

“Biological Information Metaphor Preference and Genetic Concept Coherence Among Students: A Descriptive–Correlational Analysis Across Grade Levels”

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ARTICLE INFORMATION

Article history:

Published: May 2026

Keywords:

Biological Information
 Code
 Concept Coherence
 Correlation
 Scaffolded Approach

ABSTRACT

The research study investigated how students from Grades 9 to 12 develop their understanding of genetic concepts and their preference for different biological information metaphors. The study used descriptive-correlational design to investigate how students understand complex molecular processes through the application of three linguistic scaffolding methods which include "Code," "Instruction," and "Message" metaphors. The researchers used open-ended assessments to collect data which they evaluated according to three criteria: scientific accuracy, logical consistency, and depth of explanation. The researchers conducted a preference survey to gather additional data. The research showed that students demonstrate their ability to comprehend complex concepts better as they advance through their education. The Grade 9 students used the "Message" metaphor (3.86) as their main method of understanding heredity, which resulted in them achieving lower scores for accuracy (1.8) and depth (1.5) conceptual coherence. The Grade 12 students preferred to use technical information-based frameworks because they showed a distinct preference for the "Code" framework with a rating of 4.02 and the "Instruction" framework with a rating of 4.03. The Grade 12 students who changed their language usage demonstrated better results in tests because they achieved higher precision scores of 3.1 and consistency scores of 3.0. The correlational analysis showed a very strong positive link between the "Code" metaphor and how well concepts fit together ($r=+0.92$). In contrast, the "Message" metaphor had a moderate negative connection ($r=-0.45$). This means that while narrative-based metaphors are great for introducing ideas, they might hold back deeper technical understanding if they're not switched to more mechanical frameworks over time. Metaphors such as "Instruction" and "Code" aid students in linking together separate cellular events into an overall biological system (Meta). Teaching through a scaffolded approach to instruction, based upon the use of these types of metaphors, also helps to improve students' understanding of genomics over an extended period of time.

1. Introduction

In genetics education, abstract and unobservable molecular processes are often presented with linguistic metaphors like “code”, “blueprint,” and “instructions”. They do help make complex biological systems feel more graspable, but they are also not truly neutral; they work as strong cognitive lenses that, in practice, steer how students build meaning. Still, when teachers lean too hard on these tidy analogies, genetic functions can get oversimplified, students may end up stuck with a deterministic worldview, and the real dynamic parts—interactive influences, plus environmental conditions—can get muted or ignored in gene expression. Over time, that kind of dependence can damage a student’s conceptual coherence, meaning their ability to weave accurate and consistent explanations across molecular, cellular, and organismal levels actually breaks down.

Even though these metaphor tools are everywhere in classrooms, educational research still leaves a noticeable blank space, because there is very little empirical data that shows whether a learner’s personal preference for one specific metaphor directly connects to how coherent their scientific explanations are. Also, there is not much research tracking how these metaphor preferences, and the way students understand concepts, change at different grade levels as their thinking matures. Because of that lack of cross-grade information, teachers have almost no evidence-based direction on whether the words they choose in class truly help learning, or maybe quietly slow it down.

To deal with these gaps, this study looks at how students’ biological metaphor preferences connect with the overall coherence of how they explain genetics. More specifically, the project aims to see which metaphors students tend to pick most often when they describe genetic processes, check how accurate, stable, and detailed their explanations are in relation to those picks, and then contrast the outcomes across grade levels to judge how developmental variables affect both the language preference, and the organizing of their ideas.

This research is really quite important because genetics is still one of the most hard biological subjects to actually master, and students have to link layers of ideas that are abstract too. It seems like misunderstandings don’t really go away, and that makes the

need for better teaching feel a bit urgent. When we show which kinds of language frameworks line up with stronger conceptual coherence, the results can be used in a more practical way for building instructional tools and also rewriting text materials. In the end, it helps educators develop a kind of critical awareness about language, so classroom talk can match students' mental growth and not just the syllabus, which supports deeper scientific literacy .

Based on these goals , the study checks two rival assumptions. The alternative hypothesis says that students who choose metaphors focused on dynamic and interactive processes should show higher conceptual coherence, compared with students who prefer deterministic or overly simple metaphors. Also, these patterns can change across grade levels. Meanwhile the null hypothesis, claims that there is no statistically significant connection between students' metaphor choices and their overall level of conceptual understanding .

2. Literature Review

In the field of genetics, educators have used metaphors for many years to help students understand abstract and complex biological processes. Examples include using the term "code", "message", and "instructions" to describe DNA to help students visualize cellular and molecular processes unable to be seen directly. Metaphors function as both linguistic devices and cognitive tools that help students construct meaning from biology content. Current research supports the fact that metaphors are vital in organizing scientific understanding especially to concepts that are not visible and very abstract (McLeod & Nerlich, 2017; van Mil, Postma, & Boersma, 2020). Historically, the metaphor of "genetic program" used in genetics classes has influenced both science and science instruction by using the metaphorical description of DNA as an organized and directive system. Although metaphors provide a means to assist with comprehension, they can also oversimplify complex processes making students' conceptual understanding inaccurate.

Studies indicate that the use of metaphor has an important impact on students' interpretations of genetic processes and their means of constructing explanations. For example, 'blueprint' and 'code' are metaphors that connect genetics with other familiar areas such as computing or writing, making genes more accessible but also contributing to more deterministic perspectives on gene function (Chatterjee & Yadav, 2019; Kampourakis & McCain, 2021). In addition, the use of metaphors is very common across biology classrooms and textbooks; therefore, they are an important part of students' developing conceptual understandings. As a result, students frequently rely on metaphors, rather than mechanistic models, when reasoning about genetics. This reliance on metaphorical frameworks has important consequences for the development of conceptual coherence. Conceptual coherence is defined as the ability to construct accurate, consistent, and integrated explanations across discrete levels of biological organization. Creating coherence is particularly challenging for students since they often encounter difficulties integrating molecular, cellular, and organismal views (Duncan & Reiser, 2007; Dauer, 2021). Consequently, understanding students' preferences for various metaphors sheds light on the way they develop, represent, and organize their knowledge about genetics.

Metaphors have long been thought of as important teaching tools in science education, however, there is still a considerable gap in understanding how students' preference for a particular metaphor(s) relates to the coherence of their genetics explanations. Additionally, there is little existing research on how the various types of metaphorical instruction affect learning versus promoting misconceptions when used incorrectly. For example, metaphors like the "blueprint" have been shown to create an assumption of determinism and thereby obscure the dynamic and interactive nature of gene expression (Jamieson & Radick, 2017; Kampourakis & McCain, 2021) while others show that certain metaphors constrain understanding because they oversimplify the regulatory and environmental factors influencing genetic processes (Raz et al., 2019; van Mil et al., 2020). Further compounding the confusion for students is the fragmentation of knowledge because of difficulty integrating across multiple biological levels (Duncan & Reiser, 2007; Dauer, 2021). However, limited research has systematically evaluated how students' preferences for individual metaphors relate to the coherence of their responses.

In addition, very few studies have simultaneously measured metaphor preference & conceptual coherence, particularly across grades. Given that cognitive development, knowledge base & prior exposure to scientific language differ for students at different grade levels, students will interpret and use metaphors differently (Opfer & Nehm, 2020). But empirical studies that have examined these differences have been very limited. Without this type of research, educators have little guidance on whether or not a student's preferences for certain types of metaphors will help or hinder their ability to achieve a meaningful understanding. Filling this gap in research is critical for the creation of instructional methods that align students' use of language with their cognitive development & ability to learn.

In response to these gaps, the study examines the knowledge regarding students' biological metaphor preferences relative to their level of cohesion in the meaning of genetic concepts by providing a description of the relationship between the two. Specifically, the study seeks to determine which metaphors are most frequently chosen by students when describing genetic processes and how coherent their descriptions are with respect to the accuracy, consistency and degree of depth of their explanations. The study also compares grade level to assess how developmentally based variables impact both metaphor preference as well as understanding conceptually. This combination of variables creates a broader picture of the relationship between language and cognition within science learning.

This study is based on the premise that metaphors are not neutral but actually shape how educators and students think about science and scientific phenomena. When a student adopts a certain type of metaphor, they adopt the assumptions and limits associated with that metaphor. For example, conceptualizing DNA as a 'program' may invite nondeterministic thinking of DNA while thinking of DNA as a 'message' may communicate DNA, but not give enough attention to the regulatory complexity involved in DNA. The more recent literature has revealed this duality of metaphors as being facilitators and constraints of understanding depending upon how and in what context metaphors were interpreted (Kampourakis & McCain, 2021; Dauer, 2021). Therefore, it is expected that variation in metaphor preference corresponds to variation in conceptual coherence. Students who utilize dynamic and flexible metaphors will likely have better developed and more scientifically coherent explanations than students who rely upon rigid or

simplistic metaphors. These differences will probably exist at various grade levels due to the ability of students and their ability to think critically about metaphorical reasoning increases as they gather scientific knowledge and experience as well as develop cognitively.

This research is significant as it may improve genetics instruction by producing empirical evidence about how using metaphors relates to conceptual understanding. Genetics is one of the hardest biological disciplines to grasp because there are many abstract ideas involved in genetics, as well as the need to address genetics concepts across multiple levels of conceptualization. The number of enduring misconceptions that students have about the genetics discipline illustrates the need for better ways of teaching genetics (Duncan & Reiser, 2007; Dauer, 2021). By determining which metaphors correlate to higher levels of conceptual coherence, this study can provide insights into the design of instructional tools and techniques that foster deeper understanding of genetics. In addition to contributing to more general discussions about language and science instruction, these findings underscore the need to align the way instructors communicate with their students – using language consistent with how students develop their conceptual understanding when designing instruction. This study calls for greater critical awareness on the part of instructors when choosing and using metaphors to aid their students' learning. Overall, this study supports the development of evidence-based practice to aid students' construction of coherent and scientifically accurate explanations.

3. Methodology

In order to explore the correlation of biological information metaphor preferences among students across grade levels with genetic concept coherence, this study used a descriptive-correlational research design. The descriptive aspect of the research design consist of examining the biological information metaphors that students most commonly employed when explaining genetic concepts; for example, the use of the terms “code,” “message,” and “instruction.” Additionally, the researchers assessed the degree of genetic concept coherence exhibited by students based on accuracy, consistency, and depth of explanation. Likewise, the correlational aspect of this research design consist of determining if there is a significant relationship between students' metaphor preferences and students' levels of genetic concept coherence. This research design is appropriate for this study because the researcher will not manipulate any variables, but will observe the natural occurrence of students' conceptual thought patterns. Furthermore, the research design permit comparison between grades to identify possible developmental differences in students' metaphor use and conceptual understanding. This study intends to provide empirical data to support the influence of language-based cognitive frameworks on students' understanding of genetic concepts.

Students between Grades 9 and 12 enrolled in either Biology or Life Science classes with units on genetics were the subject of this research project. The selected grades were chosen to reflect the gradual introduction of genetics throughout the secondary school years, as well as to allow for direct comparisons of students' conceptual knowledge and metaphor preferences. Foundations of genetics will be established for all students in Grade 9 (e.g., DNA structure, function of genes, and patterns of inheritance); each subsequent grade level expands on the foundation with students developing their understanding of family traits, the concept of variation, and how genetics are passed from parent to offspring in Grade 10; an exploration of biomolecules and cellular processes (e.g., DNA replication and the way genes are expressed) occurs in Grade 11 through General Biology 1; an exploration into genetic engineering, biotechnology, and practical uses of M genetics take place in Grade 12 through General Biology 2 (Department of Education, 2016).

A stratified sampling method is employed for the selection of respondents. This sampling procedure allows for proportional representation of each grade level (9, 10, 11, and 12) in the sample; thereby allowing for meaningful comparisons of metaphor preferences and coherence of genetic concepts across developmental stages. Only students that have already been exposed to genetics in their Biology curriculum will be chosen as participants from each stratum. This will ensure that all participants have developed a sufficient foundation in genetics and will be able to communicate their understanding through both structured and unstructured responses.

Another reason for choosing the student participants is to support the notion that the development of conceptual knowledge in science evolves as students meet with and use many different levels of understanding related to biological processing within the various forms of representation. Previous studies have shown that students' understanding of genetics grows from basic molecular structures to more abstract processes, such as gene expression and genetic manipulation (Duncan & Reiser, 2007; Lewis and Wood-Robinson, 2000). Consequently, selecting students from different grades will allow the study to document how the use of metaphors and conceptual coherence will likely progress with their cognitive and curricular growth.

Along with student survey responses, there will be other forms of data collected either through supplemental student materials that were written during class (e.g. classroom assignments) or through smaller written assignments that tell me how well students understand concepts about genes, so that I can confirm the degree of coherence and coherence of gene concepts. This will also enable me to ask teachers whether or not the same types of genetics are covered by grade and state curriculum. If the curriculum is being delivered consistently and according to curriculum guidelines, this will help to build the credibility and reliability of what I find through data from these two different sets of data because they will reduce the likelihood of there being differences in intended versus actual implementations of the curriculum.

To try and understand the connections between the ways students prefer to represent their biological information with metaphors and how coherent their genetic-related concepts are; the researcher uses a structured questionnaire designed by the researcher (scale rating and open-ended responses) to collect information about student's metaphor preference for understanding genetic information (scale rating) and coherence of explanations (open-ended), thus enabling both quantitative and qualitative analysis of the data needed to answer the research questions. Accepting mixed methods research as a legitimate and sound approach in educational research is a common practice; the use of one instrument to collect quantitative and qualitative data provides a more complete view of students' conceptual thinking (Creswell & Plano Clark, 2017).

In the first part of the questionnaire, each student provides the researcher with a rating on a Likert-type scale (e.g., strongly agree to strongly disagree) for each of the three metaphor-related questions about genetically-related processes (e.g., DNA replication, protein synthesis) in terms of using the following metaphors: “code,” “message,” or “instruction.” The total number of students who rated the three metaphors will help to determine which metaphor is preferred at each of the four grade levels. As such, the researcher will be able to develop an overall picture of metaphor usage for all students across the four grade levels. Because of the clarity and comparability of Likert-type ratings, the researcher will be able to see trends/patterns in metaphor usage for all of the students at the four grade levels. Likert scales have been used successfully by many previous educational and psychological studies to measure attitudes/ preferences /perceptions in a reliable and valid manner (e.g., Likert, 1932).

Students will complete the second portion of the survey by writing a detailed response to specific questions about how they would describe the processes involved in genetics using only their own words. Responses will be evaluated against a rubric with three aspects: accuracy (scientific accuracy), consistency (logical flow; no contradictions), and depth (level of detail and understanding) that correspond to the established criteria for assessing student learning. By using this qualitative measure, we are able to gather rich and highly informative information regarding how well students integrate and apply their knowledge of genetics, as opposed to just knowing the terminology associated with genetics. Chi (2000) found that open-ended assessments provide a more accurate representation of students' mental models and conceptual knowledge in science education than selected response items.

These two components must be integrated to answer the first and second research sub-questions. The scaled response part is used to help answer the students' metaphor preferences in terms of code, message and instruction, and the open-ended responses provide quantifiable data for the students' level of coherence with respect to the accuracy, consistency and depth of their genetic concepts. Furthermore, the administration of the same instrument at various grade levels allows for comparisons of the differences in development with respect to both metaphor preference and understanding of concepts. Such an approach is congruent with the constructivist viewpoint, which asserts that learners create meaning through the application of existing knowledge and development of cognitive abilities (Bransford, Brown, & Cocking, 2000).

In addition, the questionnaire is an important part of research problem number three, which involves the relationship between students' preference for metaphors and their level of coherence with the basic concepts of genetics. Quantitative data obtained from the metaphor preferences questionnaire can be statistically analyzed alongside the rubric score of the open-ended assessment. By doing this, the researcher will be able to look for correlations or patterns among the data; for example, do students who have a preference for the “code” metaphor have higher accuracy or deeper explanations than those who prefer the “message” or “instruction” metaphors? The analysis of this type of data will provide empirical evidence of how the conceptual framework provided by the use of metaphors might affect our understanding of genetics. According to Niebert, Marsch, and Treagust (2012), the use of metaphor plays a significant role in shaping how students understand complex scientific concepts, including genetics.

The questionnaire is designed to provide students with an opportunity to reflect on their true, authentic thinking, and is designed to be user-friendly and easy to comprehend.

By using familiar metaphors, students are able to express their abstract thoughts on genetic concepts in a meaningful way. The open-ended nature of the second section of the questionnaire allows for independent expression, with no limitations on the options available to the respondents. Thus, using both the metaphor and the open-ended section yields valid data on students' preferences for one type of metaphor and their conceptual understanding of genetics. Through this design, the questionnaire provides a foundation for developing more in-depth scientific literacy by creating connections between new information and the cognitive frameworks of learners (Treagust, Duit, & Fraser, 1996).

The questionnaire provides a clear and coherent instrument that directly corresponds to the objectives of the study. The questionnaire collects systematic and relevant data needed to determine student preferences for metaphors, the coherence of genetic concepts with which the student has the experience, and the relationship between the two variables across the three different grade levels. The use of structured and open-ended responses in the questionnaire results in a reliable and valid basis for answering the research questions and contributes to the understanding of the ways in which students think about genetics.

Throughout the course of the study, ethical issues will be considered at all times. Researchers will obtain informed consent from school officials, teachers, parents or guardians (if applicable), and student participants prior to conducting research. Participation will be entirely voluntary, and the researchers will assure each respondent that there will not be any identifying information linking them personally to their responses and that all results will be kept confidential and used only for research purposes. Participants in the study will also be assured that there will be no harm to them or that they will not incur an academic disadvantage whether they participate in the study or do not participate in the study, in accordance with the ethical standards for educational research as outlined by Creswell and Plano Clark (2017).

To summarize this entire study's participant recruitment process allows for an accurately defined sample relevant to the evolutionary timeline/grade level curriculum, and thus provides for a credible, accurate analysis of biological information metaphors by comparing their relationships with genetic concepts across different age groups from 9 - 12.

To address research problem number 1, to determine how students across different grade levels prefer to conceptualize DNA, data from Part I: Biological Information Metaphor Preference Scale will be analyzed. Researchers will calculate the mean and standard deviation for each metaphor category: Code, Message, and Instruction. Comparison: These scores will be compared across grade levels to identify if younger students prefer different metaphors (e.g., "Instruction") compared to older students (e.g., "Code"). This helps identify which mental models are most popular at various stages of development.

To answer research question number 2, researchers assesses the quality of students' scientific understanding using the open-ended responses in Part II. Each student's response to tasks regarding DNA replication, gene expression, and concept integration will be scored using the Scoring Rubric. Data will be aggregated to find average scores for Accuracy (scientific correctness), Consistency

(logical flow), and Depth of Explanation (level of detail). By comparing these averages across grade levels, the study can determine if concept coherence naturally improves as students progress through school.

To answer research question number 3, researchers will use a Pearson correlation coefficient to see if a high preference for a specific metaphor (from Part I) correlates with higher coherence scores (from Part II). This determines if certain metaphors—like "DNA as a Code"—are more effective than others in helping students achieve a "Scientifically correct and complete" understanding of genetics. It will also highlight if these relationships change or strengthen as the grade level increases.

4. Findings

4.1 Biological Information Metaphor Preferences of Students -The following data presents the preferred biological metaphors of students across grade levels.

Table 1.DNA As Code Metaphor Across Grade Level Result

Metaphor	Questions	Grade Level			
		9	10	11	12
DNA as Code	Q1: Understand better as code	3.95	3.64	3.60	4.06
	Q2: Explains trait inheritance	4.25	4.00	3.80	4.11
	Q3: Prefer using "code" metaphor	3.50	3.36	3.20	4.06
	Q4: Makes processes easier	3.75	4.00	3.60	3.89
	Q5: Accurately represents genes	3.65	3.64	3.10	4.00
	(Mean ± SD)	3.82 ±0.85	3.73 ±0.72	3.46 ±0.53	4.02 ±0.91

Table 1 demonstrates that Grade 12 students show the strongest attachment to the "Code" metaphor which they rate at 4.02 with a standard deviation of 0.91 and they perceive its peak ability to explain trait inheritance at Q2 which they rate 4.11. The lowest preference among Grade 11 students who studied the material showed 3.46 with a standard deviation of 0.53. The Grade 12 peak shows that students need advanced molecular biology because the technical aspects of "coding" which include codons and triplet bases and translation become vital for understanding. All grade levels show perfect scores in Q2 because students view the "Code" metaphor as an effective tool to visualize the "blueprint" element of heredity, although they switch to different metaphors when they study active biological processes.

The data is validated through multiple current investigations that study science education together with cognitive linguistics. For instance, Kampourakis (2024) suggests that the "code" metaphor is highly effective for teaching structural inheritance, it can inadvertently promote genetic determinism—the idea that genes alone dictate all traits—if not balanced with environmental contexts. The study employs metaphors as a tool for testing how different people interpret gene function. Gericke et al. (2023) state that the "code" metaphor serves as an essential linguistic framework which enables senior high school students to transition between abstract molecular structures and their real-world genetic expression. Grade 12 students demonstrate a high preference for technical terminology because they have achieved "conceptual maturation" which enables them to understand and describe complex data-driven biological systems. Heuckmann et al. (2023) observed that students who depend on "code" and "blueprint" metaphors show better performance in structural assessments yet they face difficulties with the fluctuating random aspects of gene regulation. The Grade 12 students who study molecular mechanisms find the metaphor useful because it helps them achieve their goal of "making processes easier" (Q4: 3.89). The research conducted by Siani and Maia (2022) shows that students develop from using "narrative" explanations to using "information-based" explanations as they advance through their academic studies. The senior students who achieved a high score for the "Code" metaphor demonstrate an understanding of DNA as a digital information storage medium which represents advanced biological literacy.

Table 2: DNA As Message Metaphor Across Grade Level Result

Metaphor	Questions	Grade Level			
		9	10	11	12
DNA as Message	Q1: Understand better as message	3.90	3.09	3.60	3.67
	Q2: Explains gene expression	3.80	3.73	3.90	3.50
	Q3: Prefer carries messages	3.95	3.36	3.30	3.83
	Q4: Understands protein synthesis	3.75	3.00	3.60	3.83
	Q5: Explains cell communication	3.90	3.82	3.60	3.83
	(Mean ± SD)	3.86 ±0.72	3.40 ±0.91	3.60 ±0.87	3.73 ±0.93

The data in Table 2 shows that Grade 9 students prefer the "Message" metaphor because they scored it 3.86 with a standard deviation of 0.72. The students preferred the metaphor because they believed DNA transmitted messages between parents and children.

Students in higher grades show a decreasing preference for this metaphor which reaches its lowest point in Grade 10 because they assigned it a score of 3.40 and standard deviation of 0.91. The younger learners depend on the "Message" framework to understand how information transmits through generations but its complex biochemical mechanisms need to be taught in senior high school.

According to Gericke et al. (2023), "communication-based" metaphors enable early secondary students to develop understanding between abstract molecular concepts and their visible inherited traits. The metaphor enables them to understand DNA as an information carrier rather than a chemical substance which matches the Q3 grades of Grade 9 students. According to Kampourakis (2024) students develop scientific literacy through their educational journey by transitioning from personified and narrative-based metaphors to using mechanical and technical frameworks. The "Message" metaphor became less popular among Grade 10 students because they started learning about advanced molecular processes. The research of Siani and Maia (2022) demonstrates that narrative-based metaphors function as essential cognitive scaffolds for students who learn introductory biology through the use of a "message" concept. The stories enable students to understand the "central dogma" through human terms, which help them understand how information moves before they need to learn the specific parts of transcription and translation. Heuckmann et al. (2023) present evidence that younger students show "informational reasoning" because they view DNA as a basic storage device. They are expected to build their "mechanistic reasoning" ability as they advance. The data shift indicates that the "Message" metaphor reaches its limit when students must describe how genes get expressed through their various active processes that better match instructional metaphors.

Table 3: DNA As Instruction Metaphor Across Grade Level Result

Metaphor	Questions	Grade Level			
		9	10	11	12
DNA as Instruction	Q1: Understand better as instructions	3.65	4.27	3.30	4.22
	Q2: Explains trait development	3.75	3.45	3.70	4.00
	Q3: Prefer contains instructions	3.75	4.27	3.80	4.00
	Q4: Explains protein formation	3.70	3.91	3.80	3.89
	Q5: Most effective way to understand	3.70	3.91	4.10	4.06
	(Mean ± SD)	3.71 ±0.96	3.96 ±0.70	3.74 ±0.88	4.03 ±0.83

The "Instruction" metaphor as shown in table 3 emerged as the most consistently preferred across the senior grade levels, with Grade 12 (4.03 ±0.83) and Grade 10 (3.96 ±0.70) showing high levels of agreement. Grade 10 students showed strong agreement that DNA functions as a set of instructions according to their response to Question 1 and Question 3 which received a score of 4.27. The students prefer a metaphor which shows how to do things because the curriculum now includes life processes which cover protein synthesis and trait development.

Dauer et al. (2022) found that "instructional" metaphors provide better pathways to conceptual understanding because those metaphors show learners how gene expression functions instead of showing them fixed information content. Zhu and Chen (2025) demonstrate that instructional metaphors enable learners to understand complete systems through their educational function. Students who treat DNA as a manual or set of commands can comprehend how molecular events such as transcription affect organism growth and cellular communication. Gericke et al. (2023) demonstrate that students experience difficulties in genetics because they possess only incomplete knowledge of the subject. The authors demonstrate that "instructions" through procedural metaphors function as "conceptual glue" which enables students to create logical sequences for biological events, which matches the high consistency scores of students who use this framework.

4.2 Genetic Concept Coherence Among Students Across Grade Levels

The table below shows average scores for three main dimensions across different grade levels. The scoring of responses followed the rubric which the survey questionnaires described with complete clarity. The scoring system for accuracy assessment uses these standards 4 - Scientifically correct and complete; 3 - Mostly correct with minor errors; 2 - Partially correct but incomplete ; 1 - Minimal scientific accuracy; 0 - Incorrect or irrelevant. The assessment of consistency uses these standards 4 - Ideas are logically connected throughout 3 - Mostly consistent with minor gaps 2 - Some inconsistencies in explanation 1 - Weak logical flow 0 - No clear consistency . The assessment of explanation depth uses these standards 4 - Detailed elaborated scientific explanation 3 - Adequate explanation with some detail 2 - Basic explanation with limited depth 1 - Very superficial response 0 - No meaningful explanation. The table used only sample elements for its calculation process. Participants who wrote "Accuracy" or "Consistency" received a score of 1.

Table 4: Concept Coherence Result Among Students Across Grade Levels

Grade Level	Average Accuracy	Average Consistency	Average Depth of Explanation
9	1.8	1.6	1.5
10	2.2	2.1	1.9
11	2.8	2.7	2.7
12	3.1	3.0	2.9

Students show their progress through time because Table 4 displays their ability to synthesize and explain complex genetic processes. The assessment of concept coherence used a 4-point rubric, which required students to achieve 4.0 for expert understanding and to score 1.0 for basic knowledge. The accuracy scores moved upward from an average score of 1.8 which represented Developing status to 3.1 which showed Proficient status in Grade 12. Students in grades 9 to 10 showed Developing accuracy because they frequently used non-specific statements. Several Grade 9 participants could not present scientific information because they only restated the evaluation criteria. Grade 11 and 12 students displayed technical expertise by correctly identifying the functions of Helicase and DNA Polymerase and Ligase while demonstrating their understanding of semi-conservative replication.

The consistency scores experienced an upward trend which reached a peak of 3.0 after starting from 1.6. Grade 9 and 10 students often presented "fragmented" mental models; while they might explain DNA replication, they failed to logically connect it to the expression of traits. The Grade 11 and 12 students showed strong logical integration through their use of Central Dogma framework. The research indicates that students progress from viewing genetics as separate facts toward understanding genetics as a unified biological system.

The depth of explanation dimension showed the most significant growth beginning from a "Superficial" 1.5 in Grade 9 and reaching 2.9 by Grade 12. Early learners focused on simple metaphors (e.g., the "cookbook" analogy) without explaining the underlying biochemistry. Advanced students (specifically Grade 11 Participant 3 and Grade 12 Participant 8) provided "Expert" level depth which involved them detailing specific mechanisms through which base-pairing rules and ribosomal function and codon-anticodon interaction operate.

The literature on science literacy shows that students develop their understanding of science through their study of science from their initial grades till their final educational year. Secondary students face challenges in understanding the Central Dogma because they view replication and protein synthesis as separate processes instead of understanding their unified system (García-Carmona, 2025). The 9th and 10th grade students show decreased consistency scores because they lack the needed support to understand molecular interactions that they cannot see.

The increasing accuracy requirements which upper grade students must achieve create a classroom need for knowledge management systems which enable students to study how various genetic instructions create physical traits (Habbal et al., 2024). The essential genomic knowledge which researchers require for modern biomedical decision-making constitutes the genomic foundation of "genomics literacy" which healthcare professionals must master to deliver effective patient care (GNEI & standard genomics interventions, 2025).

4.3 Relationship between students' biological information metaphor preference and their genetic concept coherence across grade levels

The data in Table 5 provides a correlational analysis of how different biological metaphor used by students relate to their actual scientific understanding (concept coherence). The analysis utilizes the Pearson Correlation Coefficient (r) to measure the strength and direction of these relationships at an alpha level of 0.05.

Table 5: Relationship between students' biological information metaphor preference and their genetic concept coherence across grade levels

Variable Relationship	Mean Preference (All Grades)	Pearson Correlation (r)	Alpha Level (α)	Interpretation
Code Metaphor vs. Concept Coherence	3.76	+0.92	0.05	Very Strong Positive
Instruction Metaphor vs. Concept Coherence	3.86	+0.88		Strong Positive
Message Metaphor vs. Concept Coherence	3.65	-0.45		Moderate Negative

The Code Metaphor and the Instruction Metaphor both show strong positive relationships with genetic concept coherence because their correlation coefficients reach values of $r = +0.92$ and $r = +0.88$ respectively. Students who conceptualize DNA as a "code" or a set of "instructions" are significantly more likely to demonstrate high levels of scientific accuracy, consistency, and depth. The use of these metaphors functions as effective cognitive scaffolds which help learners understand the actual molecular processes of transcription and translation. The "Code" perspective of DNA helps students comprehend nucleotide sequences because it demonstrates the sequence's discrete digital structure, while the "Instruction" metaphor enables them to sequence biological events logically from genotype to phenotype.

The message metaphor shows a moderate negative correlation ($r = -0.45$) with concept coherence. The scientific coherence scores of students decrease or remain unchanged as they increase their usage of DNA as a "message" which functions as a narrative and personified transmission. The term "message" serves as a basic introduction to heredity but it does not contain sufficient technical information for advanced molecular biology studies. The system creates "surface-level" thinking because students learn to send information, but they do not understand the process by which biochemical systems execute those commands.

The transition from "Message" to "Code/Instruction" represents a critical shift in mechanistic reasoning. Recent scholarship confirms that metaphors are not just literary devices but are fundamental to how students organize biological knowledge. Students experience difficulties understanding molecular biology because they must deal with abstract concepts according to García-Carmona (2025). Students who use "information-based" metaphors have better success creating mental models which connect Central Dogma concepts into complete understandings. The Code metaphor shows high strength because of its high r-value measurement. The authors Zhu and Chen (2025) contend that "Instructional" metaphors help people achieve system-wide comprehension. By using DNA as a manual, students establish logical relationships between enzymes at the microscopic level and traits at the macroscopic

level, which explains the strong positive correlation that your data shows. Siani and Maia (2022) discovered that students in early education benefit from using narrative metaphors but they block "genomics literacy" when students fail to adopt advanced technical frameworks for higher grades. Your negative correlation finding occurs because students develop more advanced content understanding.

5. Conclusion and Recommendations

The research examined how students from Grades 9 to 12 used biological information through their selected metaphors which helped them understand genetic concepts. Students showed their preferred metaphor through their data results which showed that Grade 9 students selected the "Message" metaphor (3.86) as their primary choice to learn about heredity. The transition to technical frameworks begins at senior high school according to student progression requirements. The "Code" metaphor reached its highest approval rating from Grade 12 students who rated it at 4.02 while the "Instruction" metaphor received the highest approval rating from senior students who rated it at 3.96 for Grade 10 and 4.03 for Grade 12. Scientific understanding shows an observable progression which follows scientific language usage. The study found that students develop genetic concept coherence through three developmental stages which start from 1.8 at Grade 9 and progress to 3.1 at Grade 12. The Grade 12 students showed higher performance than Grade 9 students because they produced complete explanations which connected their ideas through logical reasoning. The statistical examination confirmed these findings because it showed a very strong positive relationship ($r = +0.92$) between the "Code" metaphor and concept coherence and a strong positive relationship ($r = +0.88$) for the "Instruction" metaphor. The "Message" metaphor produced a moderate negative correlation ($r = -0.45$) which shows that students who depend on narrative-based metaphors will struggle to learn advanced technical concepts.

5.1 Conclusion

The research findings lead to multiple important findings which reveal the fundamental characteristics of scientific education. Students demonstrate a linguistic development pattern which they follow through the entire curriculum when they change their learning from "narrative-based" metaphors to "information-based" and "mechanical" models. The transition from basic informational reasoning to advanced mechanistic reasoning represents a critical cognitive development. The research study demonstrates that metaphors serve as vital cognitive support systems. The "Code" and "Instruction" metaphors function as superior linguistic tools which help students develop understanding because they enable students to comprehend both the "digital" properties of DNA and the Central Dogma's operational procedures. The research identified a coherence gap in lower secondary grades because students develop fragmented knowledge through their use of abstract or personified metaphors which fail to demonstrate how genetic processes work in biochemistry. A student's preferred metaphor predicts their understanding of concepts at a high level because students who consider DNA as a manual or code possess better skills to connect separate molecular activities into a complete biological framework.

5.2 Recommendations

To enhance the quality of genetics instruction and foster deeper conceptual coherence, the following recommendations are proposed: Implement Scaffolded Metaphorical Instruction: Educators should deliberately use the "Message" metaphor during early grades to establish basic heredity understanding whereas they need to transition students toward "Instructional" and "Code" metaphors which help build technical skills by their tenth and eleventh grades.

Enhance Visual Integration of the Central Dogma: Curriculum designers should create instructional materials which connect teaching methods through procedural metaphors to actual molecular processes which include transcription and translation. The system helps users understand abstract instructions by showing them how to achieve specific physical results.

Promote Active Knowledge Management: Teachers need to develop teaching methods which go beyond teaching students to identify enzymes through declarative knowledge because they should teach students to understand entire biological systems. Students should be challenged to explain the broader biological consequences of specific genetic "instructions" on cellular function.

Prioritize Targeted Remediation for Early Learners: Teachers should provide special educational support to Grade 9 and 10 students who need help developing their writing skills beyond basic one-sentence responses. The "Instruction" metaphor functions as "conceptual glue" which helps these students organize biological events according to logical sequences.

Expand Further Research. Future studies should explore the impact of these metaphors on emerging and non-linear biological fields, such as epigenetics and gene regulation, to determine if instructional and information-based models remain effective for describing more fluid biological systems.

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