DNA Structure Through Diagrams: A Source of Challenging the Understanding of Students

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Abstract

The subject biology intends to give students understanding, through general teaching-learning objectives based on the 'principle of constructivism' i.e. self-learning. A clear understanding of DNA structure is a central learning outcome in biology, underpinning concepts in genetics, heredity and molecular biology as well as one of the expected competency after studying the related content at higher secondary level biology. Students often misinterpret canonical diagrams of DNA, mistaking symbolic representations for literal structures. This study explores difficulties in understanding structure of DNA with diagram and how it affects diagram comprehension. In a study, a survey of 30 higher secondary students studying biology revealed widespread misconceptions regarding DNA structure, particularly about nucleotide composition, base pairing, and the significance of the double helix. Results from survey suggest that intervention with videos showing DNA being dynamically drawn by a visible hand drawing (embodied drawing) will scaffold students in improvement of conceptual understanding of DNA structure and diagram comprehension along with more accurate retention. These findings also suggest that embodied drawing can significantly improve visual literacy in biology education and should be integrated into curriculum reform and examination-based instruction.

Keywords: DNA structure · Visualization · Diagram comprehension · Biology education · Visual literacy

Introduction:

Diagrams most likely represent one of the very oldest methods of human communication. They are employed not merely for representation, but also employed to perform some kinds of reasoning, and therefore have a specific role to play in various subjects. They are typical representations of intricate notions, relationships and occurrences, frequently used when it would be difficult to describe the same information using natural images. The Culture of diagram is concerned with visual thinking and expressing the thoughts. Exploring a landscape where words meets pictures, diagrams serve as mediators of dissolving the boundaries to focus on the production of knowledge as process.

Role of Diagrams in Biology Education:

Diagrams are the pivotal teaching tool in biology education due to the fact that they simplify complex and frequently unseen processes. DNA replication, protein synthesis, or cell signalling are examples of biological processes that cannot be seen directly. Diagrams function as models, translating abstract ideas into visual formats, enabling students to construct mental models of otherwise inaccessible processes. For instance, the classic double helix illustration of DNA is now a global symbol of molecular biology that has assisted generations of students in understanding its structural foundation of heredity.

In addition to representation, diagrams also offer cognitive facilitation to learning. Diagrams minimize cognitive load by expressing information visually and supplementing text, which enhances memory by dual coding. Diagrams assist students in reasoning about biological processes instead of mere rote memorization. For example, a cell cycle diagram visualizes the sequential and cyclical nature of mitosis to aid conceptual understanding. In addition, studies have demonstrated that sketching and incrementally building diagrams promotes visual literacy and corrects prevalent misconceptions, including nucleotides being mistakenly identified as amino acids or symbolic conventions being misunderstood.

Lastly, diagrams have a deep rootedness in curriculum and assessment. Textbooks, national curricula, and international standards alike all place strong emphasis on diagram-based teaching. Tests often ask students to mark, interpret, or compare biological diagrams, so visual literacy along with diagram comprehension is a key skill to master for success in class. Diagrams also actively engage learners: when students draw or annotate them, they enhance their comprehension and convey science more clearly. In a way, diagrams are not simply pictures but potent pedagogical tools that link knowledge, reasoning, and communication in biology.

DNA Structure and the Challenge of Diagrammatic Representation:

DNA structure is a cornerstone of biology education, serving as the basis for understanding replication, transcription, and inheritance (Gilbert, 2005). While the double helix is iconic, studies show that students frequently misunderstand the symbolic meaning of diagrams, confusing nucleotides with amino acids, misinterpreting base pairing, or treating textbook illustrations as literal depictions. (Mathai & Ramadas, 2009; Novick & Catley, 2007). Researches have shown that students typically lack a coherent view of concepts like DNA structure and their relationships when studying molecular biology within instruction-based lecture with no other pedagogical applications (Melek, A., & Mahmure, N. 2009).

Conceptual and Empirical Insights from research studies:

Static vs. Dynamic Visualizations: Static visuals, such as textbook diagrams, are common in biology but often fail to capture dynamic processes like DNA replication or the spatial symmetry of the helix (Gilbert, 2005). Dynamic visuals—animations or progressive drawings—can reduce cognitive load by unfolding information over time (Höffler & Leutner, 2007). However, their transient nature may overwhelm learners if not scaffolded (Ayres et al., 2009).

Embodied Cognition in Science Learning: The theory of embodied cognition suggests that observing physical actions (e.g., drawing, pointing) can guide attention and enhance conceptual learning (Wilson, 2002; Glenberg et al., 2011). Mayer (2014) describes this as the embodiment principle in multimedia learning, which has been shown to improve comprehension when instructors' hands or gestures are visible.

Drawing as a Pedagogical Tool: Drawing promotes model-based reasoning in biology (Quillin & Thomas, 2015). Students who observe instructors drawing processes (e.g., DNA replication) learn more effectively than those who only view static outcomes (Fiorella & Mayer, 2016). Yet, the unique benefits of drawing-hand videos compared to cursor-guided animations remain underexplored.

Rationale and Purpose of the study:

Diagrams play a crucial role in science learning but can also perpetuate misconceptions when learners lack the skills to interpret them (Quillin & Thomas, 2015). Scientific diagrams often rely on conventions such as arrows for processes, dotted lines for invisible boundaries or no shading for biological diagrams. If learners don't know these conventions, they may read them literally and develop misconceptions. As Offerdahl et al. (2017) argue, developing visual literacy means the ability to extract meaning from diagrams and connect them to scientific principles is essential for modern biology instruction.

Diagrams are abstractions, not fact. A simple textbook diagram of the DNA structure can mislead students into believing that the rungs of DNA and amino acids are exactly alike in function or shape. Without teaching, they may mistake "schematic" fidelity for anatomical truth.

This research strongly suggests on the use of dynamic drawing-hand videos might support students in overcoming diagram-based misunderstandings of DNA. By showing a hand progressively constructing diagrams, learners may be better able to track symbolic conventions, sequencing, and functional connections. Studies emphasises that dynamic, embodied diagrams present direct attention and facilitate deeper learning than static images. Without scaffolding, however, learners tend to hold on to superficial visual information instead of constructing conceptual meaning.

Harvest: An International Multidisciplinary and Multilingual Research Journal

E-ISSN: 2582-9866 Volume V Special Issue IV October 2025

Research Methodology:

Design of the study:

The present research employed a survey-based descriptive design to investigate students' challenges in understanding the structure of DNA through diagrams. The descriptive approach was chosen as it allows for the systematic identification and analysis of existing misconceptions without manipulating variables. Data were collected through a structured questionnaire administered to higher secondary biology students, focusing on their interpretation of DNA diagrams and perceived strategies for improving comprehension.

Sample:

The sample consisted of 30 higher secondary students whose one subject was biology enrolled in an educational institution in Mumbai district.

Tool

A structured open-response questionnaire was developed, consisting of 12 questions on DNA structure. The items focused on recognition of the double helix, nucleotide composition, complementary base-pairing rules, interpretation of textbook diagrams, and connections between DNA structure and function.

Data Collection

The questionnaire was administered during regular class hours with prior permission from the institution.

Data Analysis

Student responses were systematically coded as correct, partially correct, or incorrect (table 1). Incorrect responses were further categorized according to misconception type.

Table 1

Category	Question	correct	Partially correct	incorrect	Misconception
1.Basic Conceptual Understanding	Shape of DNA	12	4	14	DNA is a single strand. DNA is "spiral" with no functional explanation. Confuses helix with histones/chromosomes.
	Components of Nucleotide	14	4	12	Omits phosphate/sugar. Confuses nucleotides with amino acids. Thinks nucleotides are only bases.
	Complementary Strands	17	0	13	Says bases pair "randomly." Thinks A pairs with G or T pairs with C. Confuses complementary with identical strands.
		(43)	(8)	(39)	
		47.77%	8.88%	43.33%	
2.Interpretation of Diagrams	Twisted Ladder Analogy	8	3	19	Rungs represent amino acids. Twisting is decorative, not functional.

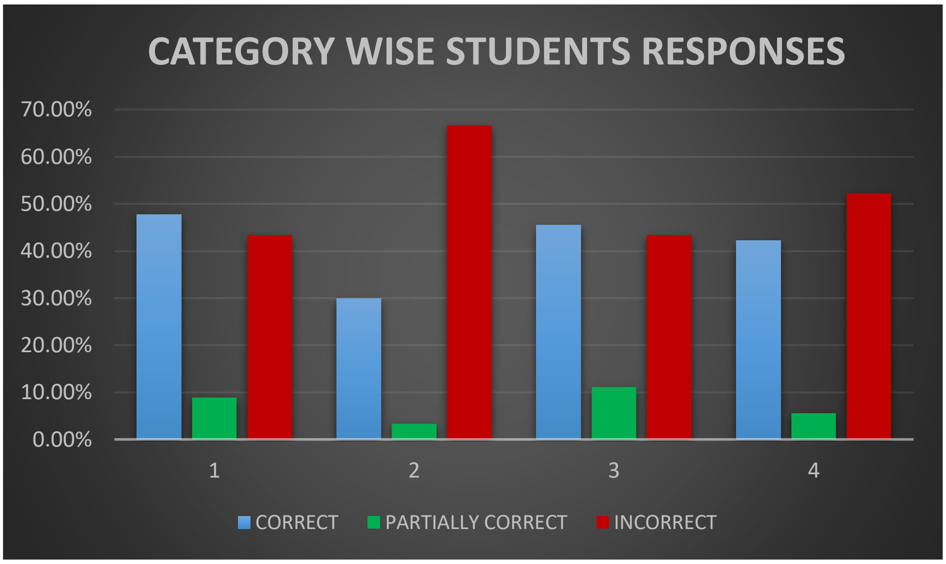
	Purine–Pyrimidine Pairing	10	0	20	Thinks purines can pair with purines. Width of DNA varies with pairing.
	Backbone and Rungs	9	0	21	Backbone = proteins. Bases form the backbone
		(27)	(3)	(60)	
		30%	3.33%	66.66%	
3.Misconception Probes	Base Pairing Randomness	11	6	13	Bases pair randomly, or pairing changes in different cells.
	Width of DNA	13	3	14	Width expands/ shrinks with different bases. DNA can “collapse” when bases mismatch
	Straight Ladder Diagram	17	1	12	Must be twisted to be DNA. Straight = RNA, twisted = DNA.
		(41)	(10)	(39)	
		45.55%	11.11%	43.33%	
4.Functional Connections	DNA Replication	13	0	17	Replication is random. New bases attach “anywhere.”
	Hydrogen Bonds	15	1	14	Bonds are covalent (permanent). Bonds “store energy” like ATP.
	Double Helix & Stability	10	4	16	Helix exists only for space-saving. Twisting prevents mutations “mechanically.”
		(38)	(5)	(47)	
		42.22%	5.55%	52.22%	
		149	26	185	
percentage		41.38%	7.22%	51.38%	

Results

Survey results (chart 1) from study showed correctness rates of different questions ranging from 30–47% with overall percentage of 41.38%. and incorrect rates ranging from 43 – 66% where students seem to be struggling with DNA related various concepts. Students performed best on complementary base pairing (56%) and the functional role of hydrogen bonds (42%) but struggled with purine–pyrimidine pairing (33%) and twisted strands of DNA (26%) while interpretation of diagram showing 66.66% of incorrectness.

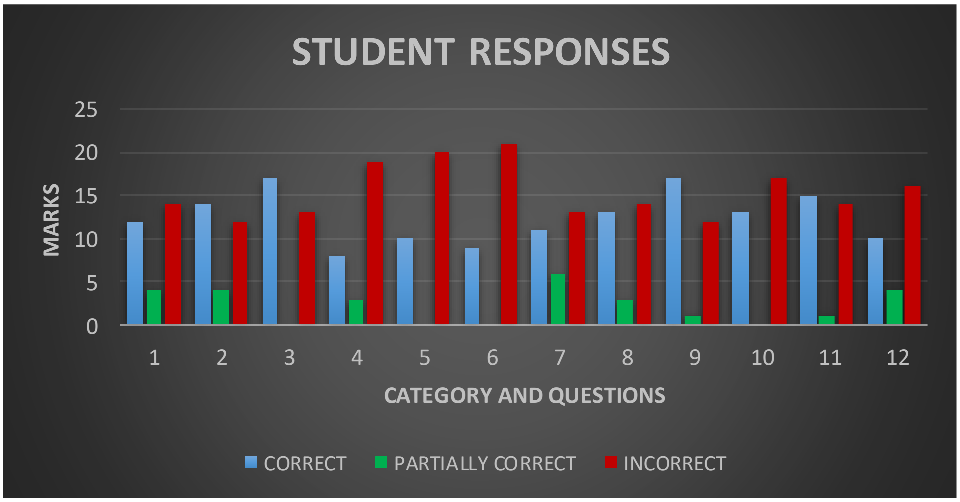
Harvest: An International Multidisciplinary and Multilingual Research Journal
E-ISSN: 2582-9866 Volume V Special Issue IV October 2025

CHART 1



After analysing student's responses given for 12 questions for 4 different categories, researcher could able to find out some misconceptions. Common misconceptions included:
•DNA drawn as a single strand or mistaken for a chromosome.
•Confusing nucleotides with amino acids.
•Believing base pairing is random.
•Assuming DNA width varies with base pairs.
• Misinterpreting simplified diagrams (e.g., straight ladder DNA = RNA).

CHART 2



Researcher categorizes student misconceptions obtained from responses of 12 questions about DNA structure into following themes:
•Misunderstanding molecular components (nucleotide/base confusion).47.77%
•Misinterpreting diagrams (ladder analogy, backbone meaning).66.66%
•Random vs. rule-based pairing.43.33%
•Structure–function disconnection 52.22%

Discussion:

The findings reveal that while students can recall basic DNA features, they struggle to interpret diagrams symbolically and to connect structural features with biological function. This aligns with prior research showing that static diagrams often reinforce rote memorization rather than conceptual reasoning (Mathai & Ramadas, 2009; Offerdahl et al., 2017).

Embodied drawing proved particularly effective for immediate comprehension, likely because the visible hand directed attention and slowed the presentation of information, reducing cognitive overload (Mayer, 2014). These benefits are long-term, suggesting that attentional guidance is as critical as embodiment.

These findings suggest that visualizing the construction of DNA—rather than only viewing its finished diagram—encourages deeper learning. The stepwise drawing process supports mental simulation (Hegarty, 2005) and fosters integration of text and image (Schnotz & Bannert, 2003). If the students not being taught explicitly how to read the visual aids intended to make information clearer can actually reinforce alternative conceptions which can solidify to form misconceptions.

For curriculum reform, drawing-hand videos reinforce a shift from rote memorization toward conceptual understanding of bio molecular processes. For examination-based education, they help students tackle common diagram-based tasks such as labelling DNA components, predicting replication outcomes, or contrasting RNA with DNA structures.

Educational implications and recommendation:

A teacher should draw the DNA double helix structure using two colour chalk on blackboard or colour pens on whiteboard while explaining its structure step by step.

Biology curricula should integrate dynamic drawing-hand videos into instruction, especially for foundational topics like DNA structure.

Assessments should test not just recall (e.g., labelling bases) but interpretation and reasoning (e.g., why purine–pyrimidine pairing ensures stability).

Curriculum reforms should emphasize visual literacy as a core competency in science education.

Conclusion:

This study suggests that only drawing from static textbook diagrams will not be helpful than watching a drawing hand videos and practicing them will enhance students' comprehension of DNA structure, addressing misconceptions and strengthening visual literacy. It also illustrates that incorporating embodied drawing videos into classroom instruction, online platforms, and exam preparation materials can better align biology education with the goals of curriculum reform and deeper conceptual understanding.

Drawing-hand videos provide an effective strategy for teaching the structure of DNA. By combining clarity, sequence, and interactivity, they help students overcome persistent misconceptions and strengthen their ability to apply structural knowledge to biological processes. Their integration into curricula and assessments can improve both classroom learning and exam performance, advancing modern biology education.

Students also make use of diagrams and images to represent environmental concepts, such as pollution, climate change and conservation. Visual literacy can promote environmental awareness, ecological literacy which ultimately leads to more environmentally conscious and responsible society.

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