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Visual Scaffolding in Discovery Learning: Reducing Cognitive Load to Enhance Mastery of Abstract Biological Concepts

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Abstract: The complexity of physiological processes in the digestive system often poses significant cognitive challenges for junior high school students, leading to suboptimal conceptual mastery. Conventional learning materials often lack the visual scaffolding needed to help students organize abstract concepts. This study aims to develop Visual Mind Map Worksheets integrated with the Discovery Learning model and to analyze their validity, practicality, and effectiveness in improving students' understanding of science concepts. This research utilized a Research and Development (R&D) design following the 4-D model (Define, Design, Develop, and Disseminate). The trial sample consisted of 28 eighth-grade students at Asa Cendekia Junior High School, selected using purposive sampling. Data were collected using expert validation sheets, learning implementation observation rubrics, and a written test measuring cognitive levels C2 (Understanding), C3 (Applying), and C4 (Analyzing). The data were analyzed using descriptive statistics, paired sample t-tests, and N-gain scores. The results indicated that the developed product met the criteria for high feasibility. Expert validation yielded an average score of 3.90 (Very Valid), while the practicality test showed a 98% implementation rate of learning activities (Very Practical). Statistical analysis revealed a significant difference between pretest and posttest scores ($p = 0.000 < 0.05$). Furthermore, the N-gain analysis demonstrated an improvement in the "Medium" category across all indicators, with a hierarchical achievement pattern: Understanding (0.635), Applying (0.416), and Analyzing (0.444). These findings conclude that the Visual Mind Map Worksheet is a feasible and effective instructional tool. By leveraging visual organization, the worksheet acts as a cognitive scaffold that helps students reconstruct complex biological information into a coherent understanding.

Keywords: visual mind map-based worksheets, discovery learning, science concept understanding, digestive system.

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INTRODUCTION

Education is a systematic system that promotes individual development by addressing physical, health, skill, cognitive, and social components (Kumar et al., 2025). The quality of a nation's education system is one measure of its growth, as it plays a significant role in enhancing the quality of human resources. Optimal education supports the development of human resources capable of adapting to the demands of science and technology. As it develops, individuals are required to master various 21st-century skills known as the 6C: critical thinking, collaboration, communication, creativity, culture, and connectivity (Yeoh et al., 2025). This requirement is in line with the Merdeka Belajar Curriculum implemented by the government to improve the quality of education in Indonesia (Mufanti et al., 2024). The curriculum, which began to be implemented in the 2022/2023 academic year, aims to encourage more flexible and learner-oriented learning (Alam & Hamzah, 2025). However, achieving deep conceptual understanding in science education remains a global challenge. In the context of biology, specifically the structure and function of living things, such as the digestive system, students often struggle because the concepts involve abstract physiological processes that cannot be observed directly. Without a strong conceptual foundation, students are unable to relate knowledge to real-life situations or think critically (Courtney et al., 2025).

Despite the emphasis on active learning, many science classrooms still rely on teacher-centered approaches. This traditional method often leads to passive learning, where students struggle to comprehend material in depth and fail to construct their own knowledge (Bakri et al., 2020). Consequently, there is a discrepancy between the expected learning outcomes, which require active engagement, and the reality of classroom practices. To address this issue, educators and researchers advocate for innovative learning models such as Discovery Learning, which encourages students to independently discover concepts, meanings, and relationships (Ozdem-Yilmaz & Bilican, 2025).

Globally, science education faces a significant discrepancy between the expected curriculum standards and actual student achievement. Developing a deep conceptual understanding remains a complex challenge for educators worldwide, not limited to any specific region. The OECD's Programme for International Student Assessment (PISA) reports consistently highlight that students across various countries struggle to apply scientific knowledge in real-life contexts. This issue indicates a fundamental gap in how scientific concepts are taught and internalized. Students often memorize facts without grasping the underlying principles, leading to fragmented knowledge that cannot support critical thinking or problem-solving (OECD, 2024).

Within the scope of science, Biology is often perceived as a subject heavy on memorization, yet it requires high-level cognitive skills to understand the interactions within systems. One of the topics that poses significant cognitive hurdles is the structure and function of living things, particularly the human digestive system. Literature suggests that students find this topic difficult because it involves abstract physiological processes, such as enzymatic breakdown and nutrient absorption, that are not visible to the naked eye (Erwinsyah & Ubaedillah, 2025). Students tend to view organs as isolated parts rather than an integrated system, leading to misconceptions and a superficial understanding of how the body functions as a whole.

These cognitive difficulties are frequently exacerbated by the prevailing pedagogical approaches in many classrooms (A. Putra, 2019). Conventional teaching methods, which rely heavily on teacher-centered lectures, fail to provide the necessary scaffolding for students to visualize abstract processes. In such learning environments, students become passive recipients of information, leading to low engagement and boredom. Without active engagement and appropriate visualization tools, students struggle to construct a coherent mental model of the material, leading to knowledge quickly forgotten after exams.

This global phenomenon is clearly reflected in Indonesian education. Empirical data from the 2022 PISA survey show that Indonesia ranks 65th in science with a score of 383, indicating a 13-point decline (OECD, 2023). Furthermore, historical data from the National Examination (UN) in East Java reveals that mastery of the digestive system material consistently fluctuates, with accuracy dropping as low as 42.95% (Rosidin, 2019). Observations at SMPS Asa Cendekia further confirm this trend, in which traditional teaching methods have led to student passivity and low conceptual mastery. Thus, the situation in Indonesia serves as a crucial case study highlighting the urgent need for innovative learning interventions. To address this issue, one recommended solution is to implement innovative learning models such as discovery learning, project-based learning, or inquiry learning (de Jong et al., 2024)

Discovery learning is one approach to improving conceptual understanding. This model is a learning process in which students independently discover concepts, meanings, and relationships between materials until they reach a conclusion (DiNapoli & Miller, 2022). Discovery learning involves observation, classification, and inference, which can boost student interest through independent exploration (Damiani et al., 2025). This model is extremely relevant to 21st-century learning because it encourages students to actively seek information, making learning more student-centered.

The combination of the discovery learning model and mind maps has enormous potential for improving conceptual understanding. This model allows for guided conceptual discovery, whereas mind maps assist students in organizing and visualizing their findings (Bernárdez et al., 2022). Collaboration between the two promotes deeper and more lasting knowledge construction. As a result, using this combination is expected to train and improve students' conceptual understanding, particularly of the digestive system.

Previous research, such as Gao et al. (2025) on the effectiveness of digital-based discovery learning and Ho et al. (2023), which analyzed concept understanding through mind mapping, supports this study. This study is unique in that it combines the discovery learning model with mind map worksheets focused on the digestive system. Furthermore, data analysis employs a variety of statistical tests, including the N-gain test, paired samples t-test, Wilcoxon, and Mann-Whitney, as well as effect size analysis, to provide a more complete picture of the magnitude of the treatment effect.

Developing a specialized worksheet that integrates these two elements is essential for bridging the gap between active exploration and conceptual consolidation. This study argues that integrating the Discovery Learning model into Visual Mind Map Worksheets can provide the guidance students need to construct a robust understanding of scientific concepts. Therefore, this research aims to produce Visual Mind Map-based Worksheets using the discovery learning model on the digestive system material that are valid, practical, and effective. Based on this objective, the research questions are formulated as follows:

1. How is the validity of the developed Visual Mind Map Worksheets?
2. How is the practicality of the developed Visual Mind Map Worksheets in the learning process?
3. How is the effectiveness of the Visual Mind Map Worksheets in improving students' concept understanding?

METHOD

Participants

The subjects of this limited trial involved 28 eighth-grade students (Class VIII C) at Asa Cendekia Junior High School. The sample was selected using convenience sampling. The primary criterion for selection was the class's baseline performance, which had the lowest average science score among the classes. This selection was intentional to rigorously test the effectiveness of the developed *scaffolding* tool (Visual Mind Map Worksheets). By implementing the product in the group with the most significant learning difficulties, this study aims to determine if the visual intervention can bridge the gap for low-achieving students. Consequently, this sample serves as a representative group for testing the product's feasibility and initial effectiveness before broader dissemination. This was supported by pre-research data showing a low level of concept understanding among eighth-grade students (Table 1).

Table 1. Results of the preliminary study on students' concept understanding

Class	Indicator				Total	Category
	Remembering (C1)	Understanding (C2)	Applying (C3)	Analyzing (C4)		
VIII A	45.19	32.69	48.46	55.38	45.43	Low
VIII B	38.89	30.25	39.26	40	37.10	Low
VIII C	26.69	21.67	31.33	42	30.42	Low
VIII D	33.93	25.6	42.86	40.71	35.78	Low
Percent	36.18%	27.55%	40.48%	44.52%	37.18%	Low

As presented in Table 1, the results of a 20-question multiple-choice test showed that the average score for all classes was in the low category, particularly in the Understanding (C2) indicator (27.55%). This preliminary data justified the development of new learning materials.

Research Design and Procedures

This study employed a Research and Development (R&D) design using the 4-D model (Define, Design, Develop, Disseminate). The Define stage established learning requirements through front-end, student, task, and concept analyses regarding the digestive system. The Design stage focused on drafting the Visual Mind Map Worksheets integrated with Discovery Learning syntax. The Develop stage involved expert validation (lecturers and teachers) and revision to ensure content feasibility. Finally, the Disseminate stage was conducted through a limited field trial involving 28 students (Class VIII C) to evaluate the product's effectiveness and practicality.

The learning process began with a stimulation stage, in which the teacher introduced stimuli to pique students' interest in the digestive system. Students were then guided through the process of identifying problems and developing hypotheses. During the data collection stage, students actively gathered relevant information and keywords from various sources to test the hypothesis. During the data processing stage, students began organizing the keywords they had discovered. The teacher asked students a series of leading questions to help them connect concepts and create a mind map framework. The next stage was verification, in which students independently created a complete mind map based on the designed framework. The learning process culminated in the generalization stage, in which students concluded from the entire set of activities and findings that they had visualized.

Instrument

The data collection technique and instruments were structured into two main categories: instruments for assessing product validity and instruments for assessing product effectiveness. Instruments for assessing product validity were adapted from the standard teaching material assessment components, focusing on three main aspects: Representation, Content, and Linguistics. The detailed indicators are presented in Table 2.

Table 2. Media aspect questionnaire instrument grid

No	Aspect	Indicator
1.	Representation	Attractiveness of the cover, font readability, and systematic arrangement. Clarity of the title, suitability of time allocation, and stated learning objectives. Clarity of usage instructions and the quality of questions in guiding concepts.

2.	Content	Alignment of the material with learning objectives and concept clarity. Effectiveness in training students to find keywords and follow mind mapping steps.
3.	Linguisticts	Appropriateness of language for the student's age and avoidance of ambiguity. Compliance with standard spelling rules (PUEBI) and correct punctuation.

This instrument was designed to assess the structural quality of the mind maps integrated into the worksheets, in line with Buzan's (2018) mind mapping principles. The indicators include keywords, hierarchy, and visual components, as detailed in Table 3.

Table 3. Mind map aspect question instrument grid

No	Aspect	Indicator
1.	Keywords / Central Idea	The effectiveness of summarizing ideas into concise, clear, and meaningful keywords or phrases, avoiding long sentences or paragraphs.
2.	Branching Hierarchy & Connectivity	The depth of the branching structure (hierarchy levels) and the logical interconnection between the main ideas and sub-topics.
3.	Color Design	The use of varied colors to distinguish between different branches, group related information, and show relationships between topics.
4.	Symbols, Images, & Curved Lines	The integration of visual elements (icons, drawings, symbols) and the use of organic/curved lines to connect ideas, enhancing memory and aesthetic appeal.
5.	Material Completeness	The mind map's content is comprehensive, covering the main topics and including supporting details.

The validation results were analyzed quantitatively. Based on the expert assessment, the worksheet obtained an average validity score of 3.90, categorized as "Very Valid." Furthermore, the reliability of the validation instrument was calculated using the Percentage of Agreement formula, yielding a score of 96%, indicating high consistency among validators.

This study used a written test as both a pretest and a posttest to measure the product's effectiveness in improving students' conceptual understanding. The instrument consisted of 20 multiple-choice questions with four answer options (A-D). The test indicators were adapted from the cognitive process dimensions of Anderson & Krathwohl's taxonomy (2001). Although the preliminary study (Table 1) measured levels C1 through C4, this main study focused specifically on cognitive levels C2 (Understanding), C3 (Applying), and C4 (Analyzing). The C1 (Remembering) level was excluded because the developed Visual Mind Map Worksheets aim to facilitate deep conceptual construction and higher-order thinking skills rather than mere rote memorization (Van Joolingen, 1999). The detailed grid and operational verbs are presented in Table 4.

Table 4. Grid of concept understanding test instrument

No	Indicator	Learning Objectives
1.	Understanding (C2)	Through descriptive texts, charts, or practicum illustrations, students demonstrate understanding by categorizing nutritional sources, identifying organ functions, and explaining the mechanisms of the digestive process.

2.	Applying (C3)	Through anatomical images, data tables, or specific scenarios, students apply their knowledge to determine nutrient roles, locate specific organ parts (e.g., taste zones), and correctly sequence the digestive organs.
3.	Analyzing (C4)	Through clinical cases, symptoms, or simulation results, students analyze the information to diagnose digestive diseases, differentiate organ roles, and evaluate the impact of dietary habits on digestive health.

Data Analysis

The parameters used in this research were evaluated for validity, practicality, and effectiveness. The percentage distribution for the category recapitulation of validation data for visual mind map-based worksheets is presented in Table 5.

Table 5. The media suitability category

Percentage (%)	Category
84% ≤ score ≤ 100%	Very Valid
68% ≤ score ≤ 84%	Valid
52% ≤ score ≤ 68%	Less Valid
36% ≤ score ≤ 52%	Not Valid
20% score ≤ 36%	Very Not Valid

The data obtained is quantitative, derived from pretest and posttest scores on the students' comprehension of the concepts (Abramovich & Connell, 2021). The percentage score for each concept understanding indicator obtained falls into four categories. According to the improvement criteria, a high score is given if the percentage score for each concept understanding indicator is between 75 and 100. A sufficient score is given between 50 and 75. A low score is given between 25 and 50. Meanwhile, the percentage score for each concept understanding indicator is considered very low if it falls between 0 and 25 (Ma et al., 2025).

The collected data were then analyzed using a prerequisite test and a normality test (Lindstromberg, 2025). If the test value was P>0.05, it was followed by a paired t-test (P-value<0.05) using SPSS V.26 software (Lu et al., 2025). The encyclopedia's effectiveness can be measured by the increase in learning motivation and concept understanding for each indicator, using N-gain, before and after learning. The N-gain scores obtained were divided into three categories. According to the improvement criteria, a score is considered high (very effective) if the N-gain score exceeds 0.7. The moderate (effective) category is used for N-gain scores between 0.3 and 0.7. Meanwhile, improvement is deemed low (less effective) if the N-gain score is less than 0.3 (Amaral et al., 2025).

■ RESULT AND DISCUSSION

Product Characteristics and Validity

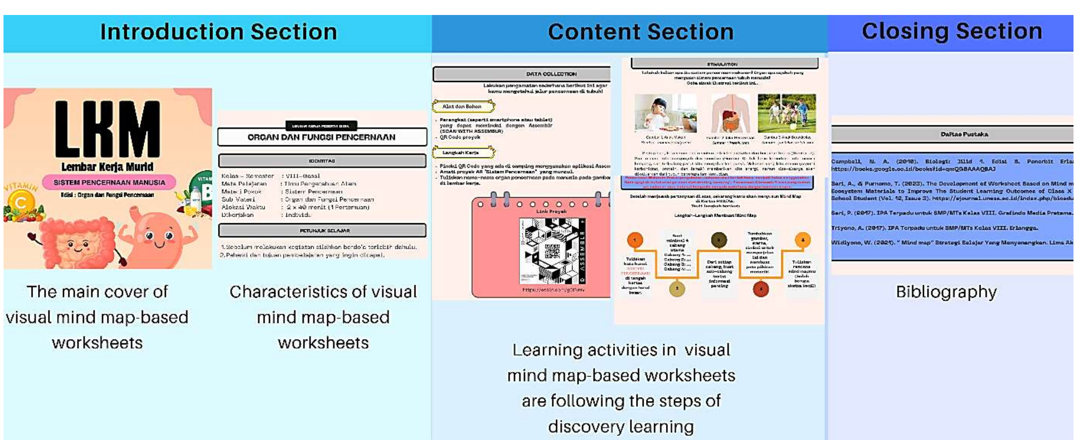

Figure 1. Human digestive system worksheets

This study produced a mind map-based Student Worksheet (LKPD) for digestive system material. This LKPD is printed and intended to support the guided discovery learning model (Figure 1). It includes relevant images, narrative stimuli, and a set of structured guiding questions. During the data collection stage, students use the LKPD to gather keywords and important information about the digestive system from various learning resources. Next, during the data processing and verification stage, students actively contribute to their understanding by answering guided questions and then creating their own mind maps, either individually or in groups. This encourages students to independently investigate and organize ideas.

Table 6. The results of the mind map-based worksheet validation

Validator	Score	Average	Percentage (%)	Category
V1	3.8	3.9	98.3	Very Valid
V2	4			
V3	4			

Product Validity Results: The feasibility of the developed Visual Mind Map Worksheets was assessed by three qualified experts: one lecturer from the Science Education Study Program (acting as a materials and media expert) and two experienced science teachers (acting as educational practitioners). The validation instrument utilized a Likert scale ranging from 1 to 4 (1 = Invalid, 2 = Less Valid, 3 = Valid, 4 = Very Valid). The assessment covered four main aspects: content feasibility (alignment with the curriculum and learning objectives), presentation/ construct (systematic arrangement and mind map structure), language (readability and communicative effectiveness), and graphics (visual appeal and layout).

The quantitative analysis of the validation data revealed consistently high scores from all experts (Table 6). Validator I (Lecturer) gave an average score of 3.8, while Validator II and III (Teachers) both awarded a perfect score of 4.0. Consequently, the overall average validity score obtained was 3.9. When converted into a percentage, the product achieved a validity level of 98.3%. Based on Riduwan's (2018) eligibility criteria, any score above 81% is classified as "Very Valid". Therefore, the developed Visual Mind Map Worksheets are declared highly valid and appropriate for use in the classroom learning trial with minor revisions based on the validators' qualitative feedback.

Before the main field trial, the test instrument underwent empirical validity and reliability testing on 28 students outside the sample group. The validity of each item was tested using the Pearson Product-Moment correlation in SPSS V.26. The results indicated that 20 items were declared valid ($r_{count} > r_{table}$) and fit for use.

Table 7. The result of the reliability test of the concept understanding instrument

Parameters	N of items	Cronbach's Alpha	Category
Understanding of concepts	20	0.722	High

Furthermore, the instrument's reliability, as assessed by Cronbach's alpha, is reported in Table 7. The calculation yielded a reliability coefficient of 0.722, which falls into the "High" category (Arikunto, 2013). This confirms that the instrument is consistent and reliable for measuring students' mastery of concepts.

Practicality of the Developed Product

The practicality of the developed Visual Mind Map Worksheets was evaluated through the observation of learning implementation. Three

Table 8. The result of learning implementation

Observer	Score	Average	Percentage (%)	Category
O1	70	68.6	98	Very Effective
O2	66			
O3	70			

observers monitored the teaching and learning process using a structured observation rubric. The rubric focused on the compliance of activities with the Discovery Learning syntax, which includes six main indicators: (1) stimulation, (2) problem statement, (3) data collection, (4) data processing, (5) verification, and (6) generalization. (Gunawan et al., 2021). Additionally, the observers assessed student engagement in constructing mind maps and their interaction during discussions.

As presented in Table 8, the observation results yielded an average score of 68.6 out of 70. This converts to 98%, placing it in the "Very Effective" category. This high percentage indicates that almost all learning stages facilitated by the worksheets were completed effectively. Furthermore, the reliability of the observation data was ensured through inter-rater reliability analysis. The scores provided by the three observers (O1=70, O2=66, O3=70) showed a high consistency with a Percentage of Agreement (PA) of 94%, indicating that the assessment was objective and reliable (Hadiprayitno et al., 2020). Thus, the Mind Map-based Worksheets are deemed practical and highly feasible for use in the learning process to support student engagement Tasman & Abdullah (2019).

Qualitatively, observations revealed distinct dynamics during the Discovery Learning phases. While students showed high engagement during Stimulation, challenges emerged in the Data Processing stage. Groups experienced an "initiation block" as they struggled to determine concept hierarchies for the fill-in-the-blank mind maps. Although the visual task fostered active discussion, it initially imposed a high cognitive load as students focused on aesthetics over substance. This cognitive adaptation, transitioning from passive textual learning to active visual construction, explains the "Medium" N-gain in the Analyzing (C4) aspect. However, by the Generalization phase, the completed mind maps significantly improved the logical structure of students' conclusions compared to conventional notes.

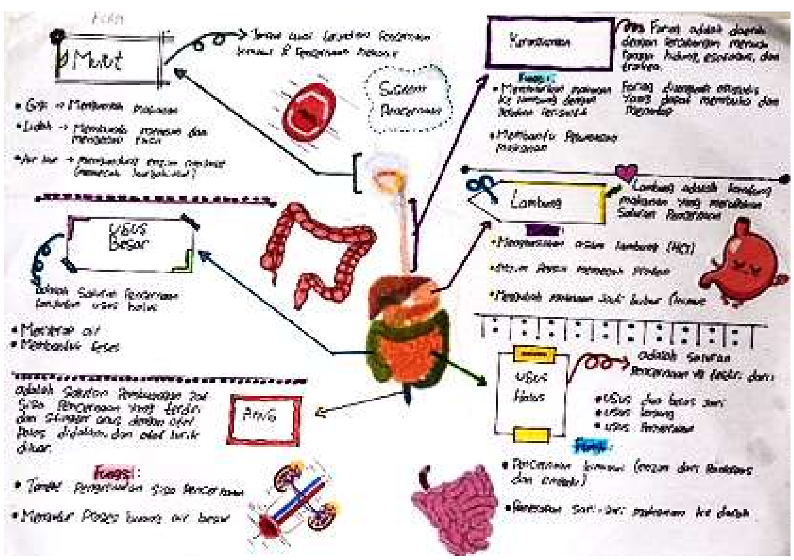

Figure 2. The result of the students' mind map

The image is the result of the students' mind maps, which depict four aspects of good concept understanding at levels C2, C3, and C4 (Figure 2). Aspect C2 (Understanding) is demonstrated by the students' ability to correctly and hierarchically identify the main keywords, sub-themes, and branches. The C3 aspect (Applying) is reflected in students' ability to add relevant images or symbols to most branches, demonstrating their understanding through visual representation. The ability to organize and elaborate on concepts demonstrates the C4 (Analysis) aspect. This is demonstrated by the use of distinct colors and branch shapes to differentiate concept categories, as well as the ability to elaborate deeply (e"4 branches) on most keywords (McCrea & Lorenzet, 2018).

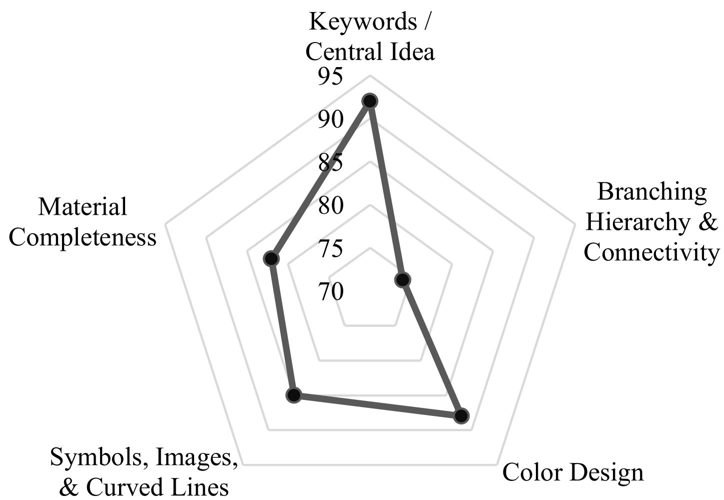

Figure 3. Profile of student mind map assessment scores

As illustrated in Figure 3, the spider chart reveals a distinct asymmetrical pattern in students' performance. The chart expands significantly towards the Keywords and Central Idea axis with an average score of 92, followed closely by Color Design at 88. This indicates that the worksheets successfully stimulated students' creativity and visual engagement. Students were able to identify the main topic vividly and utilized color coding effectively to distinguish information clusters (Hadiprayitno et al., 2020). However, the chart shows a noticeable contraction on the Branching Hierarchy and Connectivity axis, which recorded the lowest average of 74. This specific indicator measures the logical connection between main concepts and sub-concepts. This result is crucial, as it correlates directly with the N-gain findings, in which the analyzing aspect, or C4 score, was in the medium category.

The gap between the high visual scores, such as Symbols and Images at 85, and the lower logical score demonstrates that while students are proficient in the artistic aspects of mind mapping, they still face cognitive challenges in constructing valid logical hierarchies (Buzan, 2024). Nevertheless, the score for Material Completeness remains high at 82, confirming that despite the structural challenges, students successfully engaged with the substantial content of the digestive system material.

Implementing visual mind map-based worksheets to improve students' understanding of science concepts resulted in the following outcomes:

As illustrated in Figures 4 and 5, the implementation of Visual Mind Map-based Worksheets resulted in a significant shift in students' conceptual understanding. While the

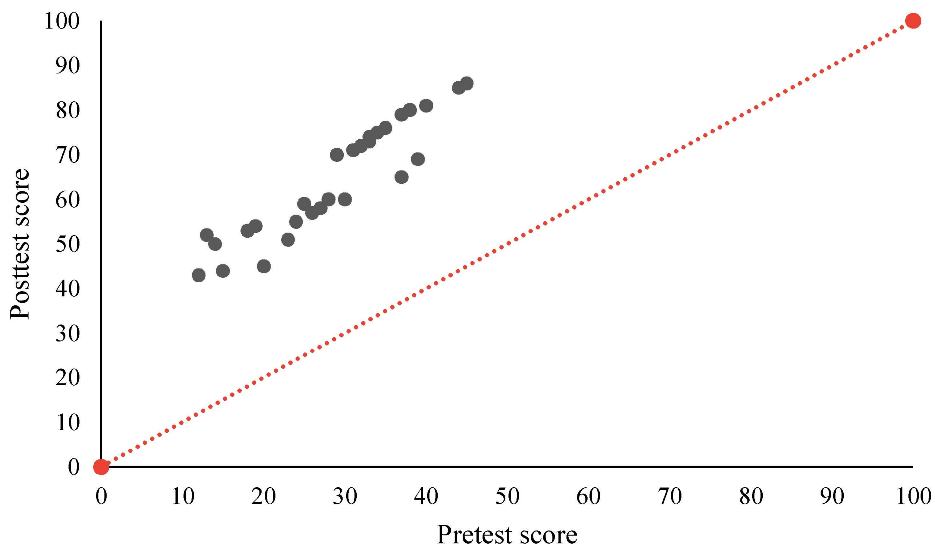

Figure 4. The score for the achievement of concept understanding

pretest scores across all indicators were uniformly low (ranging from 26% to 29%), the posttest results reveal a distinct hierarchical pattern of improvement. The highest achievement was observed in the Understanding indicator (C2) at 63.33%, followed by Applying (C3) at 60.00%, and Analyzing (C4) at 58.89%. This trend suggests that while the intervention effectively elevated students to the "Fair" category, higher-order thinking skills (C4) remain more cognitively demanding than fundamental understanding (C2).

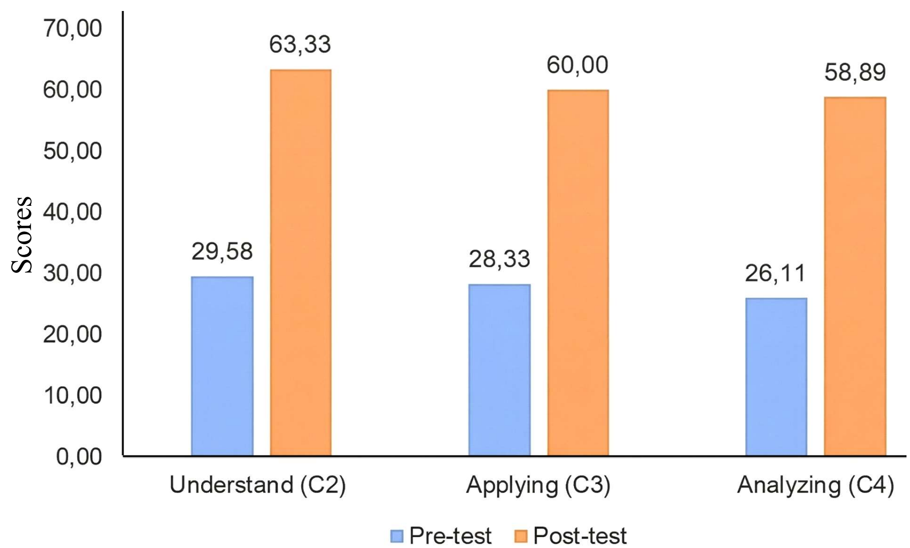

Figure 5. The score for the achievement of the sub-indicator of concept understanding

The visual nature of the mind maps successfully scaffolded the basic concepts, but the complex task of analyzing relationships (C4) naturally requires more intensive cognitive processing. This improvement demonstrates that visual mind map-based worksheets are an effective strategy for enhancing understanding of science concepts. According to (Alfieri et al., 2011)The discovery learning model improves students' understanding. In addition to the discovery learning model, evidence suggests that mind-map-based worksheet media can enhance understanding of concepts.

The observed improvement can be explained through Dual Coding Theory and Cognitive Load Theory. According to Dual Coding Theory (Conklin, 2005), the human brain processes information through two distinct channels: verbal and visual. The Visual Mind Map Worksheets leverage this by presenting information not just textually but also spatially and graphically (colors, branches) (Astriani et al., 2020). This dual input creates stronger memory traces and facilitates easier retrieval of concepts compared to text-only learning. Furthermore, in Discovery Learning, unguided exploration often leads to cognitive overload. Here, the worksheet acts as a scaffold that manages Cognitive Load (Mayer, 2002). By organizing scattered information into a structured visual hierarchy, the worksheets reduce extraneous cognitive load, allowing students to allocate their working memory resources toward germane load, the actual processing and schema construction of the digestive system (Serevina & Heluth, 2022). This mechanism explains why students could better synthesize complex biological processes into a coherent understanding.

Table 9. The result of the paired t-test on student understanding of concepts

Parameters	Testing	df	Sig.	Average	P-value/sig. (2-tailed)
Understanding of concepts	Pretest	28	.052	6.04	0.000
	Posttest	28	.059	13.04	

Based on statistical results using a paired t-test, the P-value was 0.000, indicating a significant difference (Table 9). These results show that a visual mind map-based worksheet can improve the understanding of science concepts among eighth-grade students at Asa Cendekia Junior High School, as evidenced by higher post-test scores than pre-test scores. According to Balim (2009), the discovery model and inquiry learning skills help students improve their understanding of the material taught. This is in line with Dwijayanti et al. (2020), students who learn through mind mapping-based discovery learning demonstrate stronger critical thinking skills in the indicators of interpretation, analysis, evaluation, and explanation. According to Serevina & Heluth (2022), using interactive mind-mapping worksheets in the learning process is highly effective in engaging students and making learning more interactive, resulting in significantly better student learning outcomes. The explanation above demonstrates how mind map-based worksheet learning media can improve concept understanding among eighth-grade students at Asa Cendekia Junior High School. Another possibility is that the compatibility of mind map-based worksheet learning media and the discovery learning model enhances concept understanding. The N-gain scores for each concept understanding indicator (Table 10) demonstrate the effectiveness of the mind map-based worksheet and the discovery learning model on students' concept understanding. According to Van Joolingen's (1999) criteria, all indicators tested (C2, C3, and C4) demonstrated an increase in concept understanding in the moderate (effective) category, ranging from 0.3 to 0.7. Although the category is "Medium," this indicates a substantial improvement compared to the baseline. This result is consistent with Dwijayanti et al. (2020), who found that mind-mapping-based discovery learning effectively fosters critical thinking skills (interpretation and analysis), elevating students' capabilities from a low starting point to a moderate level of mastery. Thus, while not yet in the "High" category, the intervention successfully facilitated a meaningful transition in students' cognitive abilities (AL Subaie, 2025). This demonstrates that the mind map worksheet and the discovery learning model work well together to enhance students' understanding of science concepts.

Table 10. The result of the N-gain score on student understanding of concepts

Indicator	N-gain/Mean	Category
C2 (Understand)	0.635	Medium
C3 (Apply)	0.416	Medium
C4 (Analyze)	0.444	Medium

Cognitive Mechanisms of Mind Mapping in Concept Understanding

The significant improvement in students' conceptual understanding is driven by specific cognitive mechanisms facilitated by the unique features of mind mapping. According to Paivio's Dual Coding Theory, the integration of text and imagery activates two distinct neural subsystems (Amaral et al., 2025). The verbal system processes keywords while the non-verbal system processes colors and central images, creating strong referential connections that enhance memory retention beyond what linear text can achieve.

Furthermore, the hierarchical branching structure directly supports Ausubel's Meaningful Learning Theory (Mayer, 2002). This feature compels students to identify superordinate concepts and link them to subordinate details through subsumption, ensuring that new biological information is logically anchored to existing cognitive structures. From the perspective of Sweller's Cognitive Load Theory, breaking down complex physiological processes into keywords acts as a chunking mechanism (Van Joolingen, 1999). This transformation of dense text into organized visual units effectively reduces extraneous cognitive load, thereby freeing up working memory capacity for the essential processing required to master abstract concepts.

Study Limitations

While this study demonstrates the feasibility and potential effectiveness of the Visual Mind Map Worksheets, several limitations must be acknowledged. First, as a development study primarily focused on product validation and initial feasibility (a limited trial), the sample size was limited to a single class of 28 students. Consequently, the statistical results should be interpreted as an indication of the product's potential rather than a comprehensive generalization for all student populations. Second, the study was conducted in a specific school setting with homogenous demographic characteristics. Future research should involve a larger sample size across multiple schools and use a quasi-experimental design with a control group to provide more robust empirical evidence on the intervention's wide-scale effectiveness.

■ CONCLUSION

This study successfully developed Visual Mind Map Worksheets utilizing the 4-D instructional design model to facilitate Discovery Learning on digestive system topics. Based on the empirical evidence, the developed product demonstrates robust feasibility for educational implementation. The validity was confirmed by subject-matter experts and practitioners, who awarded a "Very Valid" rating (score of 3.9), ensuring alignment with curriculum standards. Furthermore, the practicality of the worksheets was evidenced by a 98% implementation rate of the learning syntax, indicating that the material effectively guides classroom activities. Regarding effectiveness, while statistical analysis confirmed a significant improvement in students' conceptual understanding ($p < 0.05$), it is crucial to note that the magnitude of this improvement (N-gain) fell within the "Medium" category. This suggests that while the Visual Mind Map Worksheets are a statistically significant tool for scaffolding learning and enhancing engagement, they function primarily as a facilitator of conceptual progression. Consequently, the product is declared feasible for use, although future iterations or longitudinal implementation may be required to elevate the effectiveness to a higher category.

DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

During the final preparation of this manuscript, the authors used DeepL and Grammarly to refine the text's linguistic clarity and grammatical accuracy. The authors reviewed all suggestions provided by the software and assume full responsibility for the final version of the article.

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