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Metaphorical Visual Media as an Innovative Approach to Enhancing Students' Systems Thinking Skills at SMP Negeri 1 Plumbon

Jayaman Wibowo
Sekolah Menengah Pertama Negeri 1 Plumbon, Cirebon, Jawa Barat, Indonesia
Correspondence Email: jayamanwibowo78@guru.smp.belajar.id

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Abstract

Students' systems thinking skills still require strengthening through the implementation of innovative and contextual learning strategies. This study aims to examine the effect of using metaphorical visual media on improving the systems thinking skills of eighth-grade students at SMP Negeri 1 Plumbon. This study employed a quasi-experimental approach with a Nonequivalent Pretest–Posttest Control Group design involving two groups, namely the experimental class and the control class. Data were collected through a systems thinking skills test administered before and after the treatment, and were analyzed using the non-parametric Mann–Whitney test. The results of the analysis showed that the average N-Gain in the experimental class reached 0.62, which is categorized as moderate, while the control class only reached 0.32, categorized as low. In addition, the Mann–Whitney test results showed a significance value of 0.000 (< 0.05), indicating a significant difference between the two groups. These findings suggest that the use of metaphorical visual media provides a more optimal improvement compared to conventional learning. Thus, metaphorical visual media have been proven to be effective and significant in improving students' systems thinking skills.

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Kata Kunci

Media Visual Metafora,
Kemampuan Berpikir Sistem,
Pembelajaran IPA

Abstrak

Kemampuan berpikir sistem siswa masih memerlukan penguatan melalui penerapan strategi pembelajaran yang inovatif dan kontekstual. Penelitian ini bertujuan untuk mengkaji pengaruh penggunaan media visual metafora terhadap peningkatan kemampuan berpikir sistem siswa kelas VIII di SMP Negeri 1 Plumbon. Penelitian ini menggunakan pendekatan quasi eksperimen dengan desain Nonequivalent Pretest–Posttest Control Group yang melibatkan dua kelompok, yaitu kelas eksperimen dan kelas kontrol. Pengumpulan data dilakukan melalui tes kemampuan berpikir sistem yang diberikan sebelum dan sesudah perlakuan, kemudian dianalisis menggunakan uji non-parametrik Mann–Whitney. Hasil analisis menunjukkan bahwa rata-rata N-Gain pada kelas eksperimen mencapai 0,62 yang termasuk dalam kategori sedang, sedangkan kelas kontrol hanya mencapai 0,32 dengan kategori rendah. Selain itu, hasil uji Mann–Whitney menunjukkan nilai signifikansi sebesar 0,000 (< 0,05) yang menandakan adanya perbedaan yang signifikan antara kedua kelompok. Temuan ini mengindikasikan bahwa penerapan media visual metafora mampu memberikan peningkatan yang lebih optimal dibandingkan pembelajaran konvensional. Dengan demikian, media visual metafora terbukti efektif dan signifikan dalam meningkatkan kemampuan berpikir sistem siswa.

A. Introduction

Interactive learning media represent an educational innovation that leverages digital technology to create more engaging, student-centered, and participatory learning experiences. These media enable students to actively engage in the learning process through various features, including animations, simulations, interactive videos, and digital assessments. Previous studies have demonstrated that the use of interactive learning media can enhance students' critical thinking skills and deepen their conceptual understanding by promoting exploratory, inquiry-based, and self-directed learning (Moriska & Hanif, 2024). (Moriska & Hanis, 2024). In addition to enhancing conceptual understanding, the use of digital learning media can also contribute to the development of students' literacy skills. Previous studies have indicated that digital-based learning media can improve various forms of literacy, including language literacy, information literacy, and digital literacy, by providing access to diverse and multimodal representations of information (Budiarto, 2026). Furthermore, science learning environments supported by digital media can facilitate the development of humanistic literacy, enabling students to connect scientific knowledge with social, ethical, and human values (Abidin & Wibowo, 2024).

Visual metaphor-based learning media can facilitate students' understanding of abstract and complex concepts that are often difficult to comprehend through conventional instructional approaches. Previous research has shown that the use of visual metaphors in science education helps students construct meaningful conceptual connections, thereby improving conceptual understanding and increasing learning engagement (Wibowo, Jayaman; Anna, Fitria Hindriana; Zaenal, 2026). Furthermore, the integration of digital technologies into educational settings enables the use of diverse visual formats, including infographics, visual narratives, and interactive multimedia. These forms of visual media have been found to support the development of students' literacy skills by presenting information through multimodal representations that combine textual and visual elements. Studies have indicated that infographics and other digital visual media can enhance reading comprehension and conceptual understanding by facilitating more effective processing and interpretation of information (Carcamo & Pino, 2025).

Cell biology instruction has traditionally emphasized a reductionist approach, in which students are expected to learn and memorize cellular organelles as isolated components. However, a cell functions as a dynamic and highly interconnected system characterized by complex interactions among its constituent parts, analogous to an ecosystem or an industrial network. A persistent challenge in contemporary science education is students' limited systems literacy, particularly their ability to understand interdependencies and feedback mechanisms among microscopic cellular components. Without appropriate cognitive scaffolds, students often struggle to perceive the cell as an integrated, functional system rather than a collection of discrete structures (García-Magro, R., & Sánchez-Bayón, 2023).

Furthermore, cell biology education at the elementary and secondary levels presents substantial cognitive challenges because many cellular concepts are microscopic, dynamic, and inherently abstract. Traditional instructional approaches continue to emphasize the isolated study of cellular structures, leading students to memorize the names and functions of organelles without developing a deeper understanding of their functional interrelationships. Consequently, one of the major challenges in biology education in Indonesia is students' limited ability to apply systems thinking when conceptualizing the cell as an integrated and coherent system. Furthermore, cell biology education at the elementary and secondary levels presents substantial cognitive

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challenges because many cellular concepts are microscopic, dynamic, and inherently abstract. Traditional instructional approaches continue to emphasize the isolated study of cellular structures, leading students to memorize the names and functions of organelles without developing a deeper understanding of their functional interrelationships. Consequently, one of the major challenges in biology education in Indonesia is students' limited ability to apply systems thinking when conceptualizing the cell as an integrated and coherent system.

Without an adequate conceptual framework, students often struggle to perceive the cell as a complex living system composed of interconnected components that interact to maintain cellular functions. This limitation may hinder the development of scientific literacy, as students are unable to explain biological phenomena in terms of system dynamics and interdependence. Therefore, fostering systems thinking skills is essential for enabling students to understand how changes in one component of a system can influence other components and how interactions among those components contribute to the behavior of the system as a whole. Systems thinking can be defined as a set of analytical, strategic, and problem-solving competencies that enable individuals to identify, understand, analyze, predict, design, and modify complex systems by recognizing patterns, relationships, feedback mechanisms, and interdependencies among their constituent elements (Yulianto et al., 2025).

esearch has shown that the use of metaphors in learning can facilitate students' understanding of complex concepts. Metaphors function as cognitive bridges that connect new concepts with learners' prior knowledge and experiences, thereby supporting the process of conceptual understanding (Forceville, 2026). Furthermore, the integration of metaphors into digital learning media has been found to enhance instructional effectiveness. Studies indicate that metaphor-based digital learning resources can improve students' conceptual understanding, engagement, and critical thinking skills by presenting information in more contextualized, meaningful, and cognitively accessible forms (Roe et al., 2025).

The use of visual metaphors has also been shown to enhance students' emotional engagement as well as their metacognitive skills through creative design approaches. A nationally accredited study demonstrated that metaphor-based visual media can significantly support students in evaluating and reflecting on their understanding of complex cell biology concepts (Birello & Pujolà, 2023). Furthermore, the application of Design Thinking strategies by educators in developing visual metaphors that integrate local wisdom and align with future technological developments can create more meaningful and enjoyable learning experiences, often referred to as joyful learning (Limiansi et al., 2026).

The novelty of this approach lies in the reconceptualization of visual metaphors, shifting their function from mere illustrative devices to generative cognitive tools that facilitate deeper sense-making processes. Metaphors such as "The Cell as a Smart City" or "The Cell as a House of Life" help learners connect unfamiliar biological concepts with familiar visual schemas, thereby supporting more meaningful conceptual integration. An international study further explains that well-designed visual metaphors can reduce cognitive load while strengthening mental mapping, enabling students to better understand how disruptions in one organelle may influence the stability and functioning of the entire cellular system (Denzin & Lincoln, 2000).

O address these challenges, a systems thinking approach emerges as an essential competency that enables students to understand nonlinear interactions and feedback mechanisms within cellular systems. Integrating biology learning through a systems thinking framework helps students organize knowledge in alignment with the inherent characteristics of living systems (Momsen et al., 2022). However, shifting from a linear to a systemic mindset requires adequate cognitive support tools that can reduce complexity without compromising scientific integrity. In this regard, visual metaphors function as effective cognitive bridges that support conceptual integration. The integration of visual metaphors and systems thinking creates a synergistic approach that can enhance the development of scientific literacy in the digital era. Students with well-developed systems thinking skills are better able to understand how changes in one component of a system can influence other components, as well as how these components are interconnected within a dynamic whole (Yulianto et al., 2025). This approach highlights the importance of developing a visual design language within biological representations to help students bridge the gap between microscopic phenomena and real-world applications. Ultimately, the use of visual metaphors in cell biology learning not only facilitates conceptual understanding but also fosters a holistic mindset, which is essential for preparing future generations to address complex global challenges.

Recent developments in science education have emphasized the importance of systems thinking skills in enabling students to comprehend complex biological concepts, particularly in cell biology. However, prevailing instructional practices continue to rely on

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conventional visual representations that tend to depict biological structures in static and fragmented ways. Previous studies have predominantly focused on general visual media, with limited attention given to metaphorical visual representations as pedagogical tools for fostering systems thinking. Moreover, empirical evidence examining how metaphor-based visualizations support students' ability to perceive biological systems as dynamic and interconnected entities remains limited.

To address this gap, the present study proposes the integration of metaphorical visual media within an instructional design framework grounded in Design Thinking and supported by digital technologies. This approach offers a novel pedagogical perspective by transforming abstract and complex cell biology concepts into more meaningful and relatable representations, thereby enabling students to conceptualize the cell as a dynamic system rather than a collection of isolated organelles.

Accordingly, this study aims to investigate the effect of metaphorical visual media on students' systems thinking skills in learning cell biology concepts. Specifically, it examines whether the use of metaphorical visual media leads to a statistically significant improvement in students' systems thinking skills compared to conventional instructional approaches. The findings are expected to contribute to the advancement of science education by providing empirical evidence on the effectiveness of metaphor-based visual learning, as well as by supporting the development of higher-order thinking and systems thinking competencies required for 21st-century learners.

B. Method

The research employed a quasi-experimental design using a Nonequivalent (Pretest–Posttest) Control Group Design (Creswell, 2023). In this design, two groups were involved: an experimental group that received the treatment and a control group that did not receive the treatment (Anantasia & Rindrayani, 2023).

This study was conducted from February to March 2026 at SMP Negeri 1 Plumbon, involving eighth-grade students. The population comprised all eighth-grade students at the school. The sample consisted of class 8G as the control group and class 8H as the experimental group.

Data were collected using pretest and posttest instruments to examine differences in learning outcomes before and after the intervention. The quasi-experimental method was selected because it enables the investigation of cause-and-effect relationships in real-world educational settings, even in the absence of full randomization(Kohan et al., 2024). In this research design, neither the control group nor the experimental group was randomly assigned.

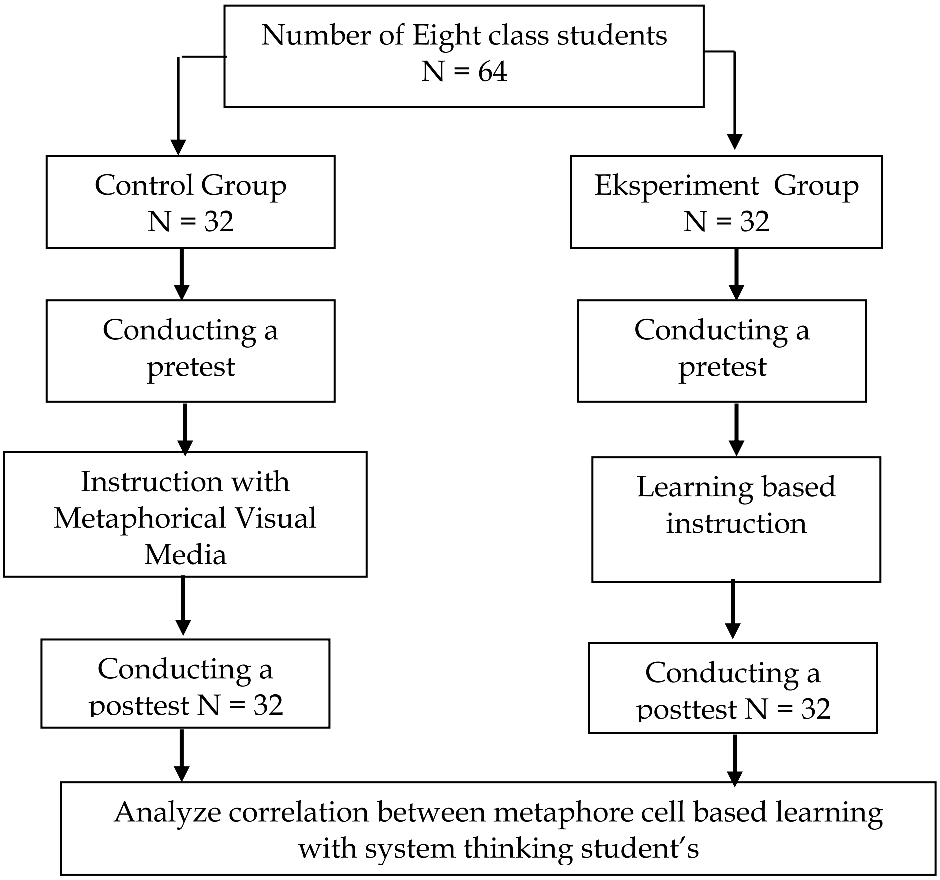

Figure 1. The process of conducting research

The systems thinking instrument was analyzed using data from 30 randomly selected students to examine its validity, item discrimination, difficulty index, and reliability, employing SPSS version 27. The findings of this analysis were used to ensure that the instrument met established psychometric standards and was suitable for assessing students' systems thinking abilities.

Validity testing is conducted to determine whether an instrument is valid for measuring a research variable (Nababan et al., 2024). In this study, instrument validity

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was examined using SPSS version 27 and the Pearson product-moment correlation to assess the appropriateness of the research instrument. The decision rule was based on the significance value: if $p < 0.05$, the item was considered valid, whereas if $p > 0.05$, the item was considered invalid.

Them discrimination is used to determine whether an item is capable of distinguishing between individuals or groups based on the measured construct, in accordance with the differences that exist among them. The criteria for the magnitude of the discrimination index are classified into four categories (Qadir, Huda, 2024). A more detailed description is presented in Table 1.

Table 1. Category of differentiating power

Item total correlation	***Category***
0,40 – 1,00	*good*
0,30 – 0,39	*midle*
0,20 – 0,29	*revision*
-1,00 – 0,19	*bad*

The reliability of an instrument, expressed as a reliability index, can be analyzed statistically through a reliability coefficient. In this study, reliability was tested using SPSS version 27 with Cronbach's Alpha to determine the internal consistency of the instrument across its items.

The decision criteria for Cronbach's Alpha reliability were as follows: values above 0.60 and below 1.00 indicate high reliability, whereas values below 0.50 indicate low reliability or an unreliable instrument (Afifah Aulia Zayrin et al., 2025).

This study employed an instrument consisting of 20 multiple-choice items to measure students' systems thinking abilities. The instrument was adapted from the Systems Thinking Scale (STS) developed by Moore et al. and aligned with the Habits of a Systems Thinker framework (Dolansky et al., 2020), which includes the dimensions of identifying interconnections, adopting a holistic perspective, and recognizing feedback mechanisms.

The analysis of the research results using the N-gain test was conducted to measure the improvement in students' abilities based on the difference between pretest and posttest scores. This analysis provides an overview of the effectiveness of an instructional intervention in improving learning outcomes. The main purpose of the N-gain test is to determine the level of improvement and categorize it into low, medium, or high gain levels. The classification criteria are defined as follows: an N-gain score greater than 0.7 ($g > 0.7$) indicates a high level of learning improvement; a score between 0.3 and 0.7 ($0.3 \leq g \leq 0.7$) indicates a moderate level; and a score below 0.3 ($g < 0.3$) indicates a low level of improvement. This test is used because it does not require assumptions of normality in the distribution of data. The detailed criteria for interpreting N-gain scores are presented in Table 2 (Matitaputty et al., 2023).

Table 2. Distribution category of N-gain Score

N- gain Value	Category
$g > 0.7$	*High*
$0.3 \leq g \leq 0.7$	*Medium*
$g < 0.3$	*Low*

Data collection in this study was conducted through the administration of pretests and posttests in both the control and experimental groups. In the experimental group, the treatment involved the use of cell metaphors designed to foster students' systems thinking skills.

The collected data were analyzed by first conducting a normality test using the Shapiro–Wilk test, as the sample size was fewer than 50 participants (Aminah et al., 2021). If the data were normally distributed, a parametric analysis using the independent samples t-test was performed. Conversely, if the data were not normally distributed, the Mann–Whitney U test was applied as a nonparametric alternative to examine differences between the two independent groups.

The Mann–Whitney U test is a nonparametric statistical method used to determine whether there are significant differences between two independent groups, particularly when the data are measured on ordinal, interval, or ratio scales but do not meet the assumption of normality (Putri & Nadia, 2025).

C. Results and Discussion

1. Results

a. Instrument validity and reliability test results

Instrument testing was conducted to ensure the quality of test items in measuring the research variables. Validity refers to the extent to which an instrument accurately measures the intended construct, while item discrimination refers to the ability of items to distinguish between high- and low-performing students. Item difficulty indicates whether

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items are classified as easy, moderate, or difficult, whereas reliability refers to the consistency of the instrument's results across items. These four psychometric properties are essential to ensure that the data obtained are valid, reliable, and trustworthy. The complete results of the instrument testing are presented below.

Table 3. Results of the Instrument Validity, Differentiating Power, and Item Difficulty Level

Item Code	Validity		Differentiating Power		Difficulty Level	
	Sig.(2-tailed)	*Category*	*Score Item-Total Correlation*	*Category*	*Mean value*	*Category*
P01	0,003	*valid*	0,575	*good*	0,70	*easy*
P02	0,001	*valid*	0,675	*good*	0,30	*difficult*
P03	0,002	*valid*	0,599	*good*	0,70	*easy*
P04	0,003	*valid*	0,566	*good*	0,25	*difficult*
P05	0,039	*valid*	0,385	*midle*	0,55	*middle*
P06	0,003	*valid*	0,579	*good*	0,85	*easy*
P07	0,008	*valid*	0,517	*good*	0,80	*easy*
P08	0,020	*valid*	0,462	*good*	0,85	*easy*
P09	0,016	*valid*	0,468	*good*	0,25	*difficult*
P10	0,010	*valid*	0,491	*good*	0,55	*middle*
P11	0,010	*valid*	0,456	*good*	0,75	*easy*
P12	0,018	*valid*	0,492	*good*	0,65	*middle*
P13	0,010	*valid*	0,560	*good*	0,65	*middle*
P14	0,003	*valid*	0,704	*good*	0,75	*easy*
P15	0,001	*valid*	0,406	*good*	0,55	*middle*
P16	0,030	*valid*	0,458	*good*	0,40	*middle*
P17	0,039	*valid*	0,386	*midle*	0,55	*middle*
P18	0,025	*valid*	0,423	*good*	0,60	*middle*
P19	0,032	*valid*	0,401	*good*	0,60	*middle*
P20	0,014	*valid*	0,468	*good*	0,35	*middle*

Meanwhile, for the overall instrument, the reliability value was obtained as follows:

Table 4. Cronbach's Alpha Value of the Instrument

Reliability Stattistics	
Cronbach's Alpha	N of items
0.886	30

Based on the results of the instrument testing, all items (P01–P20) were found to be valid, as each item had a significance value (Sig. 2-tailed) below 0.05. This indicates that all items are capable of accurately measuring the intended construct. In terms of item discrimination, most items were classified as "good," indicating their effectiveness in distinguishing between high- and low-performing students. However, several items, such as P05 and P17, were categorized as "fair," indicating a moderate level of discriminative ability compared to the other items.

Regarding item difficulty, the distribution of items was relatively balanced, comprising easy, moderate, and difficult levels. Items such as P01, P03, P06, P07, P08, P11, and P14 were classified as easy, while P02, P04, and P09 were categorized as difficult. The remaining items fell into the moderate category, indicating a proportional distribution of difficulty levels across the instrument. Overall, the instrument demonstrated good quality, as it met validity requirements, exhibited predominantly good discrimination power, and showed a balanced distribution of item difficulty, making it suitable for use in this study.

In addition, metaphor-based instructional media encourage students to engage in more structured and holistic thinking, which is a core component of systems thinking skills. By linking new scientific concepts to familiar experiences or visual representations, students are guided to analyze patterns, cause-and-effect relationships, and system dynamics. This process ultimately enhances their ability to solve complex problems more deeply, as they learn to focus not only on individual components but also on the system as an integrated whole. Meanwhile, the N-gain results for the experimental class and the control class are presented as follows:

Table 5. N-Gain Scores of the Experimental Class and the Control Class

Group	***Persentase N-Gain***			***N-gain Average***	***Category***
	Max	*Min*	*Std. Dev*		
Experiment	0.86	0.22	0.027	0.62	Midle
Control	0.80	0.09	0.032	0.32	Low

Based on the research data, there is a significant difference in the improvement of students' systems thinking skills between the experimental and control groups. The experimental group, which was taught using a visual metaphor approach, achieved an average N-gain score of 0.62, which falls within the moderate category. In contrast, the control group, which received conventional instruction, obtained an average N-gain score of 0.32, categorized as low. These findings indicate that the visual metaphor approach was substantially more effective in enhancing students' learning gains compared to traditional

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instructional methods. This result is consistent with the principles of instructional effectiveness (Taimur et al., 2019).

The test instrument, which refers to systems thinking ability, yielded the following data for the experimental class and the control class.

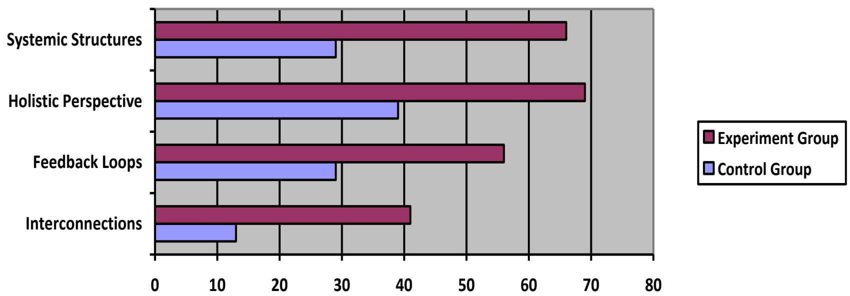

Figure 3. The graph of System Thingking Skill's

The graph indicates a clear difference between the experimental and control groups across the four dimensions of systems thinking, namely systemic structures, holistic perspective, feedback loops, and interconnections.

b. Visual Metaphor learning

This visual metaphor-based learning approach was implemented in the experimental class using an Interactive Flat Panel (IFP), which facilitated a more engaging and conducive learning environment for students.

Figure 2. Visual Metaphor–Based Learning Activities

The image depicts an interactive instructional process in which the teacher employs visual metaphors displayed on a digital screen to explain complex concepts. The teacher gestures toward a diagram that connects various symbols and colorful icons, which serve as visual analogies for students. By incorporating familiar visual elements, the teacher aims to transform abstract concepts into more concrete and comprehensible representations, thereby supporting students' conceptual understanding through meaningful visual associations.

The integration of digital media as a medium for visual metaphors fosters a modern and reflective learning environment. Rather than focusing solely on memorization, students are encouraged to interpret and construct meaning from the presented symbols. This approach effectively stimulates critical and creative thinking skills, as information presented in visual and contextually meaningful forms is more easily processed and retained by learners, particularly when it is connected to real-world experiences.

In this study, the normality test was conducted using the Shapiro–Wilk test. This method was selected due to its higher statistical power compared to the Kolmogorov–Smirnov test, particularly for small to moderate sample sizes ($n < 50$) (Bahri & Hayati, 2026).

Table 6. Shapiro-Wilk Test Result

Statistics	***Experiment***		***Control***	
	Pretest	*Postest*	*Pretest*	*Postest*
Sig	0.085	0.016	0.089	0.160
Shapiro-wilk	*Sig* > 0.05	*Sig* < 0.05	*Sig* > 0.05	*Sig* < 0.05
Conclusion	Normal	Not Normal	Normal	Normal

Based on the table above, and with the significance level set at $\alpha = 0.05$, the results of the data analysis indicate that the Shapiro–Wilk test yielded a significance value of 0.001 ($p < 0.05$). Since this value is lower than the alpha level, the data are not normally distributed. Therefore, further analysis was conducted using the Mann–Whitney U test.

When data do not meet the assumptions of normality or homogeneity, nonparametric statistical analysis is applied, specifically the Mann–Whitney U test using SPSS version 27.0 with a significance level of 5%. The Mann–Whitney U test is a nonparametric statistical method used to examine differences in the median between two independent groups measured on ordinal, interval, or ratio scales when the assumption of normality is violated (Selpia et al., 2024).

The results of the Mann–Whitney U test for the experimental and control groups are presented below.

Table 7. *Mann Whitney Test Result*

	Value
Mann-Whitney U	163.500

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Wilcoxon W	691.500
Z	-4.725
Asymp. Sig. (2-tailed)	0.000

2. Discussion

Metaphor-based learning media are closely aligned with systems thinking skills, as both emphasize the understanding of relationships among concepts as an integrated whole. Through the use of visual or symbolic metaphors, abstract concepts can be transformed into more concrete representations, enabling students to more easily recognize connections among components within a system. This approach supports students not only in understanding individual elements separately but also in comprehending how these elements interact to form a unified and dynamic whole.

The superior performance of the experimental group can be attributed to the role of visual metaphors as cognitive bridges that help simplify abstract concepts. In systems thinking, students are required not only to understand individual components but also to identify patterns of relationships and overall system dynamics. Sánchez-Mena et al. (2025) explain that instructional designs incorporating visual metaphors can significantly reduce extraneous cognitive load, thereby allowing learners to focus more effectively on processing complex causal relationships. By mapping system components onto familiar visual representations, students in the experimental group achieved a maximum score of 0.86, indicating a very high level of cognitive performance.

In the national context, the use of contextual visual media has been shown to be effective in simultaneously enhancing students' scientific literacy and critical thinking skills. Pratama et al. (2023), in a nationally indexed journal, state that appropriate visual representations help students construct more accurate mental models of phenomena that cannot be directly observed. In the experimental class, the use of visual metaphors provided a more structured cognitive framework, enabling students not only to memorize system concepts but also to visualize dynamic interactions among inputs, processes, and outputs as an integrated whole.

In contrast, the results obtained by the control group, which fell into the low category (0.32), indicate challenges in learning systems thinking without the support of representational media. Conventional instructional approaches often fail to illustrate relationships among variables in a holistic manner, leading students to rely on linear rather than systemic modes of thinking. Systems thinking requires the ability to understand circular causality, which is difficult to achieve when instruction relies solely on textual or verbal explanations without visual metaphors that can intuitively represent complexity(Arnold & Wade, 2017).

The analysis of standard deviation values also provides important insight into the consistency of treatment effects. The experimental group exhibited a lower standard deviation (0.027) compared to the control group (0.032). This finding indicates that the use of visual metaphors produced more stable and evenly distributed learning gains among students. Minkley et al. (2024) suggest that metaphor-based visualization helps minimize differences in students' initial understanding, thereby enabling learners with diverse ability levels to achieve more uniform improvements.

The increase in the minimum score from 0.09 in the control group to 0.22 in the experimental group further demonstrates that visual metaphors are particularly beneficial for students who experience greater learning difficulties. This visual support functions as an effective form of scaffolding, helping lower-performing students develop an initial understanding of fundamental relationships within a system. Sari and Rahman (2024), in a nationally indexed journal, also report that visual metaphor-based learning media can enhance students' interest and facilitate their ability to draw conclusions from complex information, as reflected in the improvement of the lowest scores in the experimental group. Furthermore, students with well-developed systems thinking skills are better able to understand how changes in one part of a system can influence other parts, as well as how each component is interconnected within the system as a whole (Yulianto et al., 2025).

The experimental group, which received an intervention involving the consistent use of visual metaphors, achieved higher scores compared to the control group. These findings are consistent with recent research indicating that visual metaphors function as a "cognitive bridge," enabling learners to connect complex problems with more familiar structures and thereby facilitating a deeper understanding of complex system dynamics (Taimur & Sattar, 2022).

In the Interconnections and Feedback Loops dimensions, the experimental group demonstrated an improvement nearly three times greater than that of the control group. Theoretically, both dimensions are highly abstract and difficult to visualize due to inherent limitations of time and space. The use of visual metaphors, such as a "spider web" or an "interconnected machine," helps learners understand non-linear relationships

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that are often overlooked in reductionist analytical approaches. Visual media can enhance cognitive abilities in recognizing circular causal relationships, which are central to effective systems thinking (Arnold & Wade, 2017).

Furthermore, the marked difference in the Feedback Loops category highlights the effectiveness of visual aids in representing sequential and recursive processes. In the context of science and management education in Indonesia, visual metaphors function as an "information anchor" that strengthens students' memory of indirect cause-and-effect relationships. A recent study by Sari et al. (2022) also confirms that the application of metaphor-based visual media in problem-based learning significantly enhances students' systems thinking skills. This improvement occurs because learners are better able to recognize interrelated variables in a more concrete manner compared to relying solely on narrative text. These findings further help explain why the experimental group demonstrated a substantially greater improvement in understanding systemic structures compared to the control group, which was taught using conventional instructional methods.

Furthermore, in the Holistic Perspective and Systemic Structures dimensions, the experimental group achieved the highest scores, indicating that visual metaphors are highly effective in fostering a comprehensive or "helicopter view" mindset. Metaphors can simplify complexity without eliminating the essential structure of the system itself. Evidence from Systems Research and Behavioral Science suggests that visual representations help reduce cognitive load when individuals attempt to understand layered system structures. As a result, learners are better able to focus on overall system behavior patterns rather than isolated components (Sayer et al., 2024).

Through a metaphorical approach, learners are able to make a "cognitive leap" from merely memorizing components to developing a deeper understanding of functional interconnections among elements. The analyzed visual metaphors are processed within a mirror network of conceptual integration (Kononchuk, 2025). This is consistent with findings by Pratama and Wijaya (2023), which show that metaphor-based visual representations help students in Indonesia overcome difficulties in understanding complex systems, such as ecosystems and social structures, by enabling them to construct more adaptive and flexible mental models.

Overall, these findings indicate that the integration of visual metaphors into learning processes and systems analysis can empirically enhance learners' understanding.

The relatively small error bars in the graph also suggest consistency in the results within the experimental group, thereby strengthening the argument that visual interventions not only produce short-term learning effects but also contribute to the systematic restructuring of learners' mental models. Therefore, the ability to "see" systems through a metaphorical approach represents an important competency that should be developed to address various systemic challenges in the future, ranging from environmental issues to organizational management (Barton, J., & Tuskan, 2025).

Based on the Mann–Whitney U test results, the SPSS 27 output indicates that the Asymp. Sig. (2-tailed) value is 0.001 ($p < 0.05$). Therefore, the null hypothesis is rejected, indicating that there is a statistically significant difference between the experimental and control groups. Accordingly, it can be concluded that the use of visual metaphor media in the cell biology topic has a significant effect on students' systems thinking skills.

This finding suggests that visual metaphor-based instruction contributes to improved systems thinking performance in the experimental group compared to the control group. Furthermore, Shin et al., (2022), emphasize the importance of conducting integrated and comprehensive research and development programs across various learning contexts to further explore the relationships among modeling, systems thinking (ST), computational thinking (CT), and student learning outcomes.

In science education, the development of systems thinking can be implemented through several approaches. First, systems learning should focus on applying systems concepts to explore and analyze complex biological phenomena from a cognitive skills perspective. Second, instruction should emphasize the conceptual core of systems theory, including attention to system boundaries, enabling students to perceive systems as holistic entities rather than merely networks of interacting components. Third, the use of systems models can support students' conceptual development of systems thinking (Verhoeff et al., 2018). In addition, STEM education supported by the Engineering Design Process (EDP) model has been shown to enhance students' systems thinking skills (Abdurrahman et al., 2023).

D. Conclusion

The use of visual metaphor media in cell biology content shows a significant relationship with students' systems thinking abilities. By presenting cell concepts through visual metaphors, students can more easily understand the relationships among cellular components as well as the functions of each part in a more integrated manner. This

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approach not only supports conceptual retention but also encourages learners to recognize connections and interactions among system components, which constitute the essence of systems thinking.

In addition, visual metaphor media contribute to improving students' ability to analyze and integrate information at a deeper level. This is reflected in the higher systems thinking performance of students in the experimental group compared to those in the control group. Therefore, it can be concluded that the use of visual metaphor media has a positive impact on the development of systems thinking skills. Accordingly, this instructional approach can be considered an alternative learning strategy to enhance conceptual understanding and higher-order thinking skills.

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