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Multimedia Material in Developing Conceptual Understanding of The Mendelian Genetics Principles

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ABSTRACT

This study investigated the effectiveness of infographic-based multimedia materials in developing students' conceptual understanding of Mendelian genetics, particularly the Laws of Dominance, Segregation, and Independent Assortment. Using a sequential explanatory mixed-methods research design, the study involved 38 Grade 8 students at General Climaco National High School in Toledo City during School Year 2021–2022. The investigation examined students' conceptual understanding before and after the instructional intervention, considered learning performance across lower-order and higher-order thinking skills, and evaluated the quality of the infographics based on Biology teachers' assessments. Guided by the Cognitive Theory of Multimedia Learning, the instructional materials integrated textual explanations and visual representations to facilitate understanding of abstract genetic concepts. The study also examined areas requiring improvement in the multimedia materials to inform the development of an enhanced teaching-learning instructional guide. The investigation addressed the instructional challenges associated with genetics education and the potential of infographics to support conceptual learning. Its educational significance lies in informing the development of visually organized, cognitively appropriate instructional materials that respond to students' learning needs. The study contributes to Sustainable Development Goal 4 (Quality Education) by examining an instructional approach intended to improve access to meaningful and effective science learning.

Keywords: *Conceptual Understanding, Cognitive Theory of Multimedia Learning, Grade 8 Students, Infographics, Mendelian Genetics, Mixed-Methods Research, Multimedia Instruction, Science Education*

INTRODUCTION

Genetics is a fundamental field of biology that explains heredity, variation, and the transmission of characteristics across generations. Despite its importance, genetics remains challenging for secondary school learners because of its abstract concepts, specialized terminology, and biological processes that cannot be directly observed. Previous studies identified persistent difficulties in understanding genetic principles and relating them to everyday experiences (Lewis & Wood-Robinson, 2000; Wynne, Stewart, & Passmore, 2001; Marbach-Ad & Stavy, 2000; Cakır & Crawford, 2001; Law & Lee, 2004). These challenges are associated with the abstract nature of genetic processes and learners' limited ability to connect microscopic structures with observable phenomena (Venville, 2002; Corebima, 2009; Tsui & Treagust, 2003).

Mendelian genetics encompasses three fundamental principles: the Law of Dominance, Law of Segregation, and Law of Independent Assortment. Understanding these principles requires students to interpret genetic information, recognize inheritance patterns, and apply concepts to genetic crosses. However, instruction that relies primarily on verbal explanations and text-based materials may limit learners' ability to visualize complex genetic relationships. Developing both lower-order thinking skills (LOTS) and higher-order thinking skills (HOTS) is therefore essential to achieving meaningful conceptual understanding.

Multimedia-supported instruction offers opportunities to present abstract biological concepts through words, illustrations, diagrams, and other visual representations. Research suggests that multimedia materials can facilitate comprehension and meaningful learning (Najjar, 1996; Jereb & Šmitek, 2006). Visual representations and animations can also make complex biological processes more accessible (Höffler & Leutner, 2007; Mayer et al., 2005). Among these instructional materials, infographics integrate textual and visual information to communicate complex concepts in an organized and accessible format (Smiciklas, 2012; Newsom & Haynes, 2004). Their educational relevance is supported by research emphasizing the importance of multiple representations in scientific communication and learning (Demirbag & Gunel, 2014; Namdar & Shen, 2016).

The effectiveness of multimedia instruction depends on appropriate instructional design. Mayer's Cognitive Theory of Multimedia Learning (CTML) explains that meaningful learning occurs when learners actively process and integrate verbal and visual information. Its dual-channel, limited-capacity, and active-processing assumptions emphasize the importance of organizing instructional content to minimize unnecessary cognitive demands and facilitate knowledge integration (Mayer & Moreno, 2003; Mayer, 2009). Guided by these principles, infographics may support students' understanding of Mendelian genetics by

presenting essential terminology, genetic relationships, and practical examples through coordinated textual and visual explanations.

Although multimedia learning has been examined in science education, further investigation is needed to determine how infographics support students' conceptual understanding of specific Mendelian genetics principles across different cognitive levels. Evaluating students' initial and final understanding, together with teachers' assessments of instructional material quality, can identify learning difficulties and areas requiring improvement. Accordingly, this study investigated the effect of infographics on the conceptual understanding of Mendelian genetics among 38 Grade 8 students at General Climaco National High School, Toledo City, during School Year 2021–2022. Using a sequential explanatory mixed-methods design, the study examined students' understanding before and after the intervention, evaluated infographic quality through Biology teachers, and identified refinements for developing an enhanced multimedia teaching-learning instructional guide. The findings provide insights into the use of visual instructional materials to support conceptual understanding and contribute to Sustainable Development Goal 4 (Quality Education) by informing approaches to improving science instruction.

Research Problem

Developing conceptual understanding of Mendelian genetics remains challenging among secondary school students because of the abstract nature of inheritance principles and difficulties in connecting genetic concepts with observable biological phenomena. Students frequently experience misconceptions involving genes, alleles, and inheritance patterns, limiting their ability to apply scientific knowledge beyond basic recall. Machová and Ehler (2023) identified persistent misconceptions affecting students' understanding of genetic information, while Ojo (2024) reported that only 21.4% of 789 secondary school students demonstrated conceptual understanding, with 51.0% exhibiting misconceptions. Similarly, Focant, Rezsohazy, and De Kesel (2025) emphasized that oversimplified and insufficiently contextualized instruction may contribute to persistent misunderstandings in genetics.

Infographics offer a potential instructional approach by integrating concise explanations, illustrations, and visual representations to clarify complex genetic concepts. However, their effectiveness depends on appropriate multimedia design and their capacity to support different cognitive levels. Further investigation is needed to determine whether infographic-based instruction improves students' understanding of the Law of Dominance, Law of Segregation, and Law of Independent Assortment, particularly in lower-order thinking skills (LOTS) and higher-order thinking skills (HOTS).

This study addressed these concerns by examining the initial and final conceptual understanding of 38 Grade 8 students at General Climaco National High School, Toledo City, during School Year 2021–2022. Using a sequential explanatory mixed-methods design, the study evaluated changes in students' understanding following infographic-based instruction, assessed the instructional quality of the materials through Biology teachers, and identified necessary refinements. The findings served as the basis for developing an enhanced multimedia teaching-learning instructional guide intended to strengthen conceptual understanding of Mendelian genetics.

Assumptions of the Study

This study was anchored on the following assumptions:

1. The Grade 8 students possess prior knowledge and learning experiences that may influence their initial understanding of Mendelian Genetics Principles.
2. The students will respond honestly and to the best of their ability to the Concept Inventory Test, interviews, and focus group discussions.
3. The infographics, when properly designed and utilized, can help present abstract Mendelian genetics concepts through organized text and visual representations, thereby supporting students' conceptual understanding.
4. The Concept Inventory Test is an appropriate instrument for assessing students' understanding of the Law of Dominance, Law of Segregation, and Law of Independent Assortment in terms of lower-order thinking skills (LOTS) and higher-order thinking skills (HOTS).
5. The Biology teachers have sufficient knowledge and experience to evaluate the instructional quality of the infographics using the Multimedia Material Design Quality Scale.
6. The students' responses and assessment results, together with the teachers' evaluations, will provide relevant information for identifying the strengths and areas for improvement of the infographics.

Objectives of the Study

This study aimed to determine the effect of infographics on Grade 8 students' conceptual understanding of Mendelian genetics principles at General Climaco National High School, Toledo City, during School Year 2021–2022, as a basis for developing an enhanced multimedia material as a teaching-learning instructional guide.

Specifically, the study sought to:

1. Assess students' initial conceptual understanding of the Laws of Dominance, Segregation, and Independent Assortment.

2. Describe the development and utilization of infographics to enhance students' initial conceptual understanding of Mendelian genetics principles.
3. Evaluate the quality of the developed infographics as perceived by Biology teachers.
4. Determine students' final conceptual understanding of the three Mendelian genetics principles after using the infographics.
5. Examine changes in students' conceptual understanding before and after learning through infographics.
6. Identify necessary refinements to the infographics based on the study findings.
7. Propose an enhanced multimedia material as a teaching-learning instructional guide based on the findings of the study.

Conceptual or Theoretical Framework

This study was anchored on Mayer's (2009) Cognitive Theory of Multimedia Learning (CTML), which explains how individuals learn through the integration of verbal and visual information. The theory is based on three assumptions: dual-channel processing, limited cognitive capacity, and active learning. Dual-channel processing suggests that learners process verbal and visual information through separate channels, while limited capacity recognizes that each channel can process only a restricted amount of information at a given time. Active learning occurs when learners select, organize, and integrate relevant information with their existing knowledge.

Guided by this theory, the study utilized infographics to present Mendelian genetics principles through coordinated textual explanations, illustrations, and diagrams. The instructional materials were designed to facilitate students' understanding of the Laws of Dominance, Segregation, and Independent Assortment while reducing unnecessary cognitive demands. Mayer's (2009) multimedia learning principles provided the theoretical basis for organizing instructional content and evaluating the quality of the developed materials. Figure 1 illustrates Mayer's Cognitive Theory of Multimedia Learning, which served as the theoretical foundation for developing the infographic-based instructional materials.

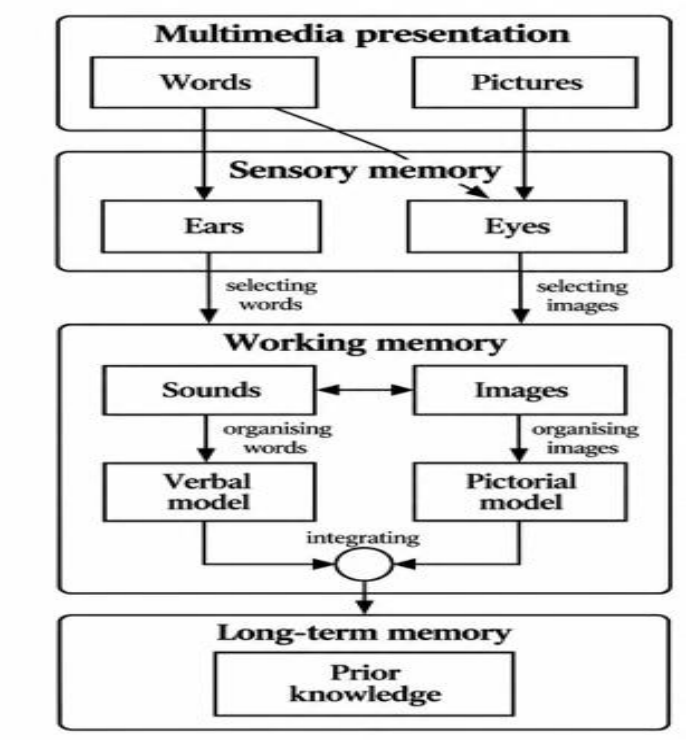


Figure 1. Cognitive Theory of Multimedia Learning

The study also adopted an Input–Process–Output (IPO) conceptual framework. The input consisted of students' prior knowledge and initial conceptual understanding of Mendelian genetics, particularly their lower-order thinking skills (LOTS) and higher-order thinking skills (HOTS), together with the theoretical principles guiding infographic development. The process involved administering the pretest, developing and implementing the infographics, evaluating their quality through Biology teachers, conducting the posttest, and gathering qualitative information through interviews and focus group discussions. The findings were analyzed to determine changes in conceptual understanding and identify areas requiring instructional improvement.

The output was a proposed enhanced multimedia material as a teaching-learning instructional guide for Mendelian genetics. This framework established the relationship between students' initial understanding, infographic-based instruction, assessment outcomes, and instructional refinement. It guided the investigation of how multimedia materials could support conceptual learning and inform improvements in science instruction. Figure 2 presents the Input–Process–Output (IPO) conceptual framework, illustrating the relationship among students' initial conceptual understanding, infographic-based instruction, assessment procedures, and the proposed enhanced multimedia teaching-learning instructional guide.

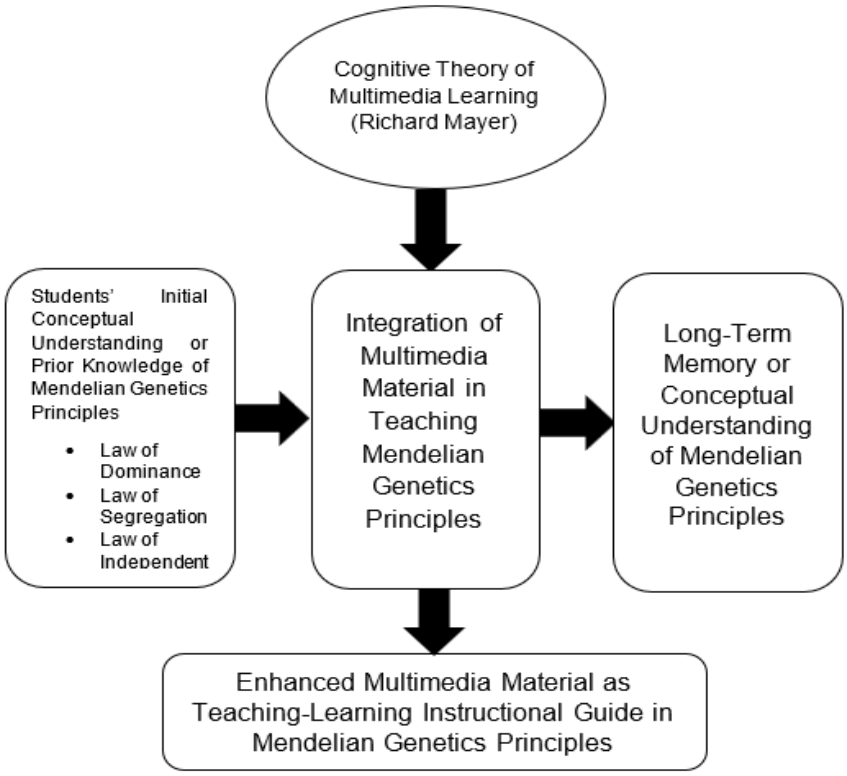


Figure 2. Conceptual Framework of the Study

METHODOLOGY

Research Design

This study employed a sequential explanatory mixed-methods research design (QUAN → qual) to investigate the use of infographics in developing Grade 8 students' conceptual understanding of Mendelian genetics. The quantitative phase utilized a single-group pretest–posttest approach to assess students' understanding of the Laws of Dominance, Segregation, and Independent Assortment before and after infographic-based instruction. The qualitative phase involved interviews and focus group discussions to provide further explanations of students' learning experiences and assessment results.

The integration of quantitative and qualitative approaches enabled the study to examine changes in conceptual understanding while exploring students' experiences with the instructional materials. Mixed-methods research allows different forms of evidence to contribute to a more comprehensive understanding of an educational problem (Maxwell, 2016; Tashakkori and Teddlie, 2010; Enosh et al., 2014; Creswell, 2003). Quantitative data were obtained through the Concept Inventory Test and teachers' evaluations of infographic quality, while qualitative information was gathered to explain learning difficulties and identify necessary instructional refinements. The findings from both phases informed the

development of an enhanced multimedia material as a teaching-learning instructional guide for Mendelian genetics.

Research Locale or Study Setting

The study was conducted at General Climaco National High School in Toledo City, Cebu, Philippines, during School Year 2021–2022. The school had a population of 1,593 students and 54 teachers. It served as the research setting for investigating the use of infographic-based instructional materials in developing Grade 8 students' conceptual understanding of Mendelian genetics. During the study period, the school implemented printed modular distance learning because of limited internet connectivity and restrictions associated with the COVID-19 pandemic. Learning modules were distributed and retrieved weekly, particularly on Tuesdays. These instructional conditions provided the context for utilizing printed infographics as supplementary learning materials. The setting was relevant to the study because it allowed the researchers to examine students' conceptual understanding of Mendelian genetics using visual instructional materials within an existing modular learning environment.

Participants or Data Sources

The study involved 38 Grade 8 students and three Biology teachers from General Climaco National High School in Toledo City, Cebu, during School Year 2021–2022. The student participants were purposively selected from seven Grade 8 sections comprising 239 enrolled students. Selection considered their availability and ability to participate in the study under the prevailing COVID-19 restrictions and printed modular learning arrangements. The 38 students participated in the pretest and posttest assessments of their conceptual understanding of Mendelian genetics, while qualitative information was gathered through interviews and focus group discussions. The three Biology teachers evaluated the instructional quality of the developed infographics using the Multimedia Material Design Quality Scale. Their assessments provided additional information for identifying the strengths and areas requiring refinement of the instructional materials.

Research Instruments or Materials

The study utilized four research instruments and instructional materials to assess students' conceptual understanding of Mendelian genetics and evaluate the developed multimedia material: the Concept Inventory Test, enhanced multimedia teaching-learning instructional guide, interview protocol, and Multimedia Material Design Quality Scale.

Concept Inventory Test on Mendelian Genetics Principles: The instrument assessed students' conceptual understanding before and after using the multimedia material. Concept inventory tests measure conceptual knowledge and identify misconceptions (Garvin-Doxas et al., 2007). The 15-item test was adapted from the DepEd Science 8 Quarter

4, Module 4 Self-Learning Module, with items classified according to Bloom's Taxonomy. Six items assessed lower-order thinking skills (LOTS) under Remembering and Understanding, while nine assessed higher-order thinking skills (HOTS), comprising six items under Applying and Analyzing and three under Evaluating and Creating. The items were equally distributed across the Laws of Dominance, Segregation, and Independent Assortment, with five items per principle. The researcher classified the existing DepEd assessment items according to their cognitive demands rather than developing new questions.

Enhanced Multimedia Material of the Mendelian Genetics Principles as Teaching–Learning Instructional Guide: The instructional material covered Grade 8 Mendelian genetics principles during the fourth quarter. It was anchored on Richard Mayer's Cognitive Theory of Multimedia Learning and guided by his 12 principles of multimedia design. The material was aligned with the content standards, performance standards, and learning competencies prescribed in the DepEd K to 12 curriculum.

Interview Protocol: Individual interviews and focus group discussions explored students' learning experiences and conceptual understanding before and after using the multimedia material. Interview questions were developed based on the quantitative findings to clarify participants' responses, perceptions, and observed changes in their understanding of Mendelian genetics.

Multimedia Material Design Quality Scale: The developed infographics were evaluated using an instrument adapted from Siricharoen (2015), incorporating Mayer's 12 principles of multimedia design. Three Biology teachers assessed the instructional quality of the material to identify its strengths and areas requiring improvement in supporting conceptual understanding.

Data Gathering Procedure

The data gathering procedure consisted of four phases: preliminary preparation, development of instructional materials, implementation, and evaluation.

Preliminary Phase: The researcher secured permission from the school administration and coordinated with the participating Biology teachers. The 38 Grade 8 students were identified, and the Concept Inventory Test was administered one week before the intervention to assess their initial conceptual understanding of the Laws of Dominance, Segregation, and Independent Assortment. Initial interviews were also conducted to identify students' learning difficulties.

Development Phase: Infographics covering the three Mendelian genetics principles were developed using Canva, guided by Mayer's Cognitive Theory of Multimedia Learning and

relevant multimedia design principles. The materials incorporated textual explanations, illustrations, diagrams, and examples aligned with the Grade 8 Science curriculum. Three Biology teachers evaluated the developed infographics using the Multimedia Material Design Quality Scale to identify their strengths and areas requiring improvement.

Implementation Phase: The researcher oriented the participating students on the use of the infographics as supplementary instructional materials. The infographics were distributed during the school's scheduled Tuesday module distribution under the printed modular learning arrangement. Students used the materials to study Mendelian genetics, and completed learning activities were collected during the following weekly retrieval schedule.

Evaluation Phase: After the intervention, the Concept Inventory Test was administered as a posttest to determine students' final conceptual understanding. Individual interviews and focus group discussions were conducted to clarify the quantitative findings and explore students' learning experiences. The pretest and posttest results, qualitative responses, and Biology teachers' evaluations were examined to identify conceptual changes and necessary refinements. These findings informed the proposed enhanced multimedia material as a teaching-learning instructional guide.

Data Analysis

The study employed quantitative and qualitative data analysis to determine changes in students' conceptual understanding of Mendelian genetics and evaluate the quality of the developed infographics.

Descriptive Statistics: Frequency, percentage, mean, and standard deviation were used to summarize students' pretest and posttest performance across the Laws of Dominance, Segregation, and Independent Assortment. The results were classified according to lower-order thinking skills (LOTS) and higher-order thinking skills (HOTS). Mean scores were also used to describe the three Biology teachers' evaluations of infographic quality using the five-point Multimedia Material Design Quality Scale.

Paired-Samples t-Test: A paired-samples t-test was employed to determine whether significant differences existed between students' pretest and posttest scores for each Mendelian genetics principle and cognitive level. Statistical significance was evaluated at the 0.05 level.

Effect Size. Cohen's d was calculated to determine the magnitude of the differences between pretest and posttest performance, supplementing the statistical significance results.

Qualitative Analysis: Responses from individual interviews and focus group discussions were examined to identify students' conceptual difficulties, learning experiences, and perceptions of the infographics. The qualitative findings were used to explain the quantitative results and identify necessary instructional refinements.

Data Processing: Quantitative data were processed using the Statistical Package for the Social Sciences (SPSS). The quantitative and qualitative findings were integrated to inform the proposed enhanced multimedia material as a teaching-learning instructional guide for Mendelian genetics.

Ethical Considerations

The study was conducted with permission from the school administration of General Climaco National High School in Toledo City, Cebu, Philippines, and with parental consent for the participation of the 38 Grade 8 students. Confidentiality was maintained throughout the collection and analysis of data obtained from the Concept Inventory Test, individual interviews, and focus group discussions. The research procedures were carried out in accordance with the applicable institutional requirements of the school and Cebu Technological University. The researcher acknowledged the participating students, Biology teachers, and school administration for their cooperation and contributions to the study.

RESULTS AND DISCUSSION

Students' Initial Conceptual Understanding of the Mendelian Genetics Principles

Table 1 presents the initial conceptual understanding of 38 Grade 8 students regarding the Laws of Dominance, Segregation, and Independent Assortment, classified according to lower-order thinking skills (LOTS) and higher-order thinking skills (HOTS). The results revealed generally low to average performance, with greater difficulties in applying and analyzing genetic concepts than in recalling basic information.

Table 1. Students' Initial Conceptual Understanding of the Mendelian Genetics Principles

Principles	Level of Questioning	Scores	f	%	x̄	SD	Descriptor
Law of Dominance	HOTS	3	1	2	0.55	0.77	Low Performing
		2	3	8			
		1	34	90			
	LOTS	2	0	0	0.71	0.46	Average Performing
		1	27	71			
		0	11	29			

Law of Segregation	HOTS	3	2	5	1.03	0.91	Low Performing
		2	10	26			
		1	26	69			
	LOTS	2	3	8	0.53	0.65	Low Performing
		1	14	37			
		0	21	55			
Law of Independent Assortment	HOTS	3	0	0	0.61	0.59	Low Performing
		2	2	5			
		1	36	95			
	LOTS	2	13	34	1.24	0.63	Average Performing
		1	21	55			
		0	4	11			
Average	HOTS				0.73	0.76	Low Performing
	LOTS				0.83	0.58	Average Performing

Legend: HOTS: 2.01 - 3 High Performing, 1.01 – 2 Average Performing, 0 – 1 Low Performing
LOTS: 1.34 – 2 High Performing, 0.68 – 1.33 Average Performing, 0 – 0.67 Low Performing

For the Law of Dominance, students obtained an average LOTS performance (M = 0.71, SD = 0.46) but low HOTS performance (M = 0.55, SD = 0.77). Most students (90%) were classified as low-performing in HOTS, indicating difficulties interpreting genetic crosses and genotype–phenotype relationships. Although some recognized basic genetic symbols, misconceptions concerning dominant and recessive alleles remained evident (Lewis & Wood-Robinson 2000; Panoutsopoulou & Wheeler, 2018; Abraham et al., 2014; Gusmalini et al., 2020). Difficulties identifying homozygous recessive genotypes and predicting phenotypic expressions reflected incomplete understanding of genetic notation and allele interactions (Abraham et al., 2014; Smith & Knight, 2016; Hillis et al., 2019; Smith & Knight, 2012). These findings were consistent with research identifying persistent misconceptions about dominance and genotype–phenotype relationships (Machová & Ehler, 2021; Nurputri & Kartikawati, 2023).

For the Law of Segregation, students demonstrated low performance in LOTS (M = 0.53, SD = 0.65) and HOTS (M = 1.03, SD = 0.91). Approximately 55% were low-performing in LOTS, while 69% were low-performing in HOTS. Students encountered difficulties explaining allele separation during gamete formation, identifying alleles in diploid organisms, predicting offspring traits, and interpreting Punnett squares. These difficulties reflected misconceptions involving genes, alleles, chromosomes, and inheritance processes (Awang-Kanak et al., 2016; Kılıç Mocan, 2021). Similar challenges in applying segregation principles to genetic probability and inheritance problems were reported by Machová and

Ehler (2021), particularly when students were required to integrate multiple genetic concepts (Machová & Ehler, 2021; Awang-Kanak et al., 2016).

For the Law of Independent Assortment, students obtained an average LOTS performance (M = 1.24, SD = 0.63) but low HOTS performance (M = 0.61, SD = 0.59). While 34% demonstrated high performance in LOTS, 95% were classified as low-performing in HOTS. Students experienced difficulties distinguishing independent assortment from other Mendelian principles, interpreting dihybrid crosses, and predicting offspring genotypes and phenotypes. These findings reflected challenges in coordinating multiple inheritance patterns and applying genetic probability (Lewis & Wood-Robinson, 2000; Duncan & Reiser, 2007). Previous research similarly indicated that students may recognize genetic concepts without demonstrating sufficient understanding to apply them in complex problems (Smith et al., 2008; Lewis & Kattmann, 2004). Difficulties with dihybrid Punnett squares further suggested limitations in connecting procedural calculations with conceptual understanding (Tan & Treagust, 1999; Duncan & Reiser, 2007). Overall, the initial assessment revealed substantial conceptual difficulties across the three Mendelian genetics principles, particularly in HOTS. These findings provided the basis for developing infographic-based instructional materials that clarified genetic terminology, illustrated inheritance processes, and presented guided examples of genetic crosses.

Developing and Using of Infographics to Enhance Students' Initial Conceptual Understanding of the Mendelian Genetics Principles

The initial assessment identified conceptual difficulties that informed the development of infographic-based instructional materials. Multimedia resources can help simplify abstract scientific concepts and present complex information in accessible formats (Ministry of National Education, 2007; Koning, et al., 2009; Siagian, et al., 2014). Infographics combine textual and visual information to support comprehension, while effective multimedia design requires appropriate integration of verbal and visual elements (Panian, 2005; Ware, 2012; Bull, 2013). The researcher developed printed infographics using eight applicable principles from Mayer's (2009) multimedia design framework: multimedia, spatial contiguity, temporal contiguity, coherence, individual differences, signaling, segmenting, and pre-training. The modality, redundancy, voice, and image principles were not incorporated because the materials were static and intended for printed modular instruction.

Multimedia Principle: Textual explanations were combined with relevant illustrations to clarify abstract concepts, particularly genotype–phenotype relationships and inheritance patterns. Visuals were selected to address difficulties identified during the initial assessment rather than merely decorate the instructional material. This approach followed the principle that learners benefit from coordinated words and pictures (Bull, 2013). Spatial Contiguity Principle. Related explanations and illustrations were positioned close to one

another, allowing students to associate genetic terminology with corresponding visual representations. This arrangement reduced the need to search across different sections and supported the interpretation of genotype–phenotype relationships (Sorden, 2012).

Temporal Contiguity Principle: Corresponding words and graphics were presented together on the same page, allowing students to examine explanations and visual representations simultaneously. This arrangement was intended to facilitate connections between related information (Sorden, 2012).

Coherence Principle: Unnecessary decorations, unrelated illustrations, and excessive information were excluded to maintain attention on essential concepts. Relevant examples and uncluttered layouts were used to reduce potential distractions during learning (Sorden, 2012).

Individual Differences Principle: Familiar and conversational language was used to explain technical concepts, including genotype and phenotype. Simple illustrations were incorporated to make the materials more accessible and engaging while maintaining their instructional purpose (Sorden, 2012).

Signaling Principle: Arrows, colors, labels, and callouts emphasized important concepts and guided students through genetic crosses. Visual cues were particularly useful in presenting Punnett squares and the FOIL method for determining allele combinations in dihybrid crosses (Sorden, 2012).

Segmenting Principle: The content was divided into manageable sections, with separate presentations for the Laws of Dominance, Segregation, and Independent Assortment. Monohybrid and dihybrid crosses were explained through sequential procedures and examples, allowing students to examine one concept before proceeding to another (Mayer, 2009).

Pre-Training Principle: Essential terminology and foundational concepts were introduced before complex genetic problems. Each principle included a “Remember” section to reinforce important information before students proceeded to examples and applications (Mayer, 2009). The organized presentation was intended to support information processing and retention, consistent with established explanations of memory and visual learning (Atkinson & Shiffrin, 1968; Dzulkifli & Mustafar, 2013). Collectively, these principles guided the development of infographics that addressed students’ identified misconceptions through concise explanations, relevant illustrations, and structured learning activities. The materials were designed to support conceptual understanding within the printed modular learning environment.

Qualities of the Infographics as Perceived by the Biology Teachers

Table 2 presents the evaluations of three Biology teachers regarding the quality of the developed infographics based on eight applicable multimedia design principles. The overall weighted mean was 4.63, interpreted as Strongly Agree, indicating favorable teacher assessments of the instructional materials.

Table 2. Multimedia Material Design Quality Scale

Principles of Designing Multimedia Material	Weighted Mean	Standard Deviation	Verbal Description
1. Multimedia Principle	5.00	0	Strongly Agree
2. Spatial Principle	4.50	0.54	Strongly Agree
3. Temporal Contiguity	4.63	0.52	Strongly Agree
4. Coherence Principle	4.63	0.52	Strongly Agree
5. Individual Difference Principle	4.50	0.54	Strongly Agree
6. Signaling Principle	4.88	0.35	Strongly Agree
7. Segmenting Principle	4.50	0.54	Strongly Agree
8. Pre-training Principle	4.88	0.35	Strongly Agree
General Weighted Mean and SD	4.63	2.14	Strongly Agree

Legend: 4.20 – 5 Strongly Agree, 3.40 – 4.19 Agree, 2.60 – 3.39 Neutral, 1.80 – 2.59 Disagree, 1.00 – 1.79 Strongly Disagree

The Multimedia Principle obtained the highest mean (M = 5.00, SD = 0.00), reflecting unanimous agreement that textual and visual elements were appropriately integrated. The Spatial Contiguity Principle received a mean of 4.50 (SD = 0.54), indicating favorable evaluations of the placement of related text and images. However, teachers identified instances where closer positioning could improve clarity (R. J. M. Balataria, personal communication, June 26, 2022; R. Ferrer, personal communication, June 26, 2022).

The Temporal Contiguity and Coherence Principles each obtained a mean of 4.63 (SD = 0.52), suggesting that related explanations and visuals were presented together and that unnecessary information was generally minimized. The Individual Differences Principle received a mean of 4.50 (SD = 0.54). Teachers appreciated the conversational language and engaging illustrations but recommended simplifying certain terms and limiting potentially

distracting visual elements (C.J. Butlig, personal communication, June 26, 2022; R. Ferrer, personal communication, June 26, 2022; R.J.M. Balataria, personal communication, June 26, 2022).

The Signaling Principle obtained a mean of 4.88 (SD = 0.35), reflecting favorable assessments of visual cues emphasizing important concepts. The Segmenting Principle received a mean of 4.50 (SD = 0.54), indicating that organizing lessons into smaller sections supported clarity. Nevertheless, teachers recommended improving transitions, simplifying multistep instructions, and adding clearer headings (R. Ferrer, personal communication, June 26, 2022; R. J. M. Balataria, personal communication, June 26, 2022; C.J. Butlig, personal communication, June 26, 2022). The Pre-Training Principle also obtained a mean of 4.88 (SD = 0.35), indicating favorable evaluations of the introductory explanations and terminology presented before complex activities. Overall, the teachers considered the infographics well designed according to the selected multimedia principles. Their evaluations also identified opportunities to improve textual clarity, visual organization, and instructional sequencing.

Students' Final Conceptual Understanding of the Mendelian Genetics Principles

Table 3 presents students' final conceptual understanding following the implementation of the infographic-based instructional materials. The results indicate varying performance across the three Mendelian genetics principles, with generally higher scores in LOTS than in HOTS.

Table 3. Students' Final Conceptual Understanding of the Mendelian Genetics Principles

Principles	Level of Questioning	Scores	f	%	x̄	SD	Descriptor
Law of Dominance	HOTS	3	2	5	1.00	0.87	Low Performing
		2	8	21			
		1	28	74			
	LOTS	2	14	37	1.32	0.57	Average Performing
		1	22	58			
		0	2	5			
Law of Segregation	HOTS	3	6	16	1.18	1.11	Average Performing
		2	9	23			
		1	23	61			
	LOTS	2	5	13	0.68	0.70	Average Performing
		1	16	42			
		0	17	45			
Law of Independent Assortment	HOTS	3	1	3	0.97	0.88	Low Performing
		2	11	29			
		1	26	68			

	LOTS	2	20	53	1.45	0.65	High Performing
		1	15	39			
		0	3	8			
Average	HOTS				1.05	0.95	Average Performing
	LOTS				1.15	0.64	Average Performing

Legend: HOTS: 2.01 - 3 High Performing, 1.01 – 2 Average Performing, 0 – 1 Low Performing
LOTS: 1.34 – 2 High Performing, 0.68 – 1.33 Average Performing, 0 – 0.67 Low Performing

For the Law of Dominance, students obtained a mean of 1.32 (SD = 0.57) in LOTS, indicating average performance, and 1.00 (SD = 0.87) in HOTS, indicating low performance. Approximately 37% demonstrated high performance in LOTS, while 74% remained low-performing in HOTS. These findings indicated stronger performance in basic conceptual questions than in tasks requiring interpretation and application.

For the Law of Segregation, students obtained average performance in both LOTS (M = 0.68, SD = 0.70) and HOTS (M = 1.18, SD = 1.11). However, 45% remained low-performing in LOTS and 61% in HOTS, suggesting continued difficulties in understanding allele separation and applying inheritance principles to genetic problems.

For the Law of Independent Assortment, students achieved high performance in LOTS (M = 1.45, SD = 0.65) but low performance in HOTS (M = 0.97, SD = 0.88). More than half (53%) demonstrated high LOTS performance, whereas 68% remained low-performing in HOTS. This pattern suggested that students were more successful in recognizing basic principles than in analyzing dihybrid crosses and predicting inheritance outcomes.

Overall, final assessment scores were higher than initial scores across the three Mendelian genetics principles. Nevertheless, difficulties persisted in higher-order tasks, particularly those requiring the application and integration of multiple genetic concepts. These findings indicated the need for continued instructional support and further refinement of the materials.

Changes in Students' Conceptual Understanding of the Mendelian Genetics Principles Before and After Learning Using Infographics

Table 4 presents the differences between students' initial and final conceptual understanding scores, analyzed using paired-samples t-tests at the 0.05 significance level. Cohen's d was used to determine the magnitude of the observed differences.

Table 4. Changes in Students' Conceptual Understanding of the Mendelian Genetics Principles

Principles	Level of Questioning	Mean		Std. Deviation	t value	p value	Cohen's d	Interpretation
		ICUT	FCUT					
Law of Dominance	HOTS	0.55	1.00	0.86	- 3.21	0.003	- 0.55	significant improvement
	LOTS	0.71	1.32	0.72	- 5.20	<0.001	- 0.85	significant improvement
Law of Segregation	HOTS	1.03	1.18	0.92	- 1.06	0.295	- 0.17	no significant improvement
	LOTS	0.53	0.68	0.89	- 1.10	0.279	- 0.18	no significant improvement
Law of Independent Assortment	HOTS	0.61	0.97	0.97	- 2.34	0.025	- 0.37	significant improvement
	LOTS	1.24	1.45	0.74	- 1.75	0.088	- 0.28	no significant improvement

Legend:
ICUT – Initial Conceptual Understanding Test
FCUT – Final Conceptual Understanding Test
<0.05 Significant Improvement, >0.05 no significant improvement

For the Law of Dominance, statistically significant improvements were observed in both cognitive levels. LOTS scores increased from 0.71 to 1.32, with a significant difference, $t = -5.20$, $p < .001$, and a large effect size (Cohen's $d = -0.85$). HOTS scores increased from 0.55 to 1.00, also showing a significant difference, $t = -3.21$, $p = .003$, with a moderate effect size ($d = -0.55$). These results indicated meaningful improvements in students' performance on questions involving dominance relationships and genetic interpretation.

For the Law of Segregation, LOTS scores increased from 0.53 to 0.68, but the difference was not statistically significant, $t = -1.10$, $p = .279$, with a small effect size ($d = -0.18$). Similarly, HOTS scores increased from 1.03 to 1.18 without reaching statistical significance, $t = -1.06$, $p = .295$, $d = -0.17$. These findings indicated limited measurable changes in students' understanding of segregation principles.

For the Law of Independent Assortment, HOTS scores increased significantly from 0.61 to 0.97, $t = -2.34$, $p = .025$, with a small-to-moderate effect size ($d = -0.37$). In contrast, LOTS scores increased from 1.24 to 1.45, but the difference was not statistically significant, $t = -1.75$, $p = .088$, with a small effect size ($d = -0.28$). The findings suggested improvement in students' ability to address more complex inheritance problems, although changes in basic conceptual understanding were not statistically significant.

The negative t-values and effect sizes reflected the calculation of differences as pretest minus posttest scores. Overall, statistically significant improvements occurred in three of the six assessed domains: Dominance LOTS, Dominance HOTS, and Independent Assortment HOTS. The remaining domains showed numerical increases without statistically significant differences. Because the study employed a single-group pretest–posttest design, these findings demonstrate changes associated with infographic-based instruction but do not independently establish a causal effect.'

Refinement of the Infographics Based on the Results

The assessment results and Biology teachers' evaluations identified areas requiring refinement to improve the instructional clarity and accessibility of the infographics. Although the materials received favorable quality ratings, students continued to demonstrate difficulties in applying Mendelian genetics principles, particularly in tasks involving allele segregation, genetic crosses, and inheritance probabilities.

The recommended refinements included simplifying technical terminology, reducing excessive text, improving the proximity of related explanations and illustrations, and maintaining consistency in visual presentation. These adjustments were consistent with the coherence and spatial contiguity principles, which emphasize the elimination of unnecessary information and the integration of related verbal and visual elements (Sorden, 2012; Meyer, 2009).

Additional improvements involved strengthening visual cues, particularly arrows and color-coded representations used in Punnett squares and the FOIL method. Clearer labels, more consistent instructional sequencing, and simplified step-by-step procedures were identified as necessary to support students in following genetic processes. These refinements reflected the importance of signaling and structured presentation in multimedia instruction (Sorden, 2012; Bull, 2013; Mayer, 2009).

The "Remember" sections were also identified as important instructional features for reinforcing foundational concepts before introducing more complex applications. Incorporating additional real-life examples and guided practice activities could further support students in connecting genetic terminology with inheritance patterns. These recommendations were consistent with instructional approaches emphasizing progressive learning and the management of cognitive demands (Bruner, 1966; Sweller, 2011).

The identified refinements informed the proposed enhanced multimedia material as a teaching-learning instructional guide for Mendelian genetics. Further evaluation of the

revised materials was recommended to determine whether these improvements would address the remaining conceptual difficulties, particularly in higher-order thinking skills.

General Discussion

The study concluded that infographic-based multimedia materials were associated with improvements in Grade 8 students' conceptual understanding of Mendelian genetics, although the extent of improvement varied across the three principles and cognitive levels. Initial assessments revealed generally low to average performance, particularly in higher-order thinking skills (HOTS). Following the intervention, statistically significant improvements were observed in both lower-order thinking skills (LOTS) and HOTS for the Law of Dominance and in HOTS for the Law of Independent Assortment. However, improvements in both cognitive levels for the Law of Segregation and in LOTS for the Law of Independent Assortment were not statistically significant. These findings indicated that students continued to experience difficulties in interpreting genetic relationships and applying inheritance principles to complex problems.

The developed infographics received favorable evaluations from the three Biology teachers, obtaining an overall weighted mean of 4.63, interpreted as Strongly Agree. The materials demonstrated appropriate application of selected multimedia design principles, particularly the integration of text and illustrations, visual signaling, and the introduction of foundational concepts before complex activities. Nevertheless, the evaluations identified areas requiring improvement, including simplifying technical explanations, improving text–image alignment, refining instructional sequencing, and providing clearer examples of genetic crosses. Although the findings suggested that infographics could support conceptual learning, the single-group pretest–posttest design did not establish that the observed improvements were caused exclusively by the instructional intervention.

Based on these findings, it is recommended that Biology teachers integrate appropriately designed infographics into Mendelian genetics instruction, particularly to support the visualization of abstract concepts and the development of higher-order thinking skills. Instructional materials should incorporate concise explanations, relevant illustrations, guided Punnett square activities, and contextualized examples while addressing persistent misconceptions about allele segregation and independent assortment. The proposed enhanced multimedia material as a teaching-learning instructional guide should incorporate the identified refinements and undergo further evaluation to determine its instructional effectiveness. Future studies may employ comparison groups and broader student samples to examine whether infographic-based instruction produces consistent improvements in conceptual understanding across different learning contexts.

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