

# Conceptual Difficulties and Instructional Challenges in Teaching and Learning Genetics Concepts

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## ABSTRACT

Genetics is widely recognized as one of the most conceptually challenging areas in secondary science because many of its key ideas are abstract and difficult for students to visualize. This study identified the conceptual difficulties of secondary students and examined the instructional challenges encountered by teachers in teaching genetics concepts. Using a descriptive research design, the study involved students from selected public secondary schools in Iligan City, Philippines, who completed a 30-item needs assessment test. In addition, five (5) in-service science teachers answered a needs assessment questionnaire to provide qualitative data on classroom difficulties and instructional strategies related to genetics. Descriptive statistics were used to analyze quantitative data, while thematic analysis was applied to the teachers' responses.

The findings revealed that 83.75% of students falls below the passing mark of 75%. The results demonstrated low mastery of students in competencies related to non-Mendelian inheritance, mitosis and meiosis, and molecular processes involving DNA, RNA, and protein synthesis. Teachers likewise identified recurring instructional challenges, including the sequential complexity of genetics lessons, the abstract nature of molecular concepts, students' limited prior knowledge, and inadequate instructional resources. These findings suggest the need for more visual, scaffolded, and context-based approaches to improve students' understanding of genetics.

**Keywords:** conceptual difficulties, genetics concepts, instructional challenges, science education

## INTRODUCTION

Genetics is one of the most conceptually demanding areas of secondary science due to its abstract nature, microscopic scale, and difficulty for students to visualize. When taught effectively, science helps learners develop skills such as problem-solving and critical thinking. According to the latest PISA 2022 results, only about 23% of students in the Philippines achieved Level 2 or higher in science, compared with the OECD average of 76%. At this level, students can recognize appropriate explanations for familiar scientific phenomena and use simple evidence to judge whether a conclusion is valid. OECD (2023) further reported that very few Filipino students reached Level 5 or 6 proficiency in science. Numerous studies likewise agree that genetics is a conceptually difficult area that often results in low levels of understanding because of its abstract nature, specialized terminology, and the inherent complexity of its processes (Knippels et al., 2005; Tsui & Treagust, 2004a, 2004b).

Concepts such as DNA structure, protein synthesis, and genetic mutations require students to comprehend abstract molecular processes that cannot be directly observed. As a result, students often develop misconceptions that persist despite formal instruction (Lewis & Wood-Robinson, 2000; Balan, 2018). The Philippines' persistently low performance in science, as reflected in international assessments such as PISA 2022, further underscores the need to reassess instructional practices and learner engagement in science education. Various studies have identified several factors contributing to the low science performance of

Filipino students, including teacher quality, the teaching-learning process, the school curriculum, instructional materials, and administrative support (SEI-DOST & UP NISMED, 2011).

Studies from local and international sources indicate that instructional strategies significantly influence students' performance in genetics. Traditional teaching methods that provide limited interaction tend to reduce student motivation and weaken conceptual understanding and retention. In contrast, engaging and learner-centered approaches, such as educational games, collaborative learning, and active learning strategies, have been shown to promote deeper learning and sustain student interest (Cardozo et al., 2016; Stoten, 2017). However, the design of effective instructional interventions requires a clear understanding of learners' needs; thus, identifying students' misconceptions, preferred learning approaches, and knowledge gaps is essential.

This study aimed to identify the key conceptual difficulties encountered by learners in genetics as well as the teaching preferences of science teachers in delivering genetics instruction. The findings may serve as a basis for improving teaching strategies and methodologies that address difficulties in understanding genetics concepts.

## **METHODOLOGY**

This section presents the research methodology applied in the study. Particularly, it contains the research design, research setting, instruments used, research subjects, and data analysis.

### **Research Design**

A descriptive research design was used to examine students' conceptual difficulties in genetics concepts. Purposive non-random sampling was used, wherein the researchers selected specific classes to participate in the study. The target respondents were learners from selected national high schools in Iligan City. In addition, five in-service science teachers also served as respondents in the study.

### **Development of the Needs Assessment Test Questionnaire for Students**

The student test was developed for this study to assess learners' understanding of key genetics concepts. Moreover, the test questionnaire served as the basis for gathering information on learners' knowledge of genetics concepts. The instrument underwent content and face validation by the research adviser, who is also an expert in the development of needs assessment questionnaires. Additional validation experts were likewise consulted to establish the content and face validity of the instrument. The instrument obtained a mean rating of 3.90, interpreted as "satisfactory." It consisted of a 30-item multiple-choice test aligned with the Table of Specifications and the learning competencies in the DepEd K-12 Science Curriculum and was administered to respondents to establish reliability. The instrument obtained a KR-20 value of 0.86, which was interpreted as "good" reliability.

### **Needs Assessment Questionnaire for Teachers**

The questionnaire was adapted and modified from Guiritan et al. (2023), retrieved from the MSU-IIT College of Education Research Repository. The questionnaire was designed to assess teachers' perspectives, classroom difficulties, and resource needs related to the teaching of genetics concepts. To ensure alignment with the research objectives and the context of the present study, several items were revised. Minor changes in wording and structure were also made to improve clarity and suitability for the intended respondents. Before administration, the revised questionnaire was reviewed by experts to ensure that its content was appropriate and relevant.

### **Data Analysis**

The data were systematically classified, tabulated, and subjected to statistical analysis and interpretation. The mean was calculated to determine evaluators' average ratings of the developed needs assessment questionnaire and participants' ratings of its implementation. The Kuder-Richardson Formula 20 (KR-20) was used to assess

the reliability of the needs assessment test questionnaire, with higher coefficients indicating greater internal consistency. The reliability scale was interpreted as follows:  $\geq 0.90$ , “Excellent”;  $0.80-0.89$ , “Good”;  $0.70-0.79$ , “Acceptable”;  $0.60-0.69$ , “Questionable”;  $0.50-0.59$ , “Poor”; and  $< 0.50$ , “Unacceptable.” Additionally, thematic analysis was conducted on teachers’ responses.

## RESULTS AND DISCUSSION

This section presents the data gathered, the analysis of such data and their interpretation.

Table 1. Students’ Performance on the Achievement Test

Number of Students	Students’ Performance	Percentage	Remarks
6	7.50%	90-100	Passed
0	0.00%	85-89	Passed
2	2.50%	80-84	Passed
5	6.25%	75-79	Passed
67	83.75%	Below 75	Failed

Legend: Below 75 (Failed); 75-79 (Passed); 80-84 (Passed); 85-89 (Passed); 90-100 (Passed)

### Reference. Based on Department of Education (DepEd) Order No. 8, s. 2015.

Table 1 presents students’ performance on the achievement test, revealing that a substantial proportion scored below the passing mark of 75%, with 83.75% of the student population. This outcome suggests widespread difficulty in mastering genetics concepts, potentially resulting from multiple interrelated factors. The inherent complexity of genetics, involving abstract concepts and microscopic processes, often poses significant challenges for students (Duncan & Reiser, 2007). The results may also reflect weaknesses in classroom instruction or lesson sequencing. Traditional science instruction methods frequently fail to engage students actively or connect concepts to real-world contexts, resulting in only surface-level understanding. This observation aligns with Bransford, Brown, and Cocking (2000), who emphasized the importance of learner-centered, knowledge-centered, and assessment-driven approaches for effective learning.

Table 2. Ranking of Mastery Level of Topics in Genetics

TOPICS	% of Students with Correct Answers	Mastery Level	RANK
Stages of Mitosis	29.58%	Not Mastered	1
Stages of Meiosis	35.83%	Not Mastered	2
Non-Mendelian Inheritance & Multiple Genes	44.38%	Not Mastered	3
DNA, RNA, and Protein Synthesis	46.25%	Not Mastered	4
Genetic Engineering	47.50%	Not Mastered	5
Evolutionary Genetics	48.75%	Not Mastered	6
Mendelian Genetics	60.25%	Least Mastered	7

Legend: Not Mastered (50 and below), Least Mastered (51-74), Nearly Mastered (75-79), Mastered (80-100)

### Reference. Based on DepEd PPST Module 11

Table 2 displays students’ mastery levels across various genetics content areas, indicating that most students did not achieve the mastery threshold. Research suggests that learners often struggle to visualize dynamic processes such as mitosis and meiosis due to their abstract and microscopic characteristics (Kindfield, 1994). Insufficient understanding at this foundational level can impede comprehension of subsequent genetics concepts. The low performance in Stages of Meiosis with only 35.83% of responses being correct, corroborates the findings of Marbach-Ad and Stavy (2000), who observed that students frequently confuse the processes and purposes of mitosis and meiosis. These results highlight the need for enhanced instructional strategies, such as simulations or animations, to more effectively illustrate these processes. In the area of

Mendelian Genetics, 60.25% of responses were correct, resulting in a “Least Mastered” classification, which suggests this domain was closest to mastery.

Conversely, other critical domains including Non-Mendelian Inheritance and Multiple Genes, DNA, RNA, and Protein Synthesis, Evolutionary Genetics, and Genetic Engineering also fell below the mastery threshold. These topics require higher-order thinking and the integration of multiple biological concepts. Students often struggle with molecular genetics because it necessitates understanding complex and abstract processes that typically lack visible outcomes (Duncan & Reiser, 2007). The findings indicate significant deficiencies in students’ conceptual understanding and application of biological principles.

Table 3. Teaching Difficulties Encountered when Teaching Genetics

Themes	Codes	Statements
Abstract Molecular Visualization Challenges	visualization difficulties, abstract nature of genetics, microscopic processes, molecular level challenges	"The primary difficulty is the molecular nature of the process. Students often struggle to visualize how microscopic sequences of DNA translates into physical traits." IN3 "Many students struggle with understanding the processes involved in protein synthesis and mutation because these topics are abstract and difficult to visualize." IN5
Conceptual Knowledge Gaps	inadequate coverage, basic concept gaps, insufficient prior knowledge	"Protein synthesis and mutation is not discussed thoroughly." IN1 "They lack basic concepts about genetics particularly protein synthesis and mutation." IN2
Sequential Process Complexity	multi-step processes, sequencing difficulties, overwhelming complexity, process integration	"Additionally, the multi-step nature of protein synthesis (transcription to translation can be overwhelming for learners to sequence correctly." IN3
Inadequate Instructional Resources	resource scarcity, material sourcing difficulties, inappropriate resources, instructional support gaps	"Sourcing appropriate instructional materials for the students to really understand the concepts." IN4

Table 3 outlines the teaching difficulties encountered by teachers when instructing genetics. The results reinforce the study's quantitative findings by highlighting several instructional challenges. Teachers characterized biology, particularly molecular-level mechanisms such as protein synthesis and mutation, as highly abstract. Because these processes occur at the biochemical level, students often struggle to construct accurate explanations and models of molecular interactions within the cell. Recent studies similarly indicate that genetics remains one of the most challenging topics in biology due to its conceptual complexity, symbolic representations, and the necessity to integrate multiple levels of biological organization (Focant et al., 2025; Borja & Mutya, 2024). Further investigations reveal that many secondary students exhibit misconceptions or incomplete understanding of core genetics concepts, suggesting that gaps in prerequisite knowledge are a major barrier to meaningful learning in this area (Ojo, 2024).

Table 4. Teaching Interventions or Strategies

Themes	Codes	Statements
Visual Learning Support	diagrams, 3D-models, videos, animations	"I currently rely on detailed diagrams, 3D-model, and step-by-step animations to make the process more concrete" IN3 "I usually use diagrams, videos, and group activities to help students better understand the steps involved in genetic processes" IN5

		<i>"I also use videos to let them understand better"</i> IN2
Interactive Experiential Learning	game-based learning, experimentation, paper-lab simulations, group activities	<i>"To overcome teaching difficulties in any topic I usually do game-based or experimentation or demonstration"</i> IN1 <i>"I also use "paper-lab" simulations where students manually transcribe and translate a short sequence of code to see the results of a mutation firsthand"</i> IN3
Strategic Preparation and Resource Curation	advance preparation, sourcing materials, instructional material selection	<i>"Prepare. Source out learning materials or instructional materials ahead of time"</i> IN4

Table 4 summarizes teachers' responses regarding the interventions and strategies employed to address difficulties in teaching genetics. Thematic analysis indicates that teachers frequently utilize diagrams, videos, animations, and 3D models to facilitate visual learning, especially when teaching genetic processes. For experiential learning, teachers reported implementing game-based activities, experimentation, and paper-based or laboratory simulations for topics such as transcription and translation.

Additionally, the utilization of asynchronous video lecture with online learning simulator aids in enhancing students' motivation and improve their misconceptions in topics like cell division (Ecle & Barquilla, 2026). Nonetheless, educational institutions continue to explore diverse approaches to improve student performance and strengthen learner engagement with subject matter, recognizing these as essential for conceptual understanding and achievement of learning competencies at each grade level (Degracia, 2022).

Table 5. Attended or conducted seminars, trainings, or webinars related to the development or use of puzzles or hands-on learning tools

Themes	Codes	Statements
General vs. Specific Training Gap	general workshops attended, lack of specific puzzle training, interest in specialized training	<i>"I have not yet attended a specific training focused on Tarsia puzzles, though I have participated general workshops regarding active learning and the use of manipulatives in the science classroom."</i> IN3 <i>"I have attended general seminars on interactive and student-centered teaching strategies, but none specifically focused on puzzle-based learning tools like Tarsia."</i> IN5
Hands-On Learning Engagement	hands-on tools, laboratory experiences, manipulatives use, 3D model creation, concept understanding through practice	<i>"Hands-on learning tools only such as small-scale laboratory by CISTEM"</i> IN1 <i>"Yes, but only about making a 3D-DNA model"</i> IN4 <i>"use of manipulatives in the science classroom"</i> IN3 <i>"The learning tools indeed helps learners understand the concept through hands-on learning."</i> IN2

Table 5 presents teachers' responses regarding their participation in seminars, training sessions, or webinars related to the development or use of puzzles and other hands-on learning tools. The findings indicate that while some teachers had attended seminars on interactive, hands-on instructional tools such as 3D DNA models, manipulatives, and small-scale laboratory activities, no one had participated in training specifically focused on puzzle-based learning tools.

Hands-on and interactive approaches have been associated with stronger motivation, better engagement, and improved conceptual understanding in science classes (Ouyang & Xu, 2024). Simulations and interactive laboratory activities have also been found to increase students' interest in biology (Navarro et al., 2024).

Table 6. Teachers' Perspectives on Familiarity with the Tarsia Puzzle

Themes	Codes	Statements
Limited Awareness of Tarsia	unfamiliar with tarsia, not really familiar, not yet familiar	"Not really familiar." IN1 "Not yet familiar." IN4 "I am not very familiar with the Tarsia Puzzle" IN5
Recognition of Puzzle Concept	educational jigsaw puzzle, puzzle-based activities, similar materials	"It is a type of educational jigsaw puzzle used to help learners learn and practice various subjects." IN2 "I have seen similar puzzle-based activities used in some learning materials." IN5
Openness to Innovation	very open to the idea, developing or using them, enhancing understanding	"I am very open to the idea of developing or using them in enhancing students' understanding in learning genetics concept." IN3

Table 6 presents teachers' perspectives on their familiarity with the Tarsia puzzle. The responses indicate that most teachers had limited or no prior exposure to Tarsia as an instructional tool, although some recognized it as a form of educational jigsaw or puzzle activity. This low level of familiarity appears to result from limited opportunities for exposure and training in this specific strategy, rather than resistance to innovation. The responses also reveal an emerging awareness that puzzle-based activities can facilitate learning by helping students connect related ideas in a more interactive manner. Collectively, these findings suggest that the use of Tarsia puzzles in genetics instruction remains relatively new among participating teachers, but the basic concept is understandable and potentially acceptable. This underscores the importance of orientation, demonstration, and professional support to enable teachers to progress from general awareness of puzzle-based learning to confident classroom application.

Table 7. Openness to the idea of developing or using Tarsia Puzzle as an Instructional Material for Genetics

Themes	Codes	Statements
Openness and Willingness	acceptance, willingness to adopt	"Yes, because this might help the students to better learn genetics." IN1 "Yes, anything for my learners." IN4 "Yes, I am very open to using them." IN3
Student-Centered Learning Challenges	genetics concept difficulty, learning barriers	"Learners always have difficulties in grasping concepts in genetics." IN2 "make difficult concepts in genetics easier to understand" IN5
Interactive Engagement as Solution	interactive learning, student engagement, active participation	"interactive activities can help students become more engaged" IN5 "make the learning process more interactive and engaging for students" IN3
Game-Based Learning Potential	game-based learning, concept breakdown, educational games	"I believe that game-based elements to learning can help break down complex genetic concepts" IN3

Table 8. Openness to Utilization of the Tarsia Puzzle

Themes	Codes	Statements
Active Learning Engagement	active participation, actual work, hands-on learning, student engagement	"Yes, it will greatly help because it will enhance their understanding through actual work." IN2 "Yes, I believe it can help students because it encourages active participation and allows them to connect concepts while solving the puzzle." IN5
Conceptual Connection Building	conceptual association, connect concepts, bridging gaps, relationship building	"Yes, I see the Tarsia puzzle game as a helpful innovation because it bridges the gap between rote memorization and active conceptual association." IN3 "Yes, I believe it can help students because it encourages active participation and allows them to connect concepts while solving the puzzle." IN5
General Enthusiasm and Interest	general positivity, belief in effectiveness	"I believe so. This must be interesting." IN4 "Yes, I believe it can help students" IN5

Tables 7 and 8 illustrate teachers' openness to incorporating the Tarsia puzzle into their instructional methods. The findings indicate that teachers were highly receptive to innovative teaching approaches, particularly puzzle-based and game-based learning tools such as the Tarsia puzzle. Further analysis revealed that teachers perceived interactive activities as effective for enhancing student engagement, promoting active participation, and facilitating connections among related genetics concepts. Puzzle-based pedagogy has been widely implemented to improve STEM education beyond the use of Tarsia. Studies consistently demonstrate that puzzle formats, ranging from digital escape rooms to traditional Tarsia activities, increase learner motivation and persistence (Ahmad, 2025; Alotaibi, 2024; Eren, 2025). In addition to engagement, puzzle-based pedagogy has been associated with improvements in conceptual understanding. Research in mathematics, chemistry, and language learning has shown that Tarsia-style puzzles and structured card-matching activities assist students in connecting representations and consolidating domain knowledge (Ogundare et al., 2024).

## CONCLUSION AND RECOMMENDATIONS

The study demonstrated that the students exhibited significant learning gaps in genetics, particularly in mitosis, meiosis, non-Mendelian inheritance, and molecular processes involving DNA, RNA, and protein synthesis. These areas were identified as the least mastered, indicating persistent challenges with the abstract and process-oriented aspects of genetics. Teachers' responses echoed these concerns, highlighting difficulties in assisting learners to visualize microscopic processes, connect prior knowledge to new concepts, and comprehend complex genetic mechanisms. Limited instructional resources further compounded these challenges. Nevertheless, the findings also revealed that teachers are receptive to adopting more interactive and learner-centered approaches to enhance the comprehensibility and engagement of genetics lessons.

These results suggest that genetics instruction at the secondary level needs stronger instructional support. More visual, scaffolded, and activity-based teaching approaches may help students develop clearer conceptual understanding of difficult genetics topics. The results may also guide teachers, curriculum developers, and future researchers in identifying priority areas for intervention and material development. Future studies may focus on designing and testing instructional strategies that improve students' mastery of genetics concepts and reduce persistent misconceptions.

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### Ethical Considerations

The study was conducted in accordance with accepted ethical standards for educational research. Participation was voluntary, and informed consent and assent were obtained from the appropriate parties prior to data collection. All personal information and participant responses were kept confidential and were used solely for academic purposes. The researchers also ensured that no participant was exposed to harm, coercion, humiliation, or psychological distress during the conduct of the research.

### Conflict of Interest Statement

The authors declare that they have no conflict of interest related to this study. No personal, professional, or financial relationship influenced the selection of participants, the collection of data, or the interpretation of the findings.

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