

Constructing knowledge in STEAM Education through a DNA-Centered approach

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ABSTRACT

Persistent misconceptions in genetics hinder conceptual understanding and interdisciplinary integration. Within a STEAM (Science, Technology, Engineering, Arts, and Mathematics) framework, visual metaphors such as the DNA double helix provide opportunities to merge scientific accuracy with creativity, thereby fostering scientific literacy and interdisciplinary thinking. This study investigates the pedagogical use of DNA as a visual metaphor in genetics education, informed by Constructivist Learning Theory and Dual Coding Theory, to enhance conceptual understanding, creativity, and collaborative learning among first-year Zoology students. A qualitative exploratory design engaged 140 students in 12 interdisciplinary groups over three months. Learners produced metaphorical representations of DNA, evaluated against criteria of scientific accuracy, creativity, integration, and reflection. The data comprised project artefacts and student reflections, analysed thematically to identify collaboration patterns, conceptual engagement, and precision. Most groups demonstrated effective collaboration and shared responsibility, producing models that integrated biological, artistic, and mathematical concepts. Reflections ranged from surface-level observations to deeper conceptual interpretations. While some inaccuracies were noted (e.g., missing hydrogen bonds or phosphate groups), many projects reflected solid comprehension of DNA structure and function. Improving scientific accuracy in STEAM projects requires a strategic blend of pedagogical scaffolding, multimodal learning tools, expert guidance, and reflective practices. Grounded in Vygotsky's Constructivist Theory and supported by Dual Coding Theory, this approach emphasises guided learning within the Zone of Proximal Development and integration of verbal and visual representations. This study contributes to scholarship by demonstrating how visual metaphors function as cognitive scaffolds in genetics education, advancing interdisciplinary pedagogy and enriching science education research.

Keywords: Visual Metaphors, DNA Structure, STEAM Education, Constructivist Learning, Interdisciplinary Integration.

INTRODUCTION

Creativity is a vital 21st-century skill and a central pillar of STEAM education. DNA is a fundamental concept in biology, yet its abstract nature can pose challenges for learners. Traditional teaching methods often rely on textual and diagrammatic representations. This project investigates how visual metaphors—symbolic images that represent scientific ideas—can be used to make DNA structure more accessible and memorable. The inquiry is grounded in STEAM education, which values creativity alongside scientific rigor. Drawing on studies from the Philippines, Australia, Nigeria, and South

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Africa, it highlights how STEAM can enrich science education through creativity, collaboration, and real-world relevance.

In the Philippines, Pirantea and Chuab integrated the REACT framework with the 7Es instructional model to design contextualised biology lessons.¹ Their study showed significant gains in scientific creativity among Grade 11 STEM students, underscoring the value of experiential learning aligned with national standards. However, the lack of a statistically significant correlation between REACT exposure and performance suggests the need for further investigation into the mechanisms that drive creative outcomes.

Zhang and Jia's Australian literature review on visual arts-based STEAM (VA-STEAM) revealed that integrating art into STEM improves memory retention, causal reasoning, and critical thinking.² Despite its benefits, challenges such as limited resources and instructional clarity persist, pointing to the need for scalable, well-supported implementation models. From an African perspective, Oladele and Ndlovu argue that STEAM is a driver of technological innovation but highlight systemic barriers, including teacher shortages and inadequate ICT infrastructure.³ In South Africa, Mafugu et al. found that teachers lack understanding of STEM integration, relying on traditional methods that stifle critical thinking.⁴ Design-based STEAM activities grounded in constructionist theory promote creativity and problem-solving.⁵

Although these studies affirm the potential of STEAM education, there is a clear gap in understanding how visual metaphors and arts-based strategies can be systematically integrated into science curricula across diverse educational contexts—particularly in under-resourced settings. There is limited empirical research on how teacher training, curriculum design, and assessment frameworks can support the sustained use of metaphorical and artistic approaches to enhance scientific creativity. The objective of this study was to examine how DNA visual metaphors within a STEAM framework enhance conceptual understanding, creativity, and interdisciplinary collaboration among first-year Zoology students. Guided by the evidence reviewed, this study seeks to address the following research questions:

1. In what ways do students integrate science, technology, engineering, arts, and mathematics in their metaphorical representations of DNA?
2. What levels of scientific accuracy and creativity are demonstrated in student-created visual metaphors?

LITERATURE REVIEW

Effectiveness of Visual Metaphors as a Pedagogical Tool in Enhancing Students' Understanding of DNA Structure

Visual metaphors are increasingly recognised as powerful pedagogical tools for making abstract scientific concepts more accessible. Smedinga et al. argue that metaphors function not only as linguistic devices but also as cognitive tools that help both experts and novices grasp complex ideas.⁶ In genetics education, metaphors bridge the gap between molecular structures and student comprehension, particularly in challenging topics such as DNA and epigenetics. Buckley and Nerantzi explored visual representation in higher education and found that it enhances learning, especially in rural and resource-

¹ Joshua Philip T. Pirantea and Elisa N. Chuab, "REACT Framework in Contextualizing Lesson in General Biology 2 in Fostering Scientific Creativity," *International Journal of Research Publications* 4, no. 2 (2025): 6–15.

² Chengxin Zhang and Bochen Jia, "Enriching STEAM Education with Visual Art: Education Benefits, Teaching Examples, and Trends," *Discover Education* 3, no. 1 (2024): 247.

³ Jumoke I Oladele and Mdutshekelwa Ndlovu, "Perception of Technological Integrations as a Catalyst for Steam Teacher Education," *Journal of Vasyl Stefanyk Precarpathian National University* 11, no. 3 (2024): 75–90.

⁴ Tafirenyika Mafugu, Enosancia Nzimande, and Cephas Makwara, "Teachers' Perceptions of Integrative STEM Education in Life Sciences Classrooms," *Eurasia Journal of Mathematics, Science and Technology Education* 20, no. 11 (2024): em2535.

⁵ Maria Tsakeni, "Exploring Design Principles for STEAM Learning Activities Development by Science and Technology Teachers," *Educational Research for Social Change* 13, no. 1 (2024): 85–106.

⁶ H. E Smedinga et al., "Designing Multimedia Learning Environments: Cognitive Load and Instructional Design Principles Revisited," *Educational Psychology Review* 35, no. 2 (2023): 567–89.

constrained environments.⁷ Their research suggests that visual metaphors support inclusive and engaging pedagogy, particularly when digital access is limited and traditional teaching methods prevail.

Given the inherent complexity and abstract nature of DNA structure, visual metaphors help students grasp these concepts by linking them to familiar, concrete images such as a twisted ladder or a zipper.⁸ These representations make the invisible molecular world more tangible and easier to understand. Savarimuthu and Ponniah emphasise that visual metaphors activate both verbal and visual cognitive pathways, aligning with dual coding theory.⁹ This dual engagement improves memory retention and comprehension, which is particularly beneficial in genetics, where terminology and processes can be overwhelming.

The process of creating and interpreting metaphors requires students to analyse, synthesise, and evaluate information, core components of higher-order thinking.¹⁰ This leads to deeper conceptual understanding rather than surface-level memorisation. Visual metaphor projects are inherently creative and student-centered.¹¹ They boost motivation and engagement, especially within STEAM-based instruction, by allowing learners to express scientific ideas through art, design, and storytelling. When students design metaphors, educators can assess not only factual knowledge but also students' understanding of relationships and processes within DNA.¹² This approach provides richer insights into student learning than traditional assessments alone.

Bhor and Varghese (2024) affirm that STEAM education integrates the arts into STEM to foster creativity, innovation, and interdisciplinary thinking. To support this, Amanova et al. conducted a systematic review showing that STEAM-based instruction positively influences learning performance, motivation, and skill development at all educational levels.¹³ Incorporating artistic elements, such as metaphorical representations of DNA, into genetics teaching enhances both engagement and conceptual understanding.

The impact of visual metaphor projects on students' scientific accuracy and creativity.

Visual metaphor projects significantly improve students' scientific accuracy, creativity, and reflective thinking, key outcomes in genetics education, particularly within a STEAM-based instructional framework.¹⁴ These projects challenge learners to symbolically represent DNA structure and function, reinforcing core genetic concepts and promoting precision in scientific thinking.¹⁵ As students translate abstract genetic ideas into visual forms, they deepen their understanding and correct misconceptions, which leads to improved performance in both assessments and practical applications.

Moreover, the process of creating metaphors fosters imaginative approaches to scientific problems. Oliveira et al. highlight how this encourages divergent thinking, enabling students to explore multiple solutions and perspectives skills that are valuable across scientific and interdisciplinary domains.¹⁶

⁷ Charles Buckley and Chrissi Nerantzi, "Effective Use of Visual Representation in Research and Teaching within Higher Education," *International Journal of Management and Applied Research* 7, no. 3 (2020): 196–214.

⁸ L. Kate Wright et al., "The DNA Landscape: Development and Application of a New Framework for Visual Communication about DNA," *CBE—Life Sciences Education* 21, no. 3 (2022): ar47.

⁹ Anisha Savarimuthu and R Joseph Ponniah, "The Mind's Eye Is Not a Metaphor: Visuospatial Working Memory and Mental Imageries for Learning and Language Comprehension," *Psychological Studies* 69, no. 2 (2024): 158–68.

¹⁰ Amalia Nurma Dewi and Bent Sørensen, "Higher-Order Thinking Skills and Metaphor," *Southern Semiotic Review* 18 (2023): 1–35.

¹¹ Suzan Arslan and Mustafa Toprak, "Visual Arts Education on Concept-Based Learning," *Education and Science* 50, no. 221 (January 27, 2025): 143–77, <https://doi.org/10.15390/EB.2025.13133>.

¹² Banuçiçek Özdemir, "The Common Metaphorical Perceptions of Prospective Teachers as to DNA-Gene-Chromosome Concepts," *Journal of Baltic Science Education* 20, no. 3 (2021): 471–94.

¹³ Aray K. Amanova et al., "A Systematic Review of the Implementation of STEAM Education in Schools," *Eurasia Journal of Mathematics, Science and Technology Education* 21, no. 1 (January 29, 2025): em2568, <https://doi.org/10.29333/ejmste/15894>.

¹⁴ Yilmaz Soysal, "Science Teachers' Conceptual Perspectives on Scientific Experiments: A Metaphorical Representation," *Research in Science & Technological Education* 43, no. 4 (2025): 1182–1207.

¹⁵ Giampiero Dalai, "Analogy and Metaphor in the Design of Visual Artifacts for Biology. The Example of the Machine de Lejeune,," 2024.

¹⁶ Alandeom W Oliveira et al., "Fostering Creativity in Science Learning: The Potential of Open-Ended Student Drawing," *Teaching and Teacher Education* 105 (2021): 103416.

These outcomes align closely with constructivist pedagogy and the goals of STEAM education.¹⁷ STEAM promotes learning through diverse modes: visual, verbal, tactile, and symbolic. Visual metaphors support this by allowing students to express DNA concepts through imagery, models, and artistic forms, reinforcing dual coding theory, which posits that combining visual and verbal information enhances comprehension and memory.¹⁸

The Arts component of STEAM empowers students to creatively express complex genetic ideas. Visual metaphors offer a platform for personalising understanding, making abstract concepts more relatable and memorable.¹⁹ These projects naturally integrate science (DNA structure), mathematics (base pairing patterns), technology (digital modelling tools), and art (symbolic representation), exemplifying STEAM's goal of breaking down disciplinary silos to promote holistic learning.²⁰

Furthermore, STEAM-based instruction is known to increase student engagement. Mafokwane (2023) suggests that when students create visual metaphors, they take ownership of their learning, increasing motivation and curiosity, especially in subjects like genetics that can seem abstract or intimidating. Finally, visual metaphor creation involves analysis, synthesis, and evaluation, hallmarks of higher-order thinking. Students must understand DNA scientifically, represent it metaphorically, and reflect on their choices, aligning with both STEAM and constructivist learning principles.²¹

THEORETICAL FRAMEWORK

This study adopted a qualitative, exploratory design rooted in a constructivist paradigm, which emphasises learning as an active, experiential process shaped by reflection and personal meaning-making. The project also relied on dual coding theory, which posits that combining verbal and visual representations enhances cognitive processing and retention.²²

Constructivist Learning Theory

Vygotsky (1978), in his sociocultural theory of cognitive development, emphasises the fundamental role of social interaction and cultural context in the development of cognition. Constructivist pedagogy positions learners as active participants in knowledge construction through real-life experiences and reflection. Funa and Talaue explored the use of constructivist-designed biology modules during the COVID-19 pandemic and found that students responded positively to materials that encouraged inquiry, collaboration, and contextual learning.²³

In STEAM, students engage in hands-on experiments, model DNA structures, and explore genetic coding through collaborative projects. Learning is contextualised; students connect DNA concepts to real-world issues (e.g., genetic engineering, forensic science). Teachers act as facilitators, guiding learners through their Zone of Proximal Development (ZPD).

Dual Coding Theory in Education

Dual coding theory, proposed by Clark and Paivio, proposes that the human mind processes information using two distinct channels, namely verbal (language-based) and non-verbal (imagery-based).²⁴ Paivio's theory suggests that learning is more effective when information is presented using

¹⁷ Caryn Babayan, *The Biological-Art Drawing Heuristic: Visualizing Complex Biological Systems in Biology Education & Research* (Temple University, 2021).

¹⁸ T. Dignam, R. Sexton, and L. Muñoz, "Innovations in Blended Learning: Pedagogical Frameworks for Higher Education," *Journal of Higher Education Research* 48, no. 1 (2025): 23–41.

¹⁹ Zhang and Jia, "Enriching STEAM Education with Visual Art: Education Benefits, Teaching Examples, and Trends."

²⁰ Diaa Ahmed Mohamed Ahmedien, "Analysing Bio-Art's Epistemic Landscape: From Metaphoric to Post-Metaphoric Structure," *BioSocieties* 18, no. 2 (June 26, 2023): 308–34, <https://doi.org/10.1057/s41292-022-00270-y>.

²¹ Jayaman Wibowo, Anna Fitri Hindriana, and Zaenal Abidin, "Students' and Teachers' Perceptions of Metaphor-Based Visual Media in Cell Biology Learning," *Quagga: Jurnal Pendidikan Dan Biologi* 17, no. 2 (July 4, 2025): 177–83, <https://doi.org/10.25134/quagga.v17i2.467>.

²² James M. Clark and Allan Paivio, "Dual Coding Theory and Education," *Educational Psychology Review* 3, no. 3 (September 1991): 149–210, <https://doi.org/10.1007/BF01320076>.

²³ A Funa and F Talaue, "The Effectiveness of Multimedia in Teaching Science Concepts: A Quasi-Experimental Study," *International Journal of Emerging Technologies in Learning* 16, no. 12 (2021): 45–56.

²⁴ Clark and Paivio, "Dual Coding Theory and Education."

both verbal and visual formats, because it creates two memory traces, increasing the likelihood of recall. Combining verbal and visual information enhances memory and comprehension. Wooten and Cuevas demonstrated that dual coding strategies significantly improved vocabulary acquisition and academic achievement in elementary social studies, supporting its broader application in science education.²⁵

METHODOLOGY

Research Design

This study adopted a qualitative exploratory design situated within a constructivist paradigm. The design was chosen to investigate how visual metaphors, integrated through STEAM principles, support genetics education by fostering creativity, collaboration, and conceptual understanding. The exploratory nature of the design allowed for in-depth examination of student experiences and the meanings they constructed through metaphorical representations of DNA.²⁶

Study Sample and Population

The study population comprised first-year undergraduate students enrolled in a Zoology course at a South African university. A total of 140 students participated, organised into 12 interdisciplinary groups of 5–7 members. All participants had prior exposure to basic biological concepts but were new to genetics and STEAM-based learning strategies, making them an appropriate sample to explore the effectiveness of metaphor-driven pedagogy.²⁷

Data Collection

During a three-month period, students engaged in a STEAM-integrated project focused on designing visual metaphors to represent DNA structure and function. Data were collected through project artefacts including drawings, sculptures, digital models, and animations, as well as written student reflections. Interactive workshops introduced DNA structure, metaphorical thinking, and STEAM integration strategies, ensuring that students had scientific and creative foundations for their projects.²⁸

Data Analysis Procedure

Data were analysed using a rubric that assessed scientific accuracy, creativity, interdisciplinary integration, artistic presentation, and collaboration. Artefacts and reflections were subjected to thematic analysis to identify patterns of engagement, conceptual understanding, and misconceptions.²⁹ Quantitative rubric scores provided descriptive insights into performance, while qualitative analysis illuminated the depth of student meaning-making and interdisciplinary synthesis.

Ethical Considerations

The study adhered to institutional ethical guidelines for research involving student assessment data. All participants were anonymised, and no personal identifiers were recorded. Ethical clearance was obtained from the university's research ethics committee before data collection. Participation was voluntary, and students were informed that their participation was for educational research purposes only, with findings intended to inform curriculum development and pedagogy.³⁰

²⁵ Jennifer O Wooten and Joshua A Cuevas, "The Effects of Dual Coding Theory on Social Studies Vocabulary and Comprehension in Elementary Education.," *International Journal on Social and Education Sciences* 6, no. 4 (2024): 673–91.

²⁶ David Aguilera and Jairo Ortiz-Revilla, "STEM vs. STEAM Education and Student Creativity: A Systematic Literature Review," *Education Sciences* 11, no. 7 (July 2, 2021): 331, <https://doi.org/10.3390/educsci11070331>.

²⁷ Mafugu, Nzimande, and Makwara, "Teachers' Perceptions of Integrative STEM Education in Life Sciences Classrooms."

²⁸ Zhang and Jia, "Enriching STEAM Education with Visual Art: Education Benefits, Teaching Examples, and Trends."

²⁹ Özdemir, "The Common Metaphorical Perceptions of Prospective Teachers as to DNA-Gene-Chromosome Concepts."

³⁰ Lev S Vygotsky, "Mind in Society: The Development of Higher Psychological Processes" (Harvard university press, 1978).

PRESENTATION OF FINDINGS

Student's artefacts

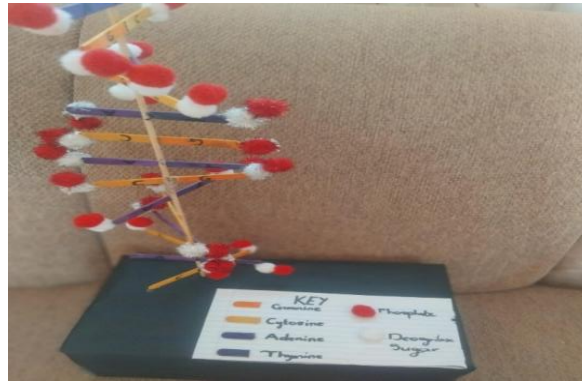


Figure 1: Project 1



Figure 2: Project 2



Figure 3: Project 3



Figure 4: Project 4

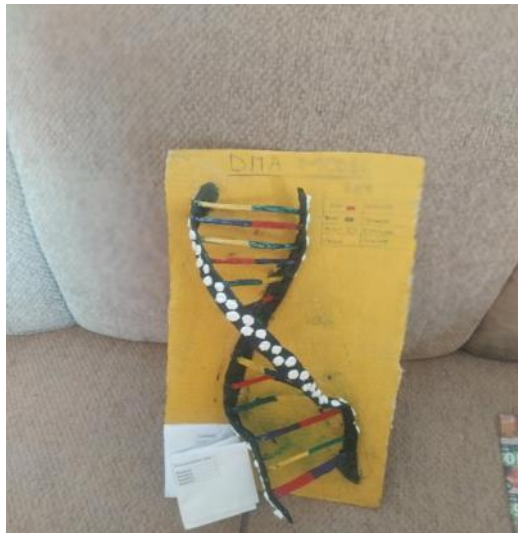


Figure 5: Project 5

Interpretation of Rubric Results

The rubric analysis confirmed that students had a foundational grasp of DNA structure, yet omissions such as hydrogen bonds, phosphate groups, and sugar bonds revealed persistent gaps in molecular accuracy. These lapses are not minor oversights; they reflect the tension between creativity and scientific precision in STEAM projects. When artistic expression is foregrounded without sufficient scaffolding, students may unintentionally sacrifice accuracy for originality. This finding underscores the importance of guided interventions; teachers must act as facilitators who help learners balance imaginative representation with molecular detail, ensuring that creativity complements rather than compromises scientific rigor.

Engagement and Interdisciplinary Learning

Students' enthusiasm was visibly heightened through artistic and hands-on activities. The process of sculpting, drawing, or digitally modelling DNA metaphors transformed abstract molecular concepts into tangible artefacts. This personalisation of learning illustrates the motivational power of STEAM pedagogy. It also validates Vygotsky's view that knowledge is socially constructed: students collaborated, shared responsibility, and co-created meaning within their Zone of Proximal Development. The metaphorical projects acted as "cognitive bridges," enabling learners to connect biology with mathematics, engineering, and art, thereby embodying the interdisciplinary spirit of STEAM.

Addressing Misconceptions

The inaccuracies observed provide valuable insight into how misconceptions surface when students translate scientific ideas into metaphors. For instance, missing hydrogen bonds suggest limited understanding of base-pairing mechanisms, while absent phosphate groups point to gaps in grasping DNA's backbone structure. These findings highlight the pedagogical need for iterative design, peer review, and expert feedback. By embedding structured reflection cycles, educators can help students refine both their creative outputs and their scientific accuracy, turning errors into opportunities for deeper learning.

This study demonstrates that visual metaphors are more than artistic embellishments; they function as cognitive scaffolds that foster creativity, collaboration, and interdisciplinary thinking. At the same time, they reveal where scientific accuracy requires reinforcement. The research contributes to scholarship by operationalising constructivist and dual coding principles in genetics education, offering empirical evidence that metaphor-driven STEAM projects enhance engagement while also demanding strategic support to maintain rigor.

Taken together, the findings show that the DNA metaphor is not merely a creative exercise but a pedagogical strategy that bridges disciplinary silos. It advances the field by illustrating how STEAM approaches can simultaneously cultivate creativity and scientific literacy, while identifying the scaffolding and reflective practices needed to correct misconceptions. In doing so, the study enriches science education research and informs curriculum design for inclusive, interdisciplinary pedagogy.

Multifaceted Learning Experience

The evaluation of student projects within a STEAM framework revealed a rich learning experience that emphasised creativity, interdisciplinary integration, and scientific understanding. Although the students demonstrated a solid grasp of DNA structure and function, several projects lacked creative representation of molecular components such as hydrogen bonds, phosphate groups, and sugar bonds. This gap highlights the challenge of balancing creativity with scientific rigor, echoing Wright et al., who found that visual communication of DNA often omits essential molecular details, resulting in partial comprehension.³¹

Creativity and Originality

Creativity is a cornerstone of STEAM education, fostering students' ability to generate novel ideas and express complex scientific concepts through metaphor and design. The use of metaphorical representations in the DNA projects enabled students to articulate abstract biological processes in more accessible and engaging ways. This aligns with Vygotsky's view that creativity is a developmental process influenced by social interaction and scaffolding within the ZPD, where learners achieve more with guidance than independently.³² Research supports that STEAM approaches enhance creativity by encouraging exploration and imaginative thinking.³³ Vygotsky's theory also emphasises the role of the More Knowledgeable Other (MKO), such as a teacher or peer, in guiding learners through creative tasks that stretch their cognitive abilities.

STEAM Integration

Effective STEAM integration involves blending science, technology, engineering, arts, and mathematics to create holistic learning experiences. In this project, artistic and hands-on activities enhanced student participation and allowed synthesis across domains. This finding resonates with Amanova et al., who demonstrated that STEAM-based instruction positively influences performance, motivation, and skill development.³⁴ Vygotsky's constructivist approach supports this interdisciplinary learning, emphasising that knowledge is constructed through social interaction and contextual experiences.

³¹ Wright et al., "The DNA Landscape: Development and Application of a New Framework for Visual Communication about DNA."

³² Lev S Vygotsky, *Mind in Society: The Development of Higher Psychological Processes*, vol. 86 (Harvard university press, 1978).

³³ Aguilera and Ortiz-Revilla, "STEM vs. STEAM Education and Student Creativity: A Systematic Literature Review."

³⁴ Amanova et al., "A Systematic Review of the Implementation of STEAM Education in Schools."

Scientific Accuracy

Scientific precision remains a critical criterion in the evaluation of STEAM projects. While the students demonstrated a foundational understanding of DNA structure and function, the omission of key molecular features suggests a need for more explicit instruction on integrating scientific detail into creative outputs. According to Vygotsky, scaffolding is essential to help learners internalise complex scientific concepts, especially when transitioning from concrete to abstract representations.³⁵ Similar findings by Özdemir show that metaphorical perceptions of DNA often reveal misconceptions that require targeted pedagogical intervention.³⁶

Collaboration

Collaboration is a defining feature of STEAM pedagogy, promoting peer learning and shared problem-solving. Vygotsky emphasised that learning is inherently social, and that collaboration within the ZPD allows students to co-construct knowledge through dialogue and joint activity. The project-based nature of the DNA models encouraged teamwork and communication, consistent with Soysal, who highlighted the role of metaphorical representation in the promotion of collaborative scientific inquiry.³⁷ However, structured support and role clarity could further optimize collaborative outcomes, ensuring equitable participation and greater engagement.

RECOMMENDATIONS

To strengthen the integration of creativity and scientific rigor in STEAM education, several recommendations emerge from this study. First, educators should provide structured scaffolding and explicit instruction on molecular details such as hydrogen bonds, phosphate groups, and sugar bonds to ensure that creative outputs remain scientifically accurate. Embedding peer-review mechanisms would further enhance accuracy, as students critically evaluate one another's metaphorical representations and collaboratively refine their work. In addition, projects should be shared on public platforms such as exhibitions or online forums, promoting science communication and accountability while cultivating transferable skills in communicating complex concepts to diverse audiences. Interdisciplinary collaboration is also essential; involving educators from biology, mathematics, engineering, and the arts can provide balanced guidance that enriches both creativity and scientific depth. Reflective practices, including journals or portfolios, should be embedded to encourage metacognition and help learners internalize their conceptual growth. Finally, systematic use of dual coding strategies that combine verbal explanations with visual metaphors can enhance retention and comprehension, while future research should explore scalable models for professional development and culturally responsive pedagogy to sustain metaphor-based STEAM approaches in diverse educational contexts. Collectively, these recommendations highlight the importance of balancing creativity with rigor, ensuring that STEAM projects foster both imaginative exploration and accurate scientific understanding.

CONCLUSION

This study demonstrates that visual metaphors, specifically the DNA double helix, can serve as powerful pedagogical tools within a STEAM framework. By engaging first-year Zoology students in interdisciplinary projects, the research revealed how metaphorical representations foster creativity, collaboration, and conceptual understanding. The findings highlight both the potential and the challenges of integrating artistic approaches into science education. Although students demonstrated a strong understanding of DNA's overall structure, omissions of molecular details such as hydrogen bonds and phosphate groups underscore the need for scaffolding to ensure scientific precision. Based on Vygotsky's constructivist theory, the study affirms the importance of social interaction, guided

³⁵ Lev Semenovich Vygotsky and Michael Cole, *Mind in Society: Development of Higher Psychological Processes* (Harvard university press, 1978).

³⁶ Özdemir, "The Common Metaphorical Perceptions of Prospective Teachers as to DNA-Gene-Chromosome Concepts."

³⁷ Soysal, "Science Teachers' Conceptual Perspectives on Scientific Experiments: A Metaphorical Representation."

learning within the Zone of Proximal Development, and the role of the educator as facilitator of conceptual growth. Simultaneously, Dual Coding Theory supports the integration of verbal and visual representations, enhancing students' ability to process and retain complex information. Together, these theoretical foundations provide a robust framework for designing STEAM projects that balance creativity with rigor.

The contribution of this study lies in demonstrating how visual metaphors function as cognitive scaffolds in genetics education, bridging disciplinary boundaries and enriching science pedagogy. It advances scholarship by operationalising constructivist and dual coding principles in practice, offering empirical evidence that metaphor-driven STEAM projects enhance engagement while also revealing areas where scientific accuracy requires reinforcement. Future research should explore scalable models for peer review, iterative design, and cross-disciplinary collaboration to strengthen the integration of arts and sciences in diverse educational contexts. Ultimately, the DNA metaphor emerges not merely as a creative exercise but as a transformative pedagogical strategy—one that cultivates scientific literacy, creativity, and interdisciplinary thinking while addressing persistent misconceptions in genetics education.

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