvement of understanding	The level of improvement in students' understanding of concepts or topics following participation in learning activities	8, 9, 10	3
			Total	**10**

(*) indicate negative statements

Table 3. Interview Questions Guidelines

No.	Indicator	Description	Question Examples	Total Item
1.	Learning experiences	Experience with the learning method and immune system material	Have you ever learned through a game-based learning activity? If so, what was your experience like?	3
2.	Perceptions towards IMUNOPOLI	Perceptions of the challenges, strengths, and weaknesses of IMUNOPOLI.	After playing IMUNOPOLI, do you feel that your understanding of the immune system has improved? Please explain your answer.	5
		Total		**8**

Measurements using subjective rating scales 1-9 were chosen because this method is commonly used in cognitive load research, does not interfere with the learning process, and is proven to be able to provide valid results in measuring cognitive load (Sweller et al., 2011). Participants are asked to rate the level of cognitive load they experienced during the activity by selecting a number from 1 to 9, where higher values indicate greater perceived cognitive load. The following Table 4 is the criteria of the subjective rating scale used in this study.

Table 4. Subjective Rating Scale Criteria

Scale	Interpretation
1	Very very disagree
2	Very disagree
3	Disagree
4	Rather disagree
5	Neutral
6	Rather agree
7	Agree
8	Very agree
9	Very very agree

Validity and Reliability

The questionnaire instrument were piloted prior to use in the main study, whereas the interview questions were validated only through expert judgment. The results of the questionnaire pilot test indicated that all items were valid (0.76) and reliable (Cronbach's alpha = 0.84). These results indicate that the instruments were appropriate for measuring cognitive load.

Research Procedure

The procedure of this study was divided into three stages: pre-implementation, implementation, and post-implementation. The IMUNOPOLI board game was implemented in the second and fourth meetings because it was used as a reinforcement tool rather than the primary instructional medium for learning immune system content. Therefore, students were required to receive lectures from the teacher before using IMUNOPOLI. The separation between material delivery and the use of the board game also was due to the limited learning duration, which made it impossible to conduct both activities within the same session.

Data collection was conducted during the second and fourth meetings, when students engaged in learning using the IMUNOPOLI board game. During the second meeting, data were collected to obtain an overview of students' cognitive load when they were first introduced to the IMUNOPOLI board game. Meanwhile, during the fourth meeting, data were collected to assess students' cognitive load when learning with the IMUNOPOLI board game was repeated. Both sets of data were classified as post-test data. The research procedure is comprehensively presented in Figure 1 as follows.

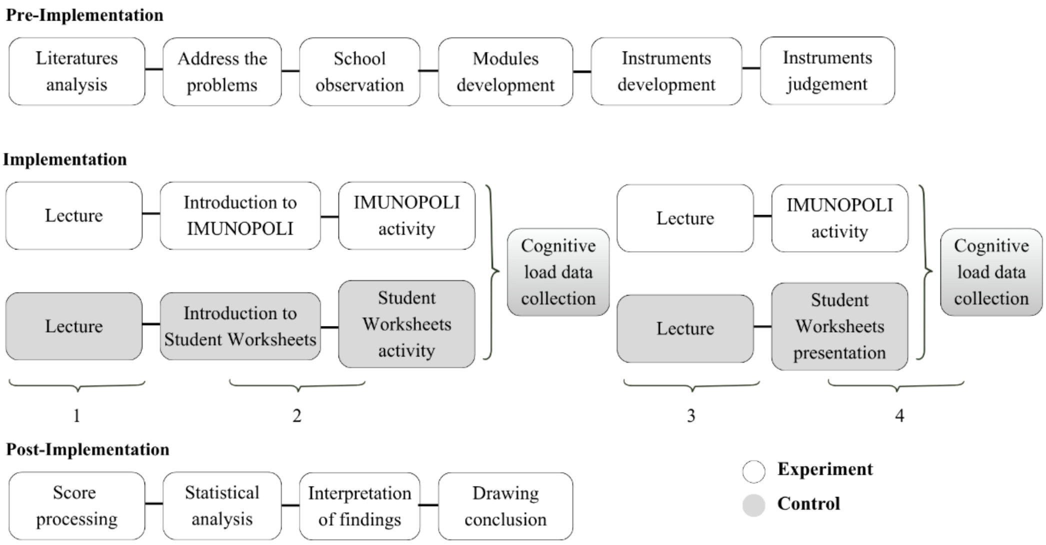

Figure 1. Research Procedure

Data Analysis

Data obtained (second and fourth meetings) from the cognitive load questionnaire were analyzed quantitatively. Negative items were reverse-scored prior to calculating the cognitive load scores. Data analysis on cognitive load scores includes prerequisite tests, hypothesis tests, and correlation tests. The prerequisite tests used in this study are the normality test (Shapiro-Wilk), the homogeneity test (Levene's test), and the linearity test. The Shapiro–Wilk test, Levene's test, and linearity test were conducted using a significance level of p-value > 0.05. Hypothesis tests were then applied to compare the two groups, controls and experiments by involving the variable, namely cognitive load. Cognitive load data were analyzed using parametric tests in the form of independent t-tests and non-parametric tests in the form of Mann-Whitney U tests, correlation tests between aspects of cognitive load using Spearman Rank test, while effect size calculations used Cohen's d and Rank-Biserial Correlation (r).

Result and Discussion

Prerequisite Test

The prerequisite tests used in this study are the normality test (Shapiro-Wilk), the homogeneity test (Levene's test), and the linearity test. The results of prerequisite test are presented in Table 5 and 6 as follows

Table 5. Prerequisite Test Results

Data	Groups	Normality	Homogeneity	Remarks	Decisions
			Second Meeting		
ICL	Control	0.007	1.000	Not normally distributed, homogeneous	Mann-Whitney U
	Experiment	0.487			
ECL	Control	0.513	0.845	Normally distributed and homogeneous	Independent t-test
	Experiment	0.367			

Data	Groups	Normality	Homogeneity	Remarks	Decisions
GCL	Control	0.000	0.489	Not normally distributed, homogeneous	Mann-Whitney U
	Experiment	0.021			
Fourth Meeting					
ICL	Control	0.009	0.578	Not normally distributed, homogeneous	Mann-Whitney U
	Experiment	0.260			
ECL	Control	0.321	0.682	Normally distributed and homogeneous	Independent t-test
	Experiment	0.296			
GCL	Control	0.001	0.154	Not normally distributed, homogeneous	Mann-Whitney U
	Experiment	0.000			

Table 6. Prerequisite Test Results

Data	Linearity	Remarks	Decisions
Second Meeting			
ICL-ECL	0,003	Not linear	
ICL-GCL	0,075	Not linear	Spearman Rank test
ECL-GCL	0,520	Linear	
Fourth Meeting			
ICL-ECL	0.009	Not linear	
ICL-GCL	0.014	Not linear	Spearman Rank test
ECL-GCL	0.739	Linear	

Students' Cognitive Load

The cognitive load managed by students during learning, either using conventional approaches or IMUNOPOLI board game-based learning, was analyzed through a comparison of questionnaire scores. The results of the statistical analysis are presented in Table 7 as follows.

Table 7. Cognitive Load Statistical Results

Data	Statistic Test	Value	Remarks
Second Meeting			
ICL	Mann-Whitney U	1.000	Not statistically different
ECL	Independent t-test	0.047	Statistically different
GCL	Mann-Whitney U	0.715	Not statistically different
Fourth Meeting			
ICL	Mann-Whitney U	0.271	Not statistically different
ECL	Independent t-test	0.212	Not statistically different
GCL	Mann-Whitney U	0.952	Not statistically different

In line with this, the *Game-Based Learning* (GBL) study by Stiller & Schworm (2019) showed the same findings, students who studied cell biology material through computer games reported a level of cognitive load that did not differ significantly between the experimental group and the control group.

Consistent with the limited duration of intervention, Arztmann et al. (2025) stated that an overly short intervention period prevents students from optimally processing both the content and the game mechanisms. As a result, students who are not yet familiar with the game rules experience increased cognitive load because they are required to understand both the game mechanisms and the learning material simultaneously.

The students' cognitive load in this study was also analyzed based on three aspects or dimensions of cognitive load, namely Intrinsic Cognitive Load (ICL), Extraneous Cognitive Load (ECL), and Germane Cognitive Load (GCL). Theoretically, cognitive load is considered optimal when intrinsic cognitive load (ICL) is low, extraneous cognitive load (ECL) is low, and germane cognitive load (GCL) is high. This indicates that the limited capacity of human working memory is used optimally to construct new concepts or knowledge, rather than being occupied by irrelevant load (Paas & Merriënboer, 2020). The comparison of the average questionnaire scores of these three aspects of cognitive load is presented in Figure 2 and 3 as follows.

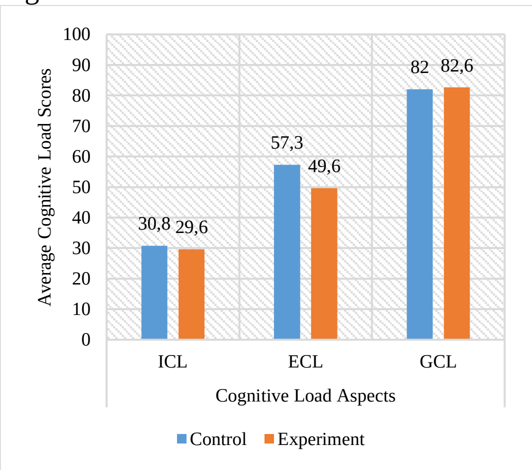

Figure 2. Average Student Cognitive Load Score on Each Aspect in Second Meeting

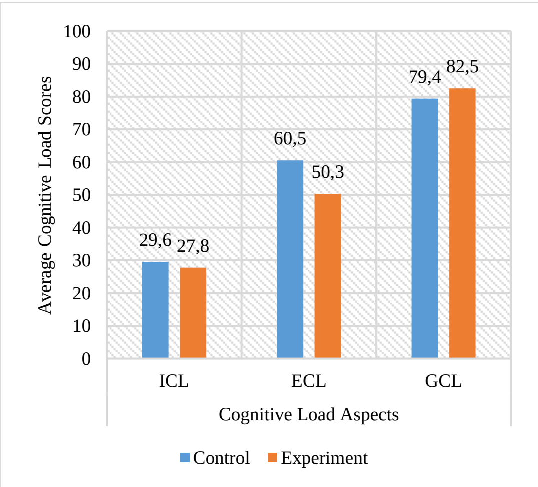

Figure 3. Average Student Cognitive Load Score on Each Aspect in Fourth Meeting

Based on Figure 2 and Figure 3, the average ICL questionnaire score of the experimental group tended to be slightly higher than the control group. However, the results of nonparametric statistical analysis in the form of the Mann-Whitney U test showed that there was no significant difference in ICL between the control and experimental group students with p-values of 1.000 and 0.271 (Table 7).

The low ICL scores observed in the experimental group may be attributed to students' prior exposure to the immune system content during the first and third instructional sessions before participating in the IMUNOPOLI board game–based learning activities. Since the IMUNOPOLI board game was implemented after teacher-led instruction using the lecture method, it is assumed that students had already developed foundational knowledge of the immune system, resulting in lower levels of intrinsic cognitive load. Ngu et al. (2023) found that students with higher levels of prior knowledge are better able to manage and process complex information, leading to lower cognitive load compared to students with limited prior knowledge, regardless of the instructional approach employed.

In the control group that received learning treatment using the Student Worksheet media, the lower ICL score was due to the worksheet's content, which applied immune system material to daily life through case studies, so students would not feel burdened by unfamiliar terms or mechanisms. Students perceived the worksheet as more structured and easier to follow, which may have contributed to their lower perceived ICL. These findings were supported by students' responses during interviews regarding the advantages of the worksheet in learning the immune system, for example:

> *"In my opinion, it becomes easier because there is guidance (through the case study) that directly discusses real-life situations about immune system, so we are not just reading theory."* (C12)
>
> *"I think it is easier because the learning process is more structured and well-organized; everything is connected and aligned (the case studies and the questions)."* (C16)

In contrast to ICL, students in the experimental group exhibited a substantial difference in ECL scores compared with those in the control group following the second meeting. These findings are consistent with the results of the parametric statistical analysis using an independent-samples t-test, which indicated a significant difference between the two groups, with a p-value of 0.047 (Table 7).

However, this decrease was not entirely consistent, as evidenced by the results of the statistical analysis after the fourth meeting. Students, in both groups, still experienced high in ECL despite the learning designs were different. This result is in line with the results of parametric statistical analysis using an independent t-test which shows that the ECL of the control group did not differ significantly from the experimental group (p-value = 0.212) as shown in Table 7.

The inconsistency in ECL scores was analyzed as a result from the unequal distribution of instructional content, in which the teacher's delivery of the immune system material during the third meeting was denser and faster-paced than during the first meeting.

The high level of ECL among students, particularly in the experimental group, may also be attributed to the confusion they experienced while using IMUNOPOLI. Since IMUNOPOLI was a new board game for the students, when they were first introduced to it, a considerable portion of their working memory capacity was allocated to understanding the rules and game mechanisms.

During gameplay, students tended to focus more on reading and comprehending the instructions rather than processing the information and immune system content presented in IMUNOPOLI. This finding was explicitly confirmed through interviews conducted with students regarding their perceptions of the strengths and limitations of IMUNOPOLI as a medium for reinforcing immune system concepts. For example:

> *"IMUNOPOLI is a game with quite a lot of rules, and we have to understand the gameplay flow first before we can play it, it is not a simple game."* (E28)
>
> *"I was somewhat confused at the beginning of the game, particularly when trying to understand the game rules."* (E22)

Regarding novelty, the visuals presented in the IMUNOPOLI board game were perceived as appealing by students, particularly the artistic illustrations of immune system elements and the use of diverse color schemes. However, this also led students to focus more on observing the visual aspects of the IMUNOPOLI board game rather than the immune system content being presented. This visual effect is further explained by the study of Javora et al. (2019), which suggests that visual complexity has the potential to increase ECL by inducing additional cognitive load, even in the absence of intentionally emphasized elements or supplementary information within the instructional media.

The high ECL results that were found in the study are in line with Chang et al. (2017) statement that positive effect of game only appears if the media is presented appropriately, excessive or inappropriate use can actually have a bad impact. It is also consistent with the findings of Bainbridge et al. (2022), which suggest that complex instructions and gameplay mechanisms presented before gameplay may contribute to elevated ECL.

The last aspect of cognitive load, namely GCL, also showed poor results. This is reflected in the average questionnaire score between the two groups being almost the same, in the range of 79-83. Nonparametric statistical analysis using the Mann-Whitney U test also indicated that there was no significant difference between the control and experimental groups with p-values of 0.715 and 0.952 (Table 7).

These results can be elaborated in relation to the discussion on ECL that students' limited working memory capacity was largely allocated to understanding the rules, mechanisms, or flow of the game, leaving only a small amount of cognitive capacity available to process the immune system content. As a result, a considerable portion of working memory resources is allocated to understanding the game itself, leaving fewer cognitive resources available for processing the educational content embedded within the game (Bainbridge et al., 2022). GCL will only increase if students still have sufficient working memory capacity to construct knowledge schemas (Hosseinpour & Keshmiri, 2025). Those statements explain the absence of differences in GCL scores between students in the experimental and control groups in this study.

Correlation Between ICL-ECL-GCL

The cognitive load aspects (ICL, ECL, and GCL) are related to each other. The average scores on each aspect of the cognitive load of the experimental group were correlated with each other to find out the relationship between the aspects. The data is calculated using the Spearman Rank test and then visualized through a scatter plot as presented in Figure 4 to Figure 9. Figures 4 and 5 present the correlation between ICL and ECL.

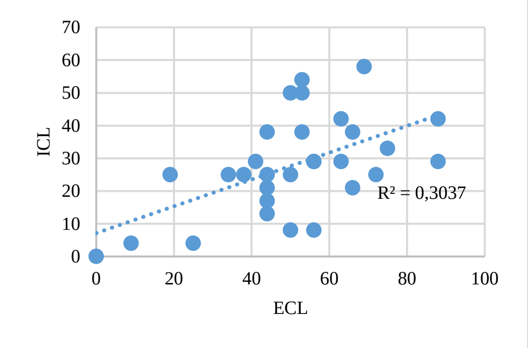

Figure 4. Correlation Between ICL and ECL in Second Meeting

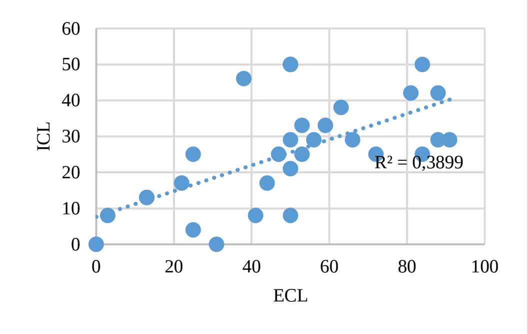

Figure 5. Correlation Between ICL and ECL in Fourth Meeting

The correlated ICL and ECL scores indicate a positive relationship direction, indicated by a ascending trend line. This is reinforced by the value of the determination coefficient (r = 0.541 dan r = 0.642) which shows that the strength of the relationship between aspects is in the moderate category (Cohen et al., 2018). The scatter plot results indicate that as the ICL score increases, the ECL score also tends to increase.

This positive correlation inconsistent with Cognitive Load Theory may also be attributed to the delivery of content through lecture methods in the first and third sessions. Students reported that they felt uncomfortable with the instructional delivery and the use of slide presentations used to explain the immune system material. This discomfort occurred because the material was delivered too quickly and densely, causing students to be burdened with understanding the immune system content within a limited period of time. The incline in students' ECL can be interpreted as their high mental effort in understanding the learning design. The high mental effort indicates that the learning design used is incompatible with the students' working memory capacity (Susanto & Munandar, 2017). Nevertheless, the positive correlation observed between ICL and ECL suggests that students expended mental effort (ECL) in the process of constructing cognitive schemas, especially when dealing with complex subject matter such as the immune system (Rahmat et al., 2017). Furthermore, the correlation between ICL and GCL is presented in Figures 6 and 7 as follows.

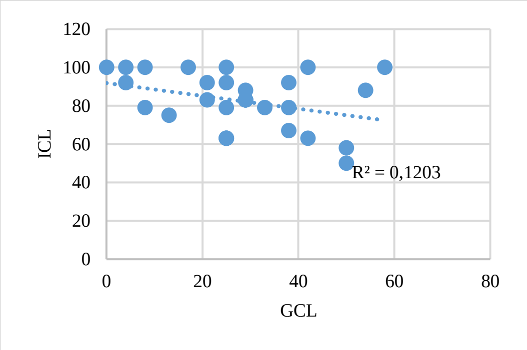

Figure 6. Correlation Between ICL and GCL in Second Meeting

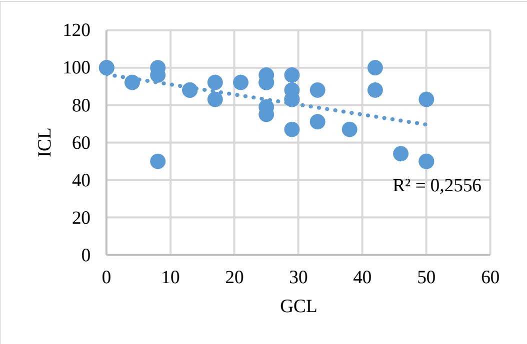

Figure 7. Correlation Between ICL and GCL in Fourth Meeting

Inversely proportional to the previous correlation, the correlation between ICL and GCL shows a negative relationship direction, indicated by an descending trend line. The value of the determination coefficient (r = -0.306 dan r = -0.525) indicates that the strength of the relationship between aspects tends to be modest (Cohen et al., 2018). When ICL increases, GCL tends to decrease. This likely occurs because when students are confronted with complex material (high ICL), their working memory becomes occupied by processing the intrinsic complexity of the content, leaving limited cognitive resources available for processing information and constructing knowledge (low GCL). The internal complexity of the immune system topic requires substantial cognitive effort to process.

Based on interviews regarding students' perceptions of the IMUNOPOLI board game, students reported that the mechanisms of the immune system and immune system disorders were the most challenging topics to understand. Several students also explained that, before participating in IMUNOPOLI-based learning, they attempted to understand the material independently through various resources, such as educational videos, textbooks, and by reviewing notes from the teacher's explanations in previous lessons.

A negative relationship between information management (ICL) and cognitive schema construction (GCL) arises because the limited working memory capacity seeks to receive complex new information (Susanto & Munandar, 2017). Higher levels of intrinsic cognitive load (ICL) may constrain students' ability to process and analyze information, thereby limiting the effective utilization of working memory capacity. Conversely, when the complexity and demands of the learning material are compatible with students' working memory capacity, intrinsic processing can proceed efficiently, facilitating a better understanding of the instructional content (Putri et al., 2021).

High material complexity (ICL) may motivate students to engage in greater knowledge-construction processes. However, this can occur effectively only when working memory resources are not fully occupied (Klepsch & Seufert, 2021). This is supported by the study conducted by Sevcenko et al. (2021) on increased difficulty in game-based learning. An increase in difficulty, whether in the content or game mechanics, can significantly raise cognitive load, which in turn may lead to a decrease in students' performance or abilities. The final discussion, the correlation between ECL and GCL is presented in Figures 8 and 9 as follows.

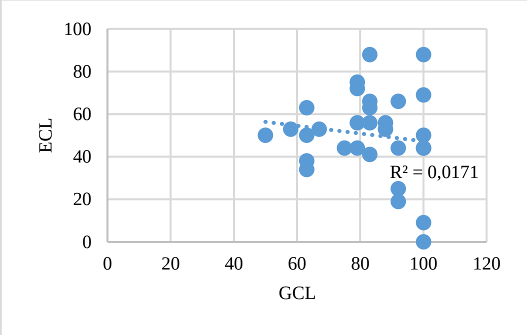

Figure 8. Correlation Between ECL and GCL in Second Meeting

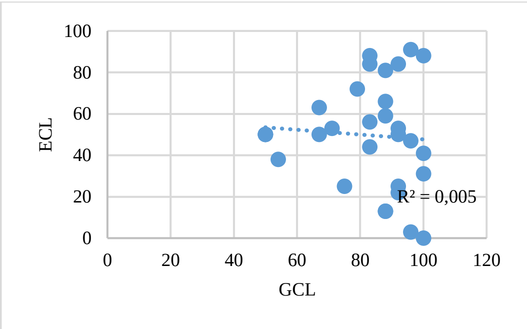

Figure 9. Correlation Between ECL and GCL in Fourth Meeting

The scatter plot results show the correlation between ECL and GCL indicates a slightly negative direction of the relationship, characterized by an insignificant descending trend line. This is supported by the value of the determination coefficient (r = -0.103 dan r = -0.144) which indicates that the strength of the relationship is weak (Cohen et al., 2018). The scatter plot illustrates that when ECL increases, the amount of irrelevant cognitive load may reduce the working memory resources allocated for processing learning content (GCL).

The increase in ECL in IMUNOPOLI-based immune system learning is stem from unclear and confusing instruction delivery, particularly in the fourth meeting due to the excessive and complex amount of material. In addition, the complex rules or mechanisms of the IMUNOPOLI board game are considered to contribute to an excessive amount of irrelevant load in students' ECL. Consequently, students experience a shortage of working memory capacity for processing information and constructing essential knowledge schemas (low GCL), as it is already occupied by other extraneous demands beyond the immune system content.

A very weak negative relationship may indicate that students still expend mental effort that places a burden on their cognitive resources while processing new information and constructing knowledge schemas (Susanto & Munandar, 2017). Rahmat et al. (2017) study further indicated that ineffective instructional design, reflected by high extraneous cognitive load (ECL), requires students to devote considerable mental effort to processing and integrating concepts and information presented by the teacher. As a result, students experience difficulties in constructing cognitive schemas, which is associated with lower germane cognitive load (GCL)

The findings of this study indicate that the correlations among the three components of cognitive load support the statement that implementation of IMUNOPOLI board game in learning the immune system has not been optimal in managing cognitive load. These correlations suggest that there is still a mismatch among the cognitive load components, which may be attributed to the limited effectiveness of the applied instructional strategy. The combination of high ICL and ECL indeed carries the risk of inducing cognitive overload if accompanied by an increase in GCL activities. However, cognitive load can be subjective, depending on individuals' working memory capacity as well as their motivation to invest mental effort in learning (Leppink, 2017).

Effect Size

The effect size in this study was calculated to see how much of an effect IMUNOPOLI board game-based learning produced on students' cognitive load. The effect size data was calculated using Rank-Biserial Correlation (r) and Cohen's d presented in Table 8 as follows.

Table 8. Cognitive Load Effect Size

Data	Effect Size	Value	Remarks
Second Meeting			
ICL	Rank-Biserial Correlation	0.000	Very weak
ECL	Cohen's d	0.530	Moderate
GCL	Rank-Biserial Correlation	0.047	Very weak
Fourth Meeting			
ICL	Rank-Biserial Correlation	0.142	Weak
ECL	Cohen's d	0.322	Modest
GCL	Rank-Biserial Correlation	0.007	Very weak

IMUNOPOLI board game-based learning reduce students' ECL during initial learning, demonstrated by a moderate effect (d = 0.530) on Cohen's d analysis. The results of the effect size calculation on ICL, and GCL actually show a very weak effect so that it is assumed that it is not yet optimal to manage students' cognitive load efficiently.

In line with this, Carenys (2025) stated that the application of GBL in learning has a moderate effect on students' ECL. The competitive elements of the game, including direct feedback and social engagement can help reduce irrelevant cognitive load. With regard to the element of social engagement, Paas & Merriënboer (2020) stated in their research that collaboration during learning has the potential to effectively increase working memory capacity because students can utilize each other's working memory capacity. Learning interventions through fun games contribute to increased working memory capacity, especially in the ability to remember and repeat (Putra et al., 2017).

Overall, the findings of this study show that low ICL in the experimental group combined with high ECL and high GCL is a combination that is considered inappropriate. However, these results can be elaborated with the findings of Manafe et al. (2025) who state that if students can bear the material that is considered complex (low ICL), even when accompanied by ineffective learning or explanation design (high ECL) will still encourage students to be more focused and active in processing information, build more in-depth knowledge schemas, and apply concepts (high GCL).

Theoretically, this study contributes to the advancement of research on board game-based learning for complex biology topics, particularly the immune system. The findings indicate that the use of the IMUNOPOLI board game did not produce significant differences in cognitive load components compared with conventional instruction. This suggests that the implementation of board games does not automatically reduce students' cognitive load, rather, their effectiveness is influenced by factors such as game design, the characteristics of the learning material, and instructional conditions. Therefore, this study provides insights into board game-based learning and cognitive load, while also serving as a foundation for future research aimed at developing more effective board game designs for managing cognitive load in complex subject matter.

Practically, the implementation of the IMUNOPOLI board game indicate that although the use of IMUNOPOLI did not produce a significant difference in students' cognitive load, the board game was able to create a more engaging learning experience than conventional instruction. Therefore, in its implementation, teachers should carefully consider game design, content presentation, and the provision of adequate guidance to ensure that gameplay supports the learning process without imposing unnecessary cognitive demands on students.

Conclusion

This study indicates that the use of the IMUNOPOLI board game has not yet optimally managed students' cognitive load, as significant differences were observed only in ECL during the second meeting, while no significant differences were found in ICL, GCL, or ECL during the fourth meeting. Furthermore, the correlation analysis among cognitive load aspects indicates an imbalance in load distribution, with correlations varying from moderate to very weak. Overall, while IMUNOPOLI has potential as an engaging learning medium, its effectiveness in supporting cognitive load management remains constrained by instructional clarity and game complexity.

The limitations of this study include the limited duration of the intervention, coupled with the use of the IMUNOPOLI board game which tends to be new in learning, resulting in less than optimal study results. Further research is recommended to use an experimental design that involves initial measurement, extending intervention duration, and combining subjective data with learning performance data, especially for ICL and GCL to obtain a more comprehensive findings of cognitive load management.

Declaration of AI Use in the Writing Process

During the preparation of this manuscript, the authors used Claude AI and ChatGPT solely for manuscript translation. After using the tool, the authors reviewed and edited the manuscript as necessary and take full responsibility for the entire content of this article.

Conflict of Interest Statement

The authors declare that there are no financial interests or personal relationships that could or may potentially influence the results of the research reported in this article.

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