BUILDING ACTIVE KNOWLEDGE: THE CORNELL METHOD IN UNDERSTANDING THE CENTRAL DOGMA OF MOLECULAR BIOLOGY

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ABSTRACT

This qualitative study examines the efficacy of the Cornell note-taking method in enhancing ninth-grade biology students' comprehension of DNA and RNA within the framework of the central dogma of molecular biology. Through an analysis of student notes from a high school in Medellín, Colombia, the research identified three levels of understanding: basic structural differentiation, correlation between form and function, and integration of all three components. The Cornell method was determined to be a highly effective strategy for improving students' understanding by promoting active learning, critical thinking, and metacognitive skills. The findings indicate that this method can significantly contribute to biology education, cultivating a more profound understanding of complex biological concepts.

1. Introduction

The central dogma of molecular biology describes the flow of genetic information within a biological system, from DNA to RNA and proteins. This fundamental concept is crucial for understanding various biological processes, such as heredity, gene expression, and protein synthesis. However, the complexities of DNA replication, transcription, and translation can be difficult for students to understand.

Traditional teaching methods often focus on rote memorization of facts and definitions. However, for a deeper understanding of complex concepts such as the central dogma, students must engage in active learning strategies that promote critical thinking and synthesis of information. (Delgado, 2014, Rendón-Criollo et al., 2021)

The Cornell Note-Taking Method, developed by Walter Pauk, offers a structured approach to note-taking that encourages active learning and improves knowledge retention. (Pauk, 2011). This method encourages students to take responsibility for their learning through active processing and synthesis of information. This approach aligns with constructivist learning theory, which emphasizes the active role of the student in the construction of knowledge. (Rendón-Criollo et al., 2021)

So, the student can meet the challenges of understanding the central dogma, motivating students to move beyond simply copying information and instead actively engage in building with the material.

This article explores how the Cornell note-taking method can be used as a tool to enhance students' understanding of the central dogma of molecular biology.

2. Theoretical references

In the teaching of biology, the central dogma of molecular biology is a concept that is of utmost importance for addressing processes that explain how genetic information flows in living beings from DNA to proteins. (Freitas et al., 2020a). It is also challenging to learn, as students tend to face challenges in understanding, such as understanding the relationships between DNA, RNA, and proteins. (Delgado, 2014). On the other hand, specialized vocabulary can confuse since students are not familiar with the meaning of words such as "DNA" "RNA" "replication" and, "transcription" (Delgado, 2014). Another difficulty that can be found in the process of learning the central dogma is the lack of practical experience since this is a molecular process that is difficult to observe, so students owe their explanations to models and simulations. (Cantillo, 2022).

Some studies showed the difficulties mentioned above, but strategies were also implemented that allowed the student to understand aspects related to the central dogma of molecular biology.

Works like Delgado´s (2014), highlight the use of technological tools to teach molecular biology concepts such as DNA, RNA, and proteins. Using tools like Moodle, they indicated that explicit instruction on metacognitive strategies, such as planning, monitoring, and evaluating learning, significantly improved students' understanding of complex biological concepts. Other works carried out used strategies such as analogies (Rendón-Criollo et al., 2021) to improve the understanding of genetic concepts in ninth-grade students.

In general terms, the strategies that allow students to appropriate the concepts and have self-regulated learning at their own pace, allow, in the case of learning the central dogma of molecular biology, to help them relate the concepts to their daily lives. (Peña-Fonseca et al., 2022a) By providing students with hands-on learning opportunities and addressing their misconceptions, teachers can help them develop a deep understanding of this important concept. (Retone & Prudent, 2023a).

Writing constitutes a fundamental part of the learning process; this skill is a method that includes sets of visual symbols to represent language visually to communicate. That is why, to be able to write, as the stages of development pass, the acquisition of certain skills prior to writing must be met. This acquisition of skills according to Alzu'biM (2019) must be gradual.

Writing involves several processes, such as discovering ideas, which consists of putting words on paper, as well as selecting and organizing them. An important part of the writing process is that you need to cover content, vocabulary organization, and the use of grammar.

According to Wells G. (1987), the uses of written language entail different degrees of cognitive activity, with the epistemic level being central to teaching and learning. Within the uses of written language, taking notes or recording information is a process that occurs in many situations. This process constitutes a stable external memory that aims to help plan a future activity, learn, think, or create. That is why note-taking becomes important since it involves understanding and production, which is like the original composition.

Those who take notes store the information in long-term memory, writing it down. In the classroom note-taking is the most common way to produce study materials (Garcia et al., 2013). When the student takes notes, he remains attentive and follows the thought process that the teacher proposes in class. In this thought process, knowing how to listen to understand, writing quickly, writing while listening to the teacher, writing and looking up at the blackboard simultaneously, and exercising memory come together. (Beltrán Llera, 1993). However, this assumption is not always met, since factors such as the lack of teaching how to take notes (Briceño, 2021), and distractions due to the regular use of mobile devices such as Smartphones (Witherby & Tauber, 2019) are a barrier to teaching note taking in the school context.

Teaching note-taking strategies involves instructing students in the use of information recording tools, but it also involves a process of helping to raise awareness about the purpose of taking notes and the conditions under which it should be done. This process, according to Piolat et al. (2005), takes several years of practice in academic contexts such as high school and college, as it places significant demands on limited working memory resources. It is then a complex activity that involves bringing together processes of understanding and production.

In the strategies for teaching note-taking, those who use a diagram or table seek the organization of the information in the space of the sheet, something very useful since the student dedicates time and effort to locate complex relationships between the information and helps the memorization process (Briceño, 2021).

The Cornell method was implemented by the professor of the Faculty of Psychology Walter Pauk of Cornell University in 1940 and consists of a double-column method, according to some authors it is an organization of notes, where the left column is one-third of the page and the one on the right is two-thirds of the page. The right column is for the reader or student to write down the ideas and facts that are shared during class. The left column is then filled with questions or main ideas of the most important points. (Briceño, 2021; Pauk, 2011). According to the creator of this note-taking method, writing down questions and ideas serves to highlight the main points, meanings, and relationships. In addition, it establishes continuity and strengthens memory (Pauk, 2011)

3. Methodology

This research uses a qualitative approach since data collected from students' writings is used, students' understanding is explored, and how they construct meaning about concepts such as DNA and RNA using the Cornell method.

Context

The writings of 21 ninth-grade students who used the Cornell method during the year 2024 in biology class at the José María Bravo Márquez Educational Institution in the city of Medellín - Colombia were chosen.

The writings of these students were selected, considering their class notes, the use of the Cornell method, and the mention of the concepts used within the explanation of the central dogma of molecular biology.

To collect the data, the Google Classroom platform was used, where students uploaded their class notes, corresponding to the current school week. The file uploaded to said platform was a photograph of the notes in his notebooks.

This research uses a content analysis methodology, based on a semantic perspective to understand students' meaning creation, which is a technique that uses a set of procedures to make reproducible and valid inferences from a text. (Bardin, 1991; Krippendorff, 1990).

4. Results and Analysis

The results of this work are based on the analysis of students' responses about DNA and RNA prepared in their class notes, in which three levels of understanding were identified: form, composition, and function.

Three levels of analysis for DNA and RNA differentiation

For the analyzed writings, three levels were established to observe how well students understand the differences between DNA and RNA. The levels focus on whether students use one, two, or three key aspects of these molecules to differentiate them.

Level 1: At this basic level, students use only one aspect to differentiate DNA from RNA. They can mention:

Shape: Recognizing the double helix shape of DNA compared to the single strand of RNA.
Composition: Identifying that DNA has thymine while RNA has uracil.
Function: Understanding that DNA stores genetic information while RNA acts as a messenger, copying and transmitting that information.

Level 2: Students at this level show a deeper understanding by using two aspects to differentiate between DNA and RNA. They can connect:

Form and composition: For example, describing the double helix structure of DNA and pointing out its specific nucleotide components.
Form and function: Recognizing the double helix shape and relating it to the role of DNA in the storage of genetic information.
Composition and function: Understanding that the presence of uracil in RNA is related to its role in protein synthesis.

Level 3: This level represents the most sophisticated understanding, where students use all three aspects: form, composition, and function, to distinguish between DNA and RNA. They demonstrate a comprehensive understanding of the structure, components, and roles of molecules in biological processes.

The texts show examples of student responses at each level, highlighting the progression in understanding as students move from focusing on a single aspect to integrating all three.

Analysis results at level 1:
The students' responses, presented in the cases (E5, E6, E13, E14, E15, E16, E19), show similarities and differences in the way they understand and articulate the functions and characteristics of DNA and RNA. These can be grouped around two main perspectives: structural and conceptual differences between DNA and RNA; and function of DNA and RNA. The similarities and differences between the cases are detailed below:

Similarities: Like RNA to DNA, students adhere to theory in their explanations
In several cases (E5, E13, E14, E15, E16), students highlight the role of DNA as a carrier of genetic information and RNA as an intermediary that copies and transmits that information for the synthesis of proteins, as we can see in some of his statements:

> *"RNA copies information from DNA. This information will then be used to create something"* (E5)
> *"Things are transmitted to RNA"* (E 14)

This pattern of understanding is consistent with the central dogma of molecular biology. In cases E5, E14, E15, and E16, the role of RNA in transcription is highlighted, as evidenced in the statement: *"DNA has information. "RNA copies the information from DNA."* (E15). This statement accurately reflects how messenger RNA (mRNA) copies the genetic code, allowing its subsequent translation into proteins. In both cases E5 and E14, students highlight the linear sequence of the flow of genetic information, from DNA to RNA, which reinforces their understanding of the biological process that follows an established order.

2. Differences: students' understanding of the central dogma of molecular biology.
We have grouped here the organization of the diverse ways of conceptualizing DNA and RNA by students, namely:
2.1 Students observe DNA and RNA like an architect evaluates a work
E6 (image 1) and E19 (image 2) make a more precise focus on the structural differences between DNA and RNA.

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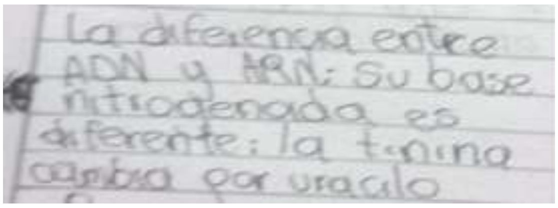

La diferencia entre
ADN y ARN: Su base
nitrogenada es
diferente: la timina
cambia por uracilo

Image 1: Text E6

E6 highlights the difference in the nitrogenous bases (adenine, guanine, cytosine, and uracil in RNA, instead of thymine in DNA), while E19 (image 2) focuses on the physical shape of the molecules (double helix in the DNA versus linear chain of RNA).

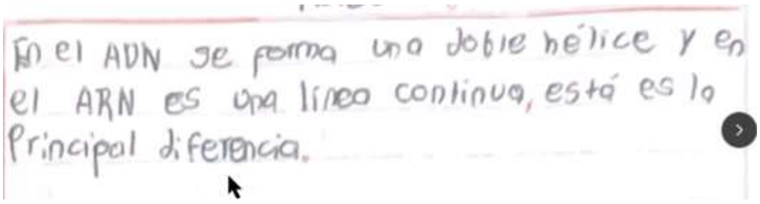

En el ADN se forma una doble hélice y en
el ARN es una linea continua, está es la
Principal diferencia.

Image 2: Text E19

In contrast, the other cases (E5, E13, E14, E15, E16) focus more on functions and not on detailed structural features.

2.2 Analogies and Explanations

In the case of E13, the student uses an analogy to differentiate the functioning of DNA and RNA, which consists of assuming DNA is a manual that contains information and RNA is a photocopy of this information:

"DNA and RNA join to form protein. The DNA is a manual, the RNA is a photocopy, and the protein is the construction..." (E13)

The manual does not operate its information on its own, but the photocopy has the information and can be used for other purposes and that is what the ARN does. This approach is different from that of E16, which describes the process in more technical language, using terms such as "mold" and "transcription."

"It is the process by which part of the genetic message of DNA is transcribed in the form of messenger RNA. Messenger RNA is synthesized within the nucleus from a single DNA strand as a template. (E16)

Despite using technical language, the student manages to describe the transcription process and understands the function and structure of each nucleotide.

2.3 Assessing the transformation of DNA, a journey to the discovery of RNA

In cases E14 and E16, we explicitly talk about a transformation from DNA to RNA, highlighting the logical and functional sequence of the information flow. This idea is visually reinforced in E14 using a diagram (image 3):

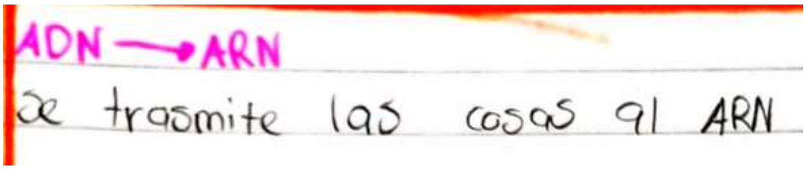

ADN → ARN
se trasmite las cosas al ARN

Image 3: Text E14

While E16 places a verbal emphasis on the idea of mold and copy. Other cases, such as E5 and E15, although they mention the copying process, do not highlight the transformation as such, but rather focus on the actions of the molecules (copying and having information).

2.4 Students unlock the mystery of gene expression, understanding how RNA orchestrates protein synthesis

Case E5 (image 4) shows the sequential and functional relationship that connects DNA and RNA in the creation of biological products, which provides a deeper understanding of the role of RNA beyond the simple copying of information.

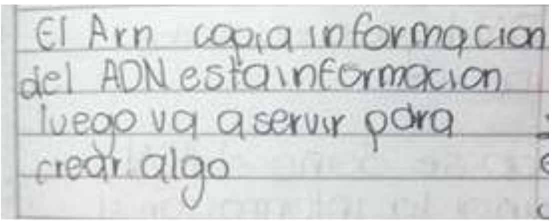

El Arn copia informacion
del ADN esta informacion
luego va a servir para
crear algo

Image 4: Text E5

In summary, for level 1 the similarities between the cases lie in the functional differentiation between DNA and RNA and the recognition of the role of both in the transcription and transfer of genetic information. As for the differences, they are presented both in detail and as the students' approach: some delve into the structural characteristics (E6, E19), others in the process of transcription and transformation (E14, E16), and some use analogies to explain the function. of these molecules (E13). This reflects a diversity in conceptual understanding of the central dogma of molecular biology and the differentiation between DNA and RNA.

Analysis results at level 2:

After analyzing the content of the cases presented (E7, E8, E10, and E20) on the students' work on DNA and RNA, similarities and differences can be identified in their approaches and how they address the function and structure of these molecules.

1. **Similarities: Linking form and function, students connect structure and action in DNA and RNA.**

1.1 Students reveal the link between DNA and RNA

All students refer to the transformation of DNA into RNA. Cases E7, E8, and E20 all mention the process of change between the two molecules in some way, suggesting a shared understanding of the central dogma of molecular biology:

> *"DNA is transformed into messenger RNA, using the template of a DNA and then converts it to RNA"* (E7)
>
> *"It is the process by which the genetic message of DNA is transcribed in the form of messenger RNA"* (E8)

1.2 Coherence with Scientific Theory

Each student shows that their understanding is consistent with scientific theory related to DNA and RNA. This is observed in the assignment of functions to each molecule, the identification of its characteristics, and the reflection on transcription processes.

1.3 Function Description

All cases include an assignment of specific functions to the molecules, which allows a better understanding of the role of each one in biological processes.

2. Differences: Exploring Students' Reasoning About the Roles of DNA and RNA

2.1 Revealing the blueprint: Students assemble the molecular puzzle of DNA and RNA to discover the blueprint of life.

Cases E7 and E8 focus more on the function of DNA and RNA, emphasizing the transformation process and the meaning of the message. This reflects a more conceptual and functional understanding of the topic.

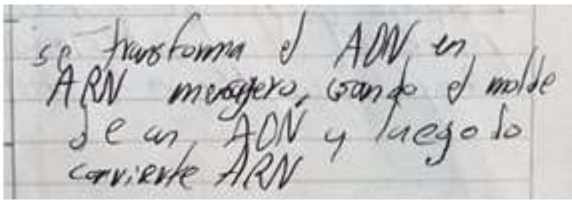

se transforma el ADN en ARN mensajero, usando el molde de un ADN y luego lo convierte ARN

Image 5: Text E7

For their part, cases E10 and E20 (image 6), place more emphasis on the structure of the molecules, such as the shape of the double helix and the composition of nucleotides, highlighting specific differences in the structure (such as the presence of uracil in RNA compared to thymine in DNA).

ADN	ARN
De sexiriboso	Ribosa
Adenina	Adenina
Guanina	Guanina
citosina	Citosina
Timina	uracilo

Image 6: Text E20

2.2 Presentation of Information

Case E7 (image 7) uses arrows to visually represent the transcription process, making it easier to understand the flow between molecules.

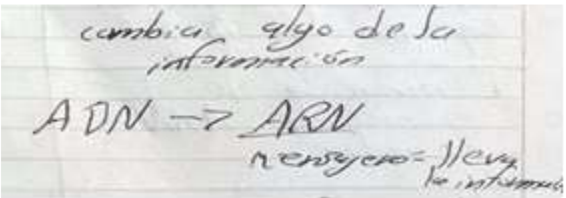

cambia algo de la información
ADN -> ARN
mensajero = lleva la información

Image 7: Text E7

Case E20 presents tabular information (see image), analyzing the differences and similarities in a more structured way, which can be useful for a quick comparative view, although it lacks the visualization of processes observed in case E7.

2.3 Focus on Analogy
Case E20 uses an analogy when discussing the function of molecules, while E10 focuses on the ladder analogy to describe the structure of DNA.

"It is represented in models with the shape of a staircase" (E10)

This shows that the student uses different techniques to communicate the same information, varying between analogies and graphic representations.

2.4 Assessing RNA
Case E8 mentions message transformation as a key characteristic, which may indicate a deeper level of analysis regarding the functional impact of RNA, contrasting with others that simply indicate the process without delving into its meaning.

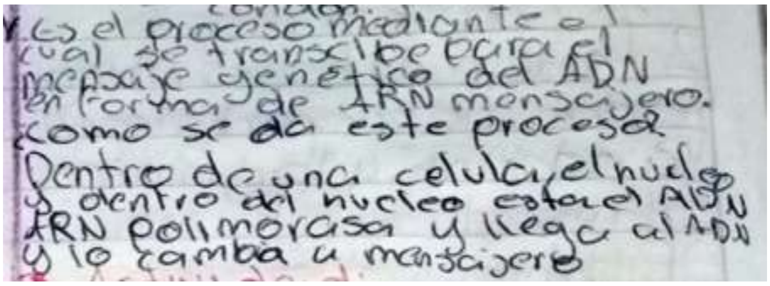

Es el proceso mediante el
cual se transcribe para el
mensaje genetico del ADN
en forma de ARN mensajero.
Como se da este proceso
Dentro de una celula, el nucleo
y dentro del nucleo esta el ADN
ARN polimerasa y llega al ADN
y lo cambia a mensajero

Image 8: Text E8
In conclusion, for level two, it can be stated that: although all students present a coherent understanding aligned with scientific theory about DNA and RNA, each one chooses different approaches and presentation styles. This reflects the diversity of ways in which scientific knowledge can be conceptualized and communicated, emphasizing several aspects such as function, structure, and visual representation.

Level 3 analysis results:
By analyzing the cases presented (E17 and E21) about the student's work in relation to DNA and RNA, similarities and differences can be identified in their approaches and in the way they address the characteristics, functions, and relationships of these molecules.

1. **Similarities: Emphasizing shared understandings**

1.1 Deciphering the genetic library: Students, as librarians, organize RNA and DNA information
Both cases E17 and E21 organize the information in a structured way, presenting the characteristics of DNA and RNA in a clear and categorized manner. This allows an effective comparison between both molecules.

1.2 As engineers, students build the idea of genetic machinery: Thymine and uracil in action

Both students mention key elements of the composition: Thymine and Uracil for DNA and RNA, respectively. They also highlight the differences in structure, specifically the double helix shape for DNA and the single strand shape for RNA.

1.3 Coherence with Scientific Theory

The explanations offered by both students are consistent with the central dogma of molecular biology, highlighting the importance of these characteristics to understand the functions of DNA and RNA molecules.

2. **Differences: highlighting nuances in students' understanding**

2.1 Use of Analogies

Case E17 uses an analogy to communicate the function of DNA and RNA, describing them as a "manual" and a "photocopy," respectively. This analogy can help make the function of each molecule more tangible and understandable.

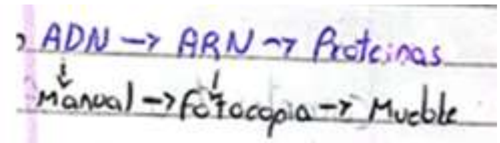
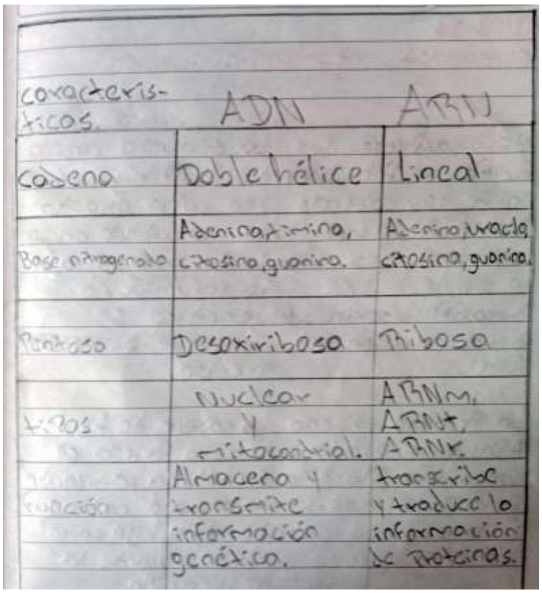


Image 9: Text E17

On the other hand, case E21 limits itself to presenting the information more directly and academically, without resorting to analogies, which can lead to a more technical but less accessible understanding.



caracteristicas	ADN	ARN
Cadena	Doble hélice	Lineal
Base nitrogenada	Adenina, timina, citosina, guanina.	Adenina, uracilo, citosina, guanina.
Pentosa	Desoxiribosa	Ribosa
Tipos	Nuclear y mitocondrial.	ARNm, ARNt, ARNr.
Función	Almacena y transmite información genética.	transcribe y traduce la información de proteínas.

Image 10: Text E21

2.2 Depth in Function Description

Case E17 explicitly mentions function and the relationship to information processing, showing a level of understanding that includes not only composition and structure but also how these characteristics relate to the functionality of molecules.

For its part, case E21, although it also mentions function, seems to focus more on the collection of characteristics, without delving into their application or functional relevance, which could indicate a more superficial approach in terms of understanding the implications of these characteristics:

2.3 Presentation of Information

Case E17 appears to be more descriptive and narrative in its presentation, which could involve a more dynamic analysis of features and functions.

N change E21 is observed more focused on the presentation of differences, which can result in a more structured and less narrative presentation.

Overall, both students demonstrate an effective understanding of the relationship between DNA and RNA by organizing and presenting the essential characteristics of these molecules. However, E17 stands out for its use of analogies and for going deeper into the function, which can facilitate the understanding of the information presented. Case E21, by offering a more technical collection of features, may be useful in contexts where greater clarity is sought in structural comparison, although it could benefit from including more in-depth analysis or contextual examples. These differences in approach and presentation highlight the variety of learning styles

The students demonstrated that they could structure the content. This is an advantage in that the method allows for an organized record so that it can be consulted repeatedly and at the discretion of the students.

5. Discussion

The analysis presented shows a consistent pattern of student learning progression through three different levels of understanding regarding DNA and RNA. This pattern aligns with the findings and suggestions presented in other works. (Cantillo Maldonado, 2022; M. Delgado Naranjo, 2014; Freitas et al., 2020b; Pelletreau et al., 2016; Peña-Fonseca et al., 2022b; Rendón-Criollo & Leal-Castro, 2021; Retone & Prudent, 2023b; 2024), emphasizing the need for diverse teaching methods that adapt to diverse learning styles and facilitate a deeper understanding of complex biological concepts.

The initial focus on structural differences observed in Level 1 of this analysis is consistent with common “misconceptions” identified in work such as those of Cantillo Maldonado (2022) and Retone & Prudent (2023b). These sources highlight the need to address preconceived notions and build on students' prior knowledge to facilitate conceptual change.

The progression to Level 2, where students connect form and function, aligns with pedagogical approaches advocated in other works. The emphasis of Rendón-Criollo & Leal-Castro (2021) on the analogies resonates with the use of comparative language and visual representations observed in the analysis of this paper. By relating abstract concepts like transcription to familiar scenarios, students can bridge the gap between theoretical knowledge and practical understanding. Similarly, Freitas et al. (2020b), highlight the value of alternative models, advocating for multisensory learning experiences that facilitate deeper engagement with the subject matter. The visual resources and practical activities described in both Delgado (2014) and Freitas et al. (2020b), support this approach, offering representations of the dynamic processes involved in the central dogma of molecular biology.

The most sophisticated level of understanding, Level 3, where students integrate form, composition, and function, reflects the successful application of the pedagogical strategies discussed. Exploring gamification in Peña-Fonseca et al. (2022b), for example, provides a framework for engaging students in interactive learning experiences that require the application of knowledge and problem-solving skills. The multi-level challenges described by the researchers, progressing from basic identification to protein modeling and sequence comparison, reflect the analytical progression observed in the results of this content analysis, culminating in a more holistic understanding of the central dogma. Furthermore, the analysis of metaphors by Wahlberg et al. (2024) highlights the importance of language and conceptual framing in scientific communication, emphasizing how carefully selected metaphors can facilitate a more nuanced understanding of complex biological processes. The nuanced interpretations and explanations observed at Level 3 of this work suggest the successful integration of such metaphorical reasoning into students' understanding.

Pelletreau et al. (2016) advocate for active learning strategies, encouraging student participation through discussions and collaborative activities. This aligns with the student-centered approach implicit in this work, where students are encouraged to create their notes, diagrams, and explanations; By actively constructing their framework of knowledge, students move from passive reception of information to becoming active participants in their learning process. The diverse approaches and representations observed at various levels of analysis suggest the success of such active learning techniques.

In summary, the findings of this work strongly support the arguments and pedagogical suggestions presented by other authors. These sources collectively highlight the importance of moving beyond traditional lecture-based teaching methods to adopt a more interactive, student-centered approach that encourages critical thinking, problem-solving, and a deep understanding of the complexities of biology. molecular.

6. Conclusions

The study reveals significant progress in the understanding of DNA and RNA concepts among ninth-grade students using the Cornell method. Initially, students focused on identifying basic structural differences between both molecules but progressed toward a more integrated understanding that includes aspects of composition and function. This progress reflects the effectiveness of the method in promoting meaningful learning, allowing students to establish connections between theoretical concepts and their practical applications. However, some faced difficulties explaining biological processes in detail and explicitly relating structure to function, suggesting the need for additional strategies to strengthen these skills.

The analysis highlights that the Cornell method promotes active reflection through the column of questions, which facilitates both the consolidation of essential concepts and the development of scientific competencies. Students used various approaches, such as analogies and diagrams, to interpret complex concepts, demonstrating how this tool can adapt to different learning styles. This flexibility makes the method an inclusive and effective option, capable of addressing the diverse ways in which students process information.

Furthermore, organizing information using this method not only improves conceptual understanding but also facilitates the clear and coherent communication of ideas. This is particularly valuable in disciplines such as molecular biology, where a precise integration of structural and functional concepts is required. In this context, the Cornell method contributed to improving students' ability to connect theoretical learning with biological processes, promoting their autonomy and critical thinking.

In general, it is concluded that the Cornell method is a pedagogical tool with high potential to promote active learning and self-regulation, essential elements for scientific training in school stages. Its implementation allowed students to advance their conceptual understanding and develop critical skills, preparing them to face educational challenges in science.

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