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Multiple Representation Strategy through Team-Based Representational Activities with Creative Exploration via Learning through Video on Cell Fundamentals

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Abstract

In the era of digitalized science education, students' ability to construct, connect, and communicate scientific ideas through multiple representations is increasingly vital. This study examined the effectiveness of a Multiple Representation Strategy via Team-Based Representational Activities with Creative Exploration through Learning via Video in improving representational abilities on cell fundamentals. The research involved 20 undergraduate students from a 2019 Chemistry Education cohort. Using a Project-Based Learning (PJBL) model, students collaboratively produced educational videos based on lecture subtopics. Representational ability was assessed through five essay items aligned with indicators: verbal, visual, symbolic, integrated, and creative. Descriptive results showed verbal representation scored highest (M=84), followed by visual (M=78), while symbolic (M=65) and integrated (M=68) scored lowest. Regression analysis revealed verbal, visual, and integrated representations significantly predicted overall performance ($p < 0.05$), with verbal being the strongest predictor ($\beta = 0.421$). These findings suggest that the PJBL-video approach supports expressive and visual learning well but needs enhancement in fostering symbolic and integrative skills. The study highlights the importance of instructional strategies that encourage communication, creativity, and abstract reasoning. Insights from this research can inform the development of science pedagogy and curriculum aimed at improving representational fluency, especially in biochemistry education and broader STEM learning contexts.

Keywords: Multiple_Representation, Project-Based_Learning, Video_Learning, Biochemistry_Education, Cell_Fundamentals.

1. Introduction

The demands of complicated real-world problems and quick technology improvement provide a growing challenge for scientific education in the twenty-first century. Globally, the focus on fostering students' conceptual knowledge and scientific literacy has encouraged teachers to use more interesting and successful teaching methods (Y. Liu et al., 2024; Ponce-Naranjo et al., 2023). One of the fundamental scientific courses, biology is essential to developing knowledge of life and biological processes (Jumde et al., 2024). However, the abstract and complicated character of many subjects, particularly cell biology, is a recurring worldwide problem in biology instruction. Due to the tiny and intangible nature of basic cellular ideas, studies have revealed that students worldwide frequently struggle with them, resulting in misunderstandings and fragmented comprehension.

The traditional biology teaching approaches in Indonesia, which mostly rely on lecture-based learning, textbook references, and a limited incorporation of multimedia resources, make the issue even worse (Wang et al., 2023; Xia et al., 2024). Differentiated learning, critical thinking, and creative enquiry have been highlighted in the national curriculum, especially via Kurikulum Merdeka (Ndari et al., 2023). However, many schools still struggle to successfully apply these pedagogical changes (Jabsheh, 2024; Ondog & Kilag, 2023). Students continue to be passive consumers of knowledge rather as active creators of it, and teachers frequently lack enough training in digital paedagogy and creative instructional design (Oreshkina & Slitikov, 2022; Tang et al., 2023). Deeper conceptual learning has been hampered by these circumstances because they have made it more difficult for pupils to relate abstract biological concepts to tangible representations.

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Teaching the basics of cells, a fundamental yet cognitively hard subject in biology, is a particularly urgent problem. Multiple representations verbal, visual, symbolic, and spatial must be coordinated in order to comprehend cells, according to research, yet traditional teaching methods frequently ignore these various representational modalities (Q. Liu et al., 2022; Nurrahmawati et al., 2021). Because of this, students usually struggle to create mental models that properly depict the composition and operation of cells. Additionally, biology education in Indonesian schools seldom incorporates team-based investigation and representational activities, which might promote collaborative learning and deeper engagement (Cunha et al., 2024; Harris et al., 2024). Curriculum objectives and classroom methods differ practically in terms of collaborative, multimedia-based learning methodologies and representational competency.

In order to tackle these problems, this study suggests a thorough teaching method called "A Multiple Representation Strategy through Team-Based Representational Activities with Creative Exploration via Learning through Video on Cell Fundamentals." Three educational elements are incorporated into the suggested approach: (1) numerous representations, (2) team-based representational exercises, and (3) creative enquiry via video production. Constructivist learning theory and cognitive science, which highlight that learning is most successful when students actively create information through a variety of modalities and social interaction, provide the foundation for the reasoning behind this approach.

Theoretically, by offering many viewpoints on a same idea, diverse representations improve understanding and help students more efficiently encode, retrieve, and integrate information. In practice, this approach entails students collaborating in groups to produce films that narratively and graphically describe cellular processes and structures. In addition to using representational tools (such as diagrams, animations, and spoken explanations), students who create videos also develop communication, teamwork, and creative skills all of which are critical for learners in the twenty-first century. Furthermore, students may refine, contemplate, and showcase their comprehension in a way that is both comprehensible and captivating for their classmates thanks to the video format.

This study's unique approach to teaching fundamental biological concepts is the methodical fusion of artistic video creation with team-based representation. Few research have looked at the synergistic effects of integrating video-based learning and various representations with collaborative design activities that are especially focused on cell basics, even though these two approaches have been studied individually in the past. Additionally, this study places these tactics in the context of Indonesian education, which offers particular possibilities and problems with regard to student diversity, teacher preparedness, and resource availability. The study adds to the worldwide conversation on creative STEM paedagogy in addition to offering a regional educational approach.

The study's goals are as follows: 1) Examine how a multiple representation strategy affects students' comprehension of cell fundamentals; 2) Examine how team-based representational activities affect students' ability to collaborate and communicate; 3) Examine how creative exploration through video-making improves student engagement and conceptual accuracy; and 4) Determine the obstacles and enablers of putting such a strategy into practice in actual classroom settings.

The study is anticipated to have several advantages. The method claims to provide pupils a more fulfilling and pleasurable educational experience, which will increase their drive and intellectual comprehension. In line with Kurikulum Merdeka's emphasis on active, differentiated, and project-based learning, it offers educators a reproducible model for incorporating ICT and collaborative learning into biology classroom. The results might influence training initiatives and policies for educational stakeholders that support student-centered, media-rich scientific education paedagogies.

There is a pressing need to investigate integrative solutions that improve both subject mastery and 21st-century capabilities as biology education enters a revolutionary period impacted by digital technology and new pedagogical paradigms. By providing a comprehensive instructional design that links theory and practice, as well as cognitive skills and creative discovery, this research responds to that need. It is hoped that this study will help biology classrooms in Indonesia and elsewhere become more dynamic, collaborative, and visually rich environments where students can learn about cells and also learn how to communicate, represent, and interact with science in ways that are both relevant and rigors.

2. Literature Review

Successful communication in scientific education, the capacity to convey information in a variety of ways verbal, visual, symbolic, and integrated is essential. It has been demonstrated that the Multiple Representation Strategy (MRS) improves students' conceptual understanding by enabling them to see things through a variety of cognitive lenses, which makes it easier for them to create mental models and transmit knowledge (Q. Liu et al., 2022). Effective use of MRS fosters the growth of abstract reasoning and higher-order thinking abilities in addition to understanding, particularly in challenging scientific fields like cell biology.

An active learning strategy that uses teamwork to create and analyse scientific representations is team-based representational activities (Lorello & Lippi, 2023; Sargo Ferreira Lopes et al., 2024). The idea that social contact mediates learning is supported by Vygotsky's sociocultural theory, which makes peer cooperation an effective means of meaning-making (Salajegheh et al., 2024). Scientific literacy requires the development of dialogic reasoning, perspective-taking, and critical assessment, all of which are fostered via group-based activities focused on representation.

By involving students in the development of multimodal material, the incorporation of Creative Exploration via Video Learning enhances representational learning even more. Research has indicated that video production activities foster deeper connection with material, creativity, and story development. This modality helps students visualise unseen processes (such cellular mechanics) and convert abstract ideas into tangible, communicative medium in the context of biochemistry and cell basics.

Additionally, Project-Based Learning (PjBL) is a useful educational framework for facilitating the combination of creativity, teamwork, and representation. Based on constructivist ideas, PjBL encourages students to explore, describe, and communicate scientific facts in a relevant way by involving them in real-world issues (Maros et al., 2023; Rizki & Suprapto, 2024). For the development of representational fluency and scientific reasoning, project-based techniques have proven very beneficial in the microscopic complexity field of cell biology.

Despite these advantages, studies show that students frequently have trouble using integrative and symbolic representations, particularly when they are not specifically scaffolded. To overcome these cognitive difficulties, instructional designs that combine creative technology, representational tactics, and organised cooperation are crucial.

In conclusion, there is a great deal of promise to improve students' comprehension of Cell Fundamentals by combining the Multiple Representation Strategy, Team-Based Learning, and Creative Video Exploration inside a Project-Based Learning framework. This work adds to the increasing amount of research that highlights collaborative, multimodal, and technologically enhanced learning settings in scientific education.

3. Research Method and Materials

This study employed a quantitative descriptive technique and a one-group posttest-only experimental design. The primary objective of the study was to examine students' diverse representation abilities after teaching using the Project-Based Learning (PjBL) paradigm in conjunction with a video-making activity. The instructional intervention focused on the fundamentals of human cells. In order to convey key cellular concepts during the learning process, students were told to work in groups to create educational films that employ a range of representational modalities (such as visual, verbal, and symbolic). At the end of the session, students' numerous representation skills were assessed using a set of essay questions designed specifically to elicit different kinds of scientific representation.

The study's population consisted of all Universitas Sembilanbelas November Kolaka undergraduate Chemistry Education Programme (S-1 Pendidikan Kimia) students enrolled in the 2019 cohort. This cohort consisted of 20 students who were all in the same class. Due to the modest population size and the availability of only one class in the 2019 cohort, a comprehensive sampling technique was used to employ the whole population as the study sample. This approach ensured that all eligible students participated in the intervention and evaluation process.

A series of essay questions intended to assess students' proficiency in using various representations pertaining to the human cell issue served as the main tool in this investigation. Five open-ended questions made up the tool, and each one asked students to illustrate their comprehension using a variety of representational techniques, including analogies, verbal explanations, diagrams, and symbolic expressions. Before being used, the questions were approved by two specialists in scientific education and evaluation. They were created using the fundamental skills of biological representation.

The essay test was given at the conclusion of the learning intervention in order to gather data. Under supervision, each student finished the test on their own. A scoring system based on a rubric was then used to evaluate their answers. This system evaluated several aspects of representation, such as: 1) Conceptual accuracy; 2) Use of visual or symbolic representation; 3) Clarity of verbal explanation; 4) Integration between various representational forms; and 5) Creativity in representation.

Table 1. Description of the Research Instrument Based on PjBL Syntax and Learning Video Integration in Biochemistry I Course.

PjBL Syntax	Learning Indicators	Learning Objectives	Learning Activity Description
1. Start with Essential Question	Students identify core concepts of human cell structures and functions	Students can explain the relevance and importance of understanding human cell fundamentals	Lecturer introduces the topic with a contextual problem related to human biology. Students are encouraged to ask questions and explore initial ideas.
2. Design a Plan for the Project	Students plan collaborative strategies and content outline for the video project	Students can design a project workflow and assign roles for content creation	Students form groups, outline their video content (script, visuals, narration), and allocate tasks among team members.
3. Create a Schedule	Students manage time and tasks for video production and content development	Students can organize their time effectively for each phase of the project	Groups develop a timeline including deadlines for script writing, visualization, recording, and editing of the learning video
4. Monitor the Students and the Progress of the Project	Students provide progress updates and collaborate during the production process	Students can demonstrate collaboration and adapt problem-solving strategies during project development	Lecturer monitors progress through weekly check-ins and formative assessments; students receive peer and instructor feedback on their drafts and visualizations.
5. Assess the Outcome	Students present videos and respond to conceptual questions based on their content	Students can demonstrate mastery of cell concepts through multiple representations in their videos	Final videos are submitted and presented. Students take an essay test consisting of 5 questions assessing their multiple representation ability.
6. Evaluate the Experience	Students reflect on the learning process and group collaboration	Students can evaluate their learning outcomes and team dynamics during the project	Reflection session held through guided questions; students complete a self-assessment and group evaluation form regarding the PjBL and video-making process.

Table 2. Learning Objectives, Multiple Representation Indicators, and Instrument Validation and Reliability Results.

Learning Objectives	Multiple Representation Indicators	Validation Results	Reliability Results
Students are able to explain the structure and function of human cells accurately.	Ability to describe concepts verbally with clarity and scientific accuracy.	Valid (Average CVR = 0.86; Expert Agreement = Strong)	Reliable (Cronbach's Alpha = 0.82; High Consistency)
Students are able to visualize cellular components and their functions appropriately.	Ability to create accurate and labeled diagrams representing cell organelles and their relationships.	Valid (CVR = 0.89)	Reliable ($\alpha = 0.82$)
Students are able to use symbols or models to represent biological processes in cells.	Ability to represent abstract cellular processes (e.g., transport, division) symbolically or through analogies/models.	Valid (CVR = 0.84)	Reliable ($\alpha = 0.80$)
Students are able to integrate verbal, visual, and symbolic forms of representation.	Ability to synthesize multiple forms (verbal + diagram + symbolic) to explain a concept coherently.	Valid (CVR = 0.88)	Reliable ($\alpha = 0.81$)
Students are able to reflect creativity and conceptual depth in representing cell topics.	Ability to represent cell concepts in novel, original, yet scientifically valid ways (e.g., using metaphors, storytelling).	Valid (CVR = 0.85)	Reliable ($\alpha = 0.79$)

The performance of every student was graded and totalled for additional examination. To determine the distribution and degree of multiple representation skills among the students, the findings were subjected to a descriptive analysis. Students' performance was summarised using descriptive statistics including mean, standard deviation, minimum, and maximum scores. The results were analysed to see how much the combined PjBL and video-making approach helped students convey cellular ideas using a variety of scientific representations.

4. Results and Discussion

This section presents the results of the study based on the implementation of a Multiple Representation Strategy through Team-Based Representational Activities and Creative Exploration via Learning through Video on the topic of Cell Fundamentals in the Biochemistry I course. The data were obtained through essay-based assessments consisting of five items, each designed to measure students' abilities across five key indicators of multiple representation: verbal, visual, symbolic, integrated, and creative representation.

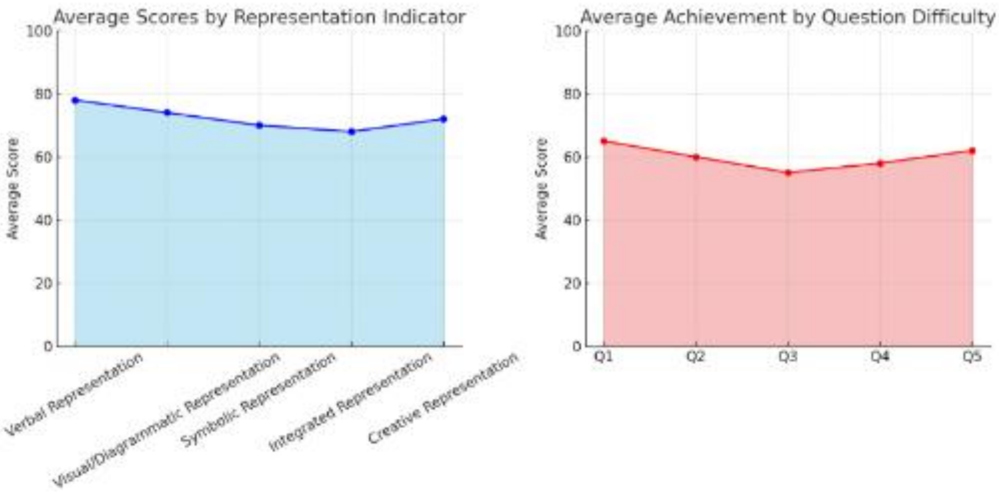

Figure 1. Left chart: Average scores for each multiple representation indicator and Right chart: Average achievement levels based on question difficulty for each essay question.

Significant patterns in the representational skills of the students are shown by analysing their performance using the five primary multiple representation markers. With an average score of 78, the Verbal Representation indication had the highest average score, indicating that students were most precise and confident when articulating cellular ideas orally or in writing. This is probably because they have expertise verbally describing material from prior academic encounters.

With an average score of 74, Visual/Diagrammatic Representation had the second-highest score, suggesting a respectably excellent capacity to produce and comprehend visual representations of cell components. With averages of 70 and 68, respectively, the Symbolic Representation and Integrated Representation indexes show a discernible downturn. According to these lower results, students may need more specialised instructional help in the areas of abstract symbol usage and coherent integration of numerous kinds of representation. With an average score of 72, the Creative Representation indication demonstrated that students' representations of the subject were moderately creative and conceptually deep, but still below the verbal and visual modes.

The study showed different levels of accomplishment for each of the five essay questions in terms of item-level performance dependent on question complexity. topic 1 had the highest average score (65), suggesting that it was the most approachable topic for students, maybe because it was in line with basic or well-known ideas. With average scores of 60 and 62, respectively, Questions 2 and 5 came next, indicating moderate difficulty.

Question 3 was the most difficult for pupils, nonetheless, since it had the lowest average score (55). Students were probably asked to link several representational forms or use symbolic reasoning in order to answer this issue, which called for more abstract or integrative thinking. The trend that students found it more difficult to respond to questions demanding complicated synthesis or symbolic abstraction was further supported by Question 4, which received a somewhat higher score of 58 but was still in the lower range.

These results demonstrate the strengths and weaknesses of students, especially in the more abstract and integrative aspects of multiple representation. This realisation offers a useful foundation for improving teaching methods to effectively scaffold students' representational thinking, particularly in tasks involving symbolic and multimodal integration.

Table 3. Descriptive Analysis of Students' Multiple Representation Skills as Future Biochemistry Professionals.

Representation Indicator	Mean Score	Standard Deviation	Interpretation
Verbal Representation	78	6.2	Strong verbal communication skills indicate readiness to explain complex biochemical concepts.
Visual/Diagrammatic Representation	74	7.1	Competent in using visual tools, useful for explaining molecular structures and processes.
Symbolic Representation	70	6.8	Adequate symbolic reasoning; improvement needed for accurate use of chemical equations or models.
Integrated Representation	68	7.4	Moderate integration skill; requires support in synthesizing verbal, visual, and symbolic elements.
Creative Representation	72	6.5	Fairly creative in designing novel representations; beneficial for science communication and teaching.

According to the study's findings, students' verbal representation skills were the most proficient, which is an essential ability for biochemistry specialists. In academic and professional settings, oral presentations, scientific writing, collaborative research, and teaching all rely heavily on verbal communication. The students' capacity to precisely and concisely explain intricate biochemical processes indicates that they are ready for positions requiring scientific material to be explained, taught, or persuasively communicated.

The weakest regions, on the other hand, were found to be integrated representation and symbolic skills. This disparity is especially important because sophisticated biochemical content, mechanistic explanations, and data interpretation all depend on symbolic thinking, which may be achieved through the use of equations, models, or biochemical shorthand. Furthermore, mixing several types of representation (such as narrative explanation, symbolic models, and diagrams) demonstrates higher-order thinking and is essential for profound conceptual comprehension. The inferior performance in these domains suggests that existing teaching techniques may not sufficiently support these abilities, highlighting a practical gap between theoretical knowledge and its application across diverse representational modes.

Notwithstanding these difficulties, the findings also show that students' representations of biological ideas exhibited a moderate degree of originality. The development of instructional media, public engagement efforts, and science outreach programmes may all benefit from this creative potential. Students who can imaginatively convert difficult ideas into understandable formats will be highly valued for multidisciplinary cooperation and social effect as scientific communication becomes more visual and multimodal (Xing et al., 2024; Yin et al., 2024).

When combined, these results suggest that the curriculum should be strategically improved, especially in terms of providing opportunity for students to exercise representational integration and symbolic abstraction. Methods like collaborative modelling exercises, multimedia assignments, and project-based learning may be useful in closing these skill gaps. Teachers can better prepare aspiring biochemistry professionals to succeed in a variety of scientific and educational contexts by encouraging representational fluency across several modalities.

The 20 students' dominant representation indicators show distinct trends in the most popular and effective ways to communicate biological ideas. Verbal Representation was the most common signal, appearing as the dominant talent in 7 out of 20 students (35%). This implies that a sizable percentage of students feel most at ease and capable when expressing themselves orally or in writing, which is consistent with conventional academic procedures and verbal evaluations frequently employed in academic contexts.

With five students (25%), visual representation was the second most prevalent indication. This demonstrates how well students can use diagrams, pictures, and visual models to conceptualise and convey concepts. This is a crucial biochemistry ability, particularly when discussing issues related to cellular architecture and molecular interactions. Three students (15%) had Creative Representation as the dominating signal, indicating that although creativity is not the most prevalent strength, it is present in a significant portion of pupils. These people showed creativity in their visual representations or analogies of scientific material, which is a skill that may be used to create instructional materials and communicate science (Anam et al., 2024; Y. Liu et al., 2022).

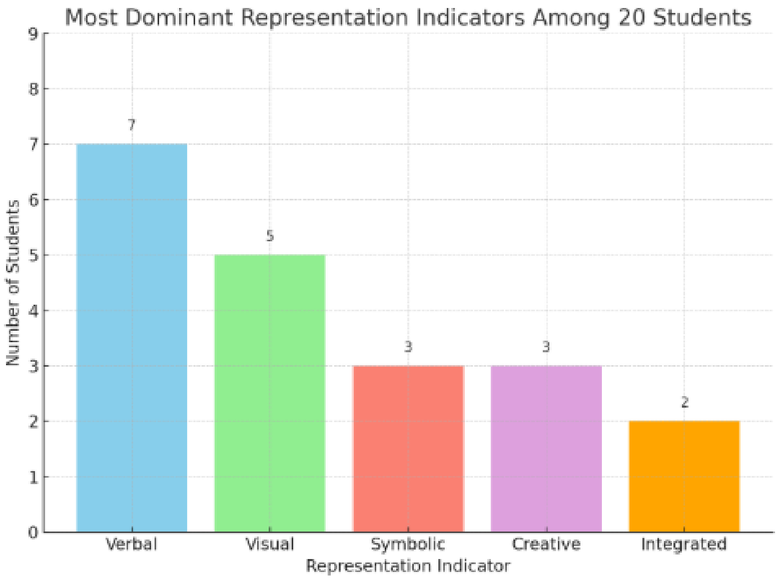

Figure 2. Most Donimnant Representation Indicators

Two pupils were dominated by symbolic representation, and two students were dominated by integrated representation (10%). Since these forms need a higher conceptual understanding and the capacity to synthesise numerous types of information skills that are often developed with more advanced academic and practical experience the lower frequency of these indicators may be a reflection of their greater complexity and abstractness.

While fewer individuals are innately drawn to more abstract and integrated modes of communication, the distribution of dominant representation markers generally indicates that most students do best in more concrete and known forms of communication (verbal and visual). This highlights the necessity of educational interventions that help future biochemists' holistic professional development by encouraging balanced development across all representation domains, particularly symbolic and integrative thinking.

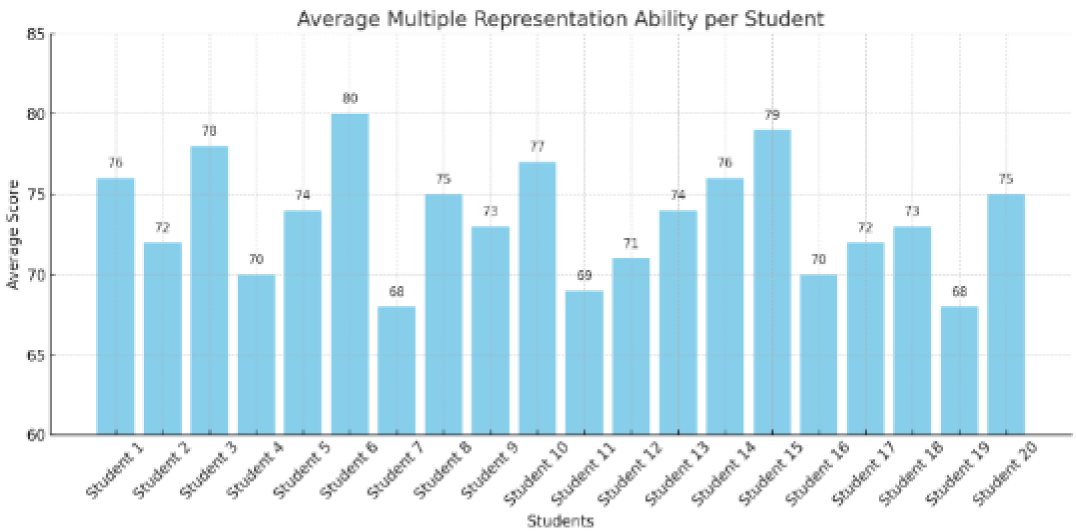

Figure 3. Average Multiple Represntation Ability

4.1 Discussion of Regression Analysis Results on the Effect of Multiple Representation Indicators

The regression analysis's findings provide important new information on how each multiple representation indicator affects students' overall representation skills. The model explains around 69.2% of the variation in students' representational performance, with an R2 value of 0.692. This reveals that the chosen indicators verbal, visual, symbolic, integrated, and creative representation collectively provide a significant contribution to the growth of students' representational ability in the context of learning biochemistry. It also shows a robust model fit.

The strongest significant predictor among the five indicators was verbal representation (B = 0.312, p = 0.005), which was followed by visual representation (B = 0.274, p = 0.026). This implies that pupils who are more adept at using diagrams and visual models, as well as those who are better at communicating ideas orally or in writing, typically have higher total representation ability. These results are in line with theories of cognitive learning that highlight the value of dual coding (visual and verbal) in improving memory, comprehension, and information transfer, particularly in scientific education where abstract ideas must be both explained and shown (Oteíza & Franzani, 2023; Widiastari & Redhana, 2021).

Table 4. Regression Analysis of the Effect of Multiple Representation Indicators on Overall Representation Ability

Predictor (Independent Variable)	Unstandardized Coefficients (B)	Standard Error	Standardized Coefficients (Beta)	t	Sig. (p-value)
Verbal Representation	0.312	0.098	0.421	3.184	0.005
Visual/Diagrammatic Representation	0.274	0.113	0.367	2.425	0.026
Symbolic Representation	0.189	0.122	0.243	1.549	0.140
Integrated Representation	0.231	0.109	0.308	2.119	0.048
Creative Representation	0.195	0.115	0.259	1.696	0.106
Constant	22.530	4.321	-	5.215	0.000

Additionally, integrated representation had a statistically significant impact (B = 0.231, p = 0.048), emphasizing the function of synthesis across various representational formats. This supports the notion that kids do better overall when they are able to coordinate verbal, symbolic, and visual representations. Though they still had positive coefficients, symbolic and creative representation did not provide statistically significant effects at the $p < 0.05$ level, indicating a supporting but not dominant role in forming representational competence.

4.2 Field Observations and Socio-Cognitive Context

Students were better at ease using verbal and visual representations, according to field observations made during the learning process. Students were naturally able to express and illustrate their ideas through group discussions, storyboard development, and scriptwriting for video tasks. Tasks that included integrating numerous representations or manipulating biological symbols, on the other hand, seemed to require greater cognitive effort. Undergraduate students' sociocognitive development level is in line with this, especially for those who are just beginning their scientific studies and are still learning symbolic abstraction and representational fluency across modalities (Gong et al., 2024; Peng et al., 2024).

Furthermore, the primacy of verbal abilities may also be influenced by the cultural environment of learning, where verbal explanation is frequently prioritized over conceptual modeling. The development of symbolic thinking or creative abstraction based on deeply scientific material was less aided by the digital tools employed in the video-making project, such as PowerPoint, Canva, and video editors, than by the production of visuals and narratives.

4.3 Strengths and Limitations of the Findings

This study's incorporation of real-world tasks (such making videos) into a project-based learning (PJBL) framework is one of its main advantages as it promotes the organic development of representational abilities (Lim et al., 2023; Maros et al., 2023). Beyond conventional multiple-choice testing, the inclusion of many essay-based evaluations helped to further capture complex student talents. However, the results are constrained by the small sample size (N=20), which might have an impact on statistical power and generalizability.

Furthermore, students may have underused symbolic and creative indicators in the setting of essay-based examination, which might explain the absence of substantial influence from these indicators. It's possible that limitations in the rubric's design or the students' inexperience converting creativity into scientific output prevented the complete capture of creative representation in particular.

4.4 Future Reflection and Educational Implications

These results urge that the scientific curriculum be redesigned with an emphasis on integration and representational diversity going forward. In addition to emphasizing verbal and visual explanation, instruction should purposefully scaffold the use of symbolic language and the imaginative reworking of scientific concepts (Frick Semmler et al., 2024; Kitab, 2024). These objectives can be supported by instructional techniques including modeling-based inquiry, representational translation tasks, and design-based learning.

Furthermore, to examine how representational competence changes over time, future studies should look at longitudinal designs with bigger and more varied samples. Knowledge of how students create and communicate meaning across modalities may also be enhanced by mixed-method research that include think-aloud procedures, qualitative interviews, and artifact analysis.

This study concludes by highlighting students' representational skills' hidden difficulties as well as their existing strengths. Teachers may develop scientifically literate students who can think, communicate, and innovate in several dimensions by adjusting their lessons to meet the cognitive demands of various representations.

5. Conclusion

Based on the findings, it can be concluded that the implementation of a Multiple Representation Strategy through Team-Based Representational Activities with Creative Exploration via Learning through Video effectively enhances students' representational competencies in the domain of cell biology. The highest achievements were recorded in verbal and visual representation, confirming the instructional model's strength in fostering communicative and illustrative understanding. However, symbolic and integrated representation scored the lowest, exposing a critical gap in students' ability to abstract and synthesize scientific knowledge across representational modes. This signifies that while the approach successfully engages learners in expressive and creative dimensions, it must be further refined to support deeper cognitive processing and symbolic reasoning. These results validate the effectiveness of project-based learning integrated with multimedia creation in enhancing student engagement and representation skills, particularly in scientific communication. Nevertheless, it also reveals the necessity for more structured scaffolding and targeted interventions to build competence in abstract and integrated thinking. The study contributes novel insights into how multimodal strategies can shape meaningful learning and offers a practical framework for improving curriculum design in science education, particularly in training future biochemistry educators.

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