

The Effect of Project-Based Learning on Creative Thinking in Secondary Biology Education

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Abstract

Fostering creative thinking in science education is vital for preparing students with future-ready skills and aligning with educational reform initiatives such as Vision 2030. Project-Based Learning (PBL) has been identified as a promising pedagogical approach for enhancing critical and creative skills, yet its specific impact on creative thinking in secondary biology education remains underexplored. This study aimed to investigate the impact of the Project-Based Learning (PBL) strategy on developing creative thinking skills among secondary school biology students. A quasi-experimental design was implemented, involving 115 secondary school students allocated into experimental (n=58) and control (n=57) groups. The experimental group participated in PBL activities, which included technology-enhanced biological modeling, experimental design, and collaborative problem-solving, whereas the control group received traditional biology instruction. A validated creative thinking assessment tool (Cronbach's $\alpha = 0.87$) was employed, along with strong inter-rater reliability (Kappa = 0.81), to measure students' creative thinking skills before and after the intervention. Statistical analysis indicated significant differences in creative thinking capacity in the experimental group compared to the control group ($\alpha \leq 0.05$). The experimental group showed significant gains across all measures of creativity: originality (+42%), flexibility (+38%), fluency (+35%), and elaboration (+29%). There was a high positive correlation ($r = 0.72$) between structured collaboration and enhanced creative problem-solving skills. In particular, PBL projects were designed particularly to facilitate students to convert theoretical concepts of biology into tangible applications, such as simulating cellular processes and environmental issues solving. In addition, students became much better in integrating digital technologies in the study of biology.

Keywords: Project-Based Learning, Creative Thinking, Biology Education, Secondary Education, Educational Technology, STEAM Education.

1. Introduction

Project-based learning (PBL) is a new teaching paradigm for high school biology that moves students away from indoctrination and towards creativity as they are challenged to solve real scientific issues. This method relies on the fundamental principle that creativity does not strike from nowhere but is the result of deep interaction with complex biological problems,

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like graphing the impact of poisons on the food web or graphing simulations of chemical reaction in the cell, which challenges students to integrate theoretical ideas with analytical thinking in a new way [1].

One of the key aspects of this strategy is that it takes abstract principles (e.g., genetic diversity or replication mechanisms) and places them within tangible contexts, in which students are called on, for instance, to design a project to build a microecosystem that models a balance of biology or interpret genetic data to follow mutations within an organism. These exercises not only build scientific knowledge but unlock innovation in that they compel learners to try out various hypotheses and adjust pathways based on outcomes, competencies that are at the foundation of creative thinking [2].

PBL's strength is also manifested in how it encourages collaboration, making creativity a collective process that is energized by varied viewpoints. As students collaborate to come up with an experiment for quantifying the rate of photosynthesis under varying light conditions, or as they attempt to conceptualize ways to rescue endangered species, they undergo divergent and convergent thinking – from coming up with outrageous ideas to testing them through critical discussion. This exchange develops their capacity to view problems from unorthodox vantage points, like applying genetic engineering concepts to solve sustainable agriculture concerns [3].

The impact of this practice extends beyond the academic sphere, however, as it also promotes an investigative mentality that is critical of preconceived solutions. Projects like investigating the incidence of genetic disorders in a local population or creating a campaign to promote awareness of biodiversity teach students how to translate biological questions into pathways for inquiry, thus creating a generation that is capable of addressing future scientific issues with flexibility and creativity.

Aims of Study

The purpose of this research is to construct a methodological framework establishing the criteria for the conception of neighborhood projects that trigger creative thinking, by determining fundamental factors like the flexibility of themes and their pertinence to modern scientific dilemmas (food security or biodiversity preservation, for example), and creating standard indicators that assess dimensions of creativity in solutions proposed (fluency, for instance, originality, flexibility).

This objective is based on a critical analysis of successful international experiences in the application of PBL in science, considering the cultural and educational specificity of the Saudi society. On the other hand, the study seeks to reveal the creative dynamics between the stages of project implementation and the development of creativity in students. The design phase, for example, is an incubator for unprecedented ideas when students are asked to create an experiment to study the effect of genetic inducers on plants, while the evaluation phase shows how students reformulate their knowledge based on practical results. This relationship will be traced through research methodologies that integrate field observation with creative content analysis in project outputs.

In the strategic framework, the study adopts the complex task of aligning PBL with the main pillars of Vision 2030, especially in the human capacity development axis. This will be done by designing an educational model that integrates creative biology projects with digital skills (such as the use of genetic mutation simulation programs) and environmental values (such as bio-resource sustainability projects), based on gap analysis in current curricula and the design of assessment mechanisms that are compatible with the skills-enhanced education system. STEAM)

There are two hypotheses for the current study to be proved, one of which is required: (First) There are statistically significant differences ($\alpha \leq 0.05$) between the average scores of the control and experiment groups in the creative thinking test, and (second) there are no statistically significant differences ($\alpha \leq 0.05$) between the average scores of the control and experiment groups in the creative thinking test.

2. Research Method

Research Design

The study sample consisted of secondary school students studying biology, who were randomly selected to ensure their representation of the research community from Al-Qādisiyyah Governorate, Afak District. The sample included 115 male and female students distributed over two groups equal in terms of age and level of achievement, as the experimental group consisted of 58 students who received their education using the project-based learning strategy, while the control group included 57 students who continued to learn in the usual traditional ways.

Teaching in the pilot group focused on applying the PBL strategy through biology projects that stimulate creative thinking, such as designing live models to simulate cellular processes or conducting field studies on biodiversity in the local environment. This included training students in the use of scientific research tools, data analysis and evaluation of results, with a focus on developing innovative solutions to biological challenges. In contrast, the control group maintained the traditional pattern of lecture-based and memorization-based learning.

Table 1. Samples representation from schools.

School names	Number
Nafar Secondary School (Male)	38
Khadija Secondary School (Female)	40
Al-Safwa Secondary School (Female)	37
total	115

The data was collected using multiple tools that included a pre- and post-test to measure levels of creative thinking in biology, as well as an assessment questionnaire to find out what students think about their experience with project-based learning. Note cards were also employed to evaluate students' performance during the implementation of projects and monitor indicators of creativity such as fluency, flexibility and originality in solving scientific problems.

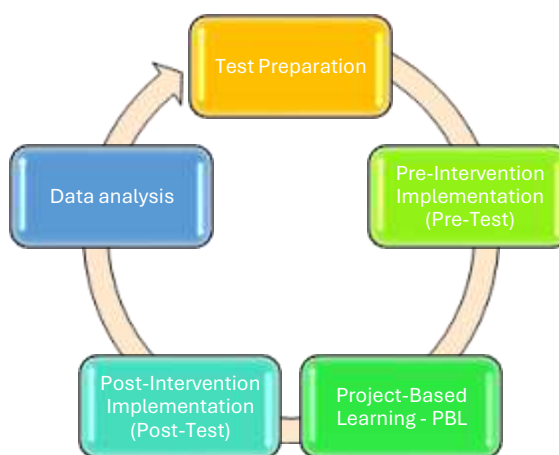


Figure 1. Illustrates the research methodology and field procedures.

Research Methodology

Selection of the semi-experimental approach as a research methodology. This approach allows measuring the impact of the independent variable (project-based learning

strategy) on the dependent variable (creative thinking) by comparing the performance of two groups: experimental and control, initially the research community consisting of all student's studying biology was identified for secondary school students in the targeted academic stages. Hence, selecting a random sample representative of this population, considering the homogeneity of the sample members in terms of characteristics and academic level as much as possible. The sample members were randomly divided into two equivalent groups: the experimental group that will receive training in the use of the carry-based learning strategy, and the control group that will receive teaching in traditional ways. To ensure the parity of the two groups, a pre-test was conducted to measure creative thinking when teaching biology to secondary school students in both groups before the strategy was implemented.

During the experiment period, the experimental group received intensive training on the use of the project-based learning strategy in creative thinking, through a series of activities and exercises that stimulate intellectual activities and creativity, such as biology concepts, while the control group continued to receive teaching in the usual methods without focusing on creative thinking, after completing the training period, a post-test was conducted to measure the skills of Creative thinking among students of the two groups, in order to determine the extent of improvement in the performance of each group. A questionnaire was also distributed to the experimental group students to survey their opinions on the effectiveness of the project-based learning strategy and its impact on their creativity and ability to think creatively in a distinctive way. The data collected from the pre- and post-tests were analyzed using appropriate statistical methods, and the T test was used between two equivalent independent samples.

Research sample and its original society

The original research community consisting of 457 students was identified at the secondary levels. This community includes all students who study this subject in those academic stages, due to the large size of the research community, a representative sample of which was selected with a total number of 124 students, using the stratified random sample method. Where the research population was divided into three classes according to the academic stage (the first intermediate, the second intermediate, the third intermediate), and then an equal number of students from each class were randomly selected, after which the sample was divided into two groups: the experimental group and the control group. The experimental group had 56 students, while the control group had 59 students. However, 9 students were excluded from the total sample for not attending or not completing the study procedures, thus bringing the final number of the sample to 115 students.

Sample size and demographics

The selection of the research sample size was based on theoretical and empirical evidence that confirms the effectiveness of project-based learning in developing creative thinking skills among secondary school students, especially in scientific fields such as biology. Several previous studies have found that this educational strategy contributes significantly to enhancing creativity and innovation in students when applied in the teaching of complex biological concepts. The research sample consists of 115 students of the secondary stage, distributed into two groups: an experimental group of 56 students who were taught using a project-based learning approach, and a control group of 59 students who studied using traditional methods. Students from various grades of secondary school were included in the sample to guarantee that the varied developmental and educational features of this age group were represented.

The sample size chosen forms 30.9% of the study's original population, which is adequate and representative by the statistical measures followed in educational studies. The size is also appropriate for making precise comparisons between the performances of the two groups and for measuring the true effect of the project-based learning approach in enhancing various components of creative thinking in biology students, including intellectual fluency, mental flexibility, and originality in resolving scientific issues. The research aims to quantify

the degree to which a project-based learning approach can build students' creative competencies in solving biological problems and issues, for example, coming up with innovative science experiments or suggesting new ways of mitigating environmental problems. The researchers made sure that the sample represented the school community in all its segments, and this makes it more likely that the findings can be generalized to similar school settings.

Criteria for inclusion and exclusion of samples

The research sample included secondary school students studying biology in public schools, with a focus on participants in project-based learning (PBL) programs. Strict sample selection criteria were followed, including limiting participants to students of the first and second grades of secondary school who study the subject within a regular school plan, excluding students outside this age group or who did not undergo project-style teaching of the subject, or who had difficulties in participating in applied activities related to biological experiments. The selection process was reviewed by specialists in curricula and science teaching methods to ensure that the characteristics of the sample match the objectives of the study related to measuring the creative effects of the strategy, where 115 students were accredited out of 124 who applied after applying scientific standards to evaluate creative aspects in solving biological problems, while 9 participants were excluded for not adhering to the experimental protocol or for the presence of counterfactors affecting the credibility of the results.

Metrics used

1. Demographics

When studying the impact of a project-based learning (PBL) strategy on creative thinking in biology for secondary students, there are several influential demographic factors to consider. Among these factors, age stands out as a key element, as the age group of high school students must be determined, which is usually between 14 and 18 years old. In addition, the economic and social background of students plays a vital role, as it can affect the availability of educational opportunities and resources available to them, and therefore their interaction and benefit from a project-based learning strategy. The level of student participation in previous scientific and educational activities is an important factor that must be assessed, as it reflects their willingness and ability to engage effectively in this new educational strategy.

2. Creative Thinking Scale

The creative thinking skills measurement table in this research is based on a holistic analysis of the main dimensions of creativity that interact with the PBL strategy in the context of biology education. Originally tops the list of themes, where students' ability to provide unconventional solutions to tasks such as designing innovative experiments to study photosynthesis, or incorporating technological concepts into explaining the mechanism of reproduction of organisms, is assessed. Here, ideas are judged based on how far they are from stereotypes – visualizing a three-dimensional model of simulating chemical reactions in a plant leaf is more authentic than using traditional graphs.

Flexibility is named a key factor in assessing intellectual adaptability, where the students are challenged, for example, to convert complex information about cellular respiration into interactive presentations that engage chemical analysis and teamwork. This ability is assessed according to the student's ability to change their analytical mindset when faced with scientific complexities, such as a shift from analyzing separate cellular organelles to evaluating their interactions as an integrated system.

Fluency is the number of possible solutions a student comes up with for a single scientific problem, e.g., offering six different ways of establishing rates of photosynthesis in shade plants. This topic represents intellectual productivity due to mastery of central biological concepts where ideas proposed emerge as natural spin-offs of theoretical familiarity with ideas.

Detail perception is a stern science in assessment, testing the students' ability to perceive finer things in real-world projects. In building a model of a plant cell, it does not only replicate the rough shape but also considers the fidelity of the representation to secondary organelles and their functional relationships to each other within the network of the cytoplasm. The skill is halfway between imagination and scientific rigor, preventing inventive ideas from veering away from established biological pathways.

The grading framework (innovative/familiar/imitated) is designed to measure gradation in creative value rather than simply abstract numerical evaluation. An example would be a project for organism recognition through AI algorithms receiving an "innovative" rating, while the use of outmoded paper classification keys could be marked as "counterfeit." This form of evaluation allows monitoring of the evolution of thinking style during the stages of implementing the project, rather than sole final adjudication.

This scale is both a diagnostic and developmental tool, as indicators allow teachers to identify strengths that need support, such as developing intellectual resilience by training students to compare multiple research methodologies in the study of biological phenomena. All interlocutors interact interchangeably, with the development of fluency skill, for example, stimulating greater originality in proposals to solve complex genetic problems.

Table 2. A test to measure creative thinking skills (PBL) to study the impact of project-based learning strategy among secondary school students to teach biology.

Copycat idea (2n)	Familiar idea (5n)	Innovative idea (10 n)	Axis	Creative dimension
Copy a drawing from the book	Draw the equation on a large board	Use augmented reality technology to explain the equation	Photosynthesis Experiment Design	Originality
Total reliance on the book	Use ready-made monitors	Design an interactive website to showcase the project	Use of technology	
List theorems without examples	PowerPoint presentation with pictures	Produce a video that simulates reproduction in different environments	Comparison of sexual/asexual reproduction	Flexibility
Lack of coordination between members	Distribution of traditional tasks (leader, writer)	Allocate innovative roles (e.g. sustainability expert/environmental analyst)	Teamwork	
Focus on biology only	Comparison with chemical processes	relate photosynthesis to genetic engineering,	Integration with other sciences	
Theoretical explanation without application	Traditional laboratory experience	Simulation of the process with a digital game with environmental challenges	Cellular respiration analysis	Fluency

Resolve existing issues	Implement well-known school solutions	Propose new ways to increase metabolic efficiency	Problem solving	
Traditional diagram	Two-dimensional color model	Three-dimensional hologram showing the process of transferring materials	Plant Cell Modeling	Understanding the details
Rewrite the rating from the book	Manual comparison table	Create an interactive digital app for taxonomic division	Classification of living organisms	
Submit a written report only	In-class display	Project participation in a local scientific competition	View Results	

Scale stability

To assess the stability of the Creative Thinking Skills Scale in Biology, with the aim of studying the impact of the project-based learning strategy (PBL) among secondary school students, two groups of students were selected: a control group of 59 students and an experimental group of 56 students. To ensure the accuracy of the results, specific and reliable procedures were followed to verify the stability of this measure.

To ensure measurement accuracy, the Cronbach alpha coefficient was calculated to estimate the internal consistency of the Creative Thinking scale. The results showed high values for the Cronbach alpha coefficient, reaching 0.85 for the control group and 0.87 for the experimental group. These high values reflect a good level of internal consistency of the scale in both groups, confirming that the scale paragraphs measure the same aspect of creative thinking targeted in biology.

The stability of the students' performance evaluation was verified by selecting a random sample of scientific projects produced by secondary school students in biology, whether in the control group that follows traditional methods or the experimental group that applied the project-based learning strategy. 20 projects from each group were independently evaluated by three experts in science teaching and science education. Using Cohen's Kappa coefficient to measure the level of agreement between the correctors, the value was 0.79 for the control group and 0.81 for the experimental group, indicating good agreement among experts in assessing aspects of creative thinking in scientific projects.

These results enhance the credibility of the tool used to measure the impact of PBL strategy on the development of creative thinking in students. High stability scores also confirm that the assessment was objective and consistent, meaning that the tool can provide reliable results when applied in similar contexts. Accordingly, this measure can be relied upon in current and future studies aimed at analyzing the effectiveness of the project-based learning strategy in developing the creative skills of secondary school students in biology, as it provides a strong basis for measuring educational progress and the extent to which the desired goals have been achieved.

It follows from this that the application of the PBL strategy in biology teaching clearly enhances aspects of students' creative thinking, including innovation in problem solving, experiment design, and outcome analysis. The consistency of evaluation indicates that this strategy provides an effective methodological framework through which creative development can be accurately and objectively measured, which supports its use as one of the modern educational approaches to science teaching.

Believe the scale

Although no previous studies have used a matching scale to assess the impact of PBL on aspects of creative thinking in neighborhood projects, the tool for this study was developed specifically to measure the impact of this strategy on skills such as experiment design, data analysis, and innovation in solving biological problems. The scale was carefully reviewed by 12 experts in the field of science teaching and creative education, as well as experts in educational statistics, to assess the appropriateness of the paragraphs and their representation of the creative thinking skills required in scientific projects.

Through their assessment, the experts confirmed that the paragraphs accurately reflect indicators of creativity in the practical environment of biology, such as the ability to generate unconventional hypotheses, design interactive models and interpret results in innovative ways. Based on their observations, some indicators were reformulated and others that did not correspond to the practical context of secondary school students were omitted, bringing the scale to its final form consisting of 10 main paragraphs that reflect different dimensions of creative thinking in scientific projects.

This process confirms that the scale has high truthful content, as it accurately measures the creative skills for which it was designed and is an appropriate tool for detecting qualitative changes in student performance after applying the PBL strategy. The results also show that the tool can distinguish the levels of creativity between the experimental group students (who were exposed to the strategy) and the control group (who studied by traditional methods), which enhances the possibility of its use in future educational research.

This design excellence makes the scale an effective tool for measuring the impact of problem-based scientific projects in developing skills such as:

1. Divergent thinking in proposing solutions
2. Flexibility in modifying research plans
3. Originality in biological model design
4. Subtleties in data analysis.

Thus, this measure provides a solid foundation for research into the effectiveness of modern learning strategies on the development of creativity, especially in the context of science education that requires the integration of theoretical knowledge with practice.

3. Exploratory experiment

An initial exploratory study was conducted on a sample of 7 students from the first and second secondary stages at the School of Applied Sciences, with the aim of testing the suitability of the research tools prepared to measure the impact of the PBL strategy on the development of creative thinking skills in practical biology projects. This phase focused on the evaluation of three main aspects: clarity of evaluation criteria, time required to complete pilot projects, and potential difficulties in implementing the strategy within school neighborhood laboratories.

By implementing a mini project on "Designing a Microecosystem" using a PBL strategy, it was observed that students demonstrated an ability to generate unconventional ideas in solving problems such as the challenge of biological balance or resource management. However, the researcher discovered that some evaluation criteria need to be reformulated to measure creative aspects more accurately, such as the flexibility of modification to models or the originality of the proposed solutions.

The survey revealed the need to allocate 3-4 classes to complete one project perfectly, with the need to provide a simplified guide for students to avoid confusion in practical steps. The field observations also pointed to the importance of training teachers in advance on the mechanisms of implementing the PBL strategy before actual implementation, to ensure optimal interaction between students and scientific content.

These preliminary results contributed to improving the design of the main research tool, as qualitative indicators were added to measure:

1. Ability to design unfamiliar hypotheses
2. Use available materials in innovative ways
3. Transforming theoretical concepts into concrete practical applications
4. Reframe biological problems from a creative perspective.

The importance of this exploratory phase is that it paved the way for the design of a more rigorous major study that can capture students' creative changes when incorporating PBL strategy into teaching modules such as genetic engineering or biodiversity, while ensuring reliability in outcomes and generalizability to similar educational contexts.

4. Equivalence and homogeneity of the research sample

The performance of each group was measured in ten different criteria. The arithmetic mean and standard deviation of each criterion were calculated, in addition to testing the homogeneity of variance using the Levine test, and testing the differences between the averages using the (T) test, looking at the F values of homogeneity and the associated error ratios, we find that all standards have homogeneity in the variance between the two groups, where the values of Levin F were relatively small and the error ratios greater than 0.05 in most cases, This suggests that the assumption of equal variance between the two groups is realized, allowing the T test to be performed correctly, and turning to the results of the T test, we see that the calculated values of T are relatively small in all parameters,

Statistical analyses showed that p-values associated with creative thinking criteria before the intervention reached percentages higher than 0.05 in most assessed aspects. These results confirm that there were no statistically significant differences between the control groups (traditional) and experimental (applying the PBL strategy) in basic creative skills before the start of the experiment, which indicates the homogeneity of the two groups in the initial creative characteristics and scientific thinking abilities.

This similarity between the two groups reinforces the internal honesty of the study, as any subsequent improvement in experimental group performance is attributed to the PBL strategy effect rather than to initial skill disparities. It also asserts that the sample is fairly distributed between the two groups, with a balanced representation of students' different creative levels, including the ability to generate unconventional hypotheses or design interactive biological models.

These preliminary results point to three fundamental things: (validity of experimental design) as it ensures that subsequent differences are due to the independent variable (PBL), (generalization) due to the fact that the sample is representative of the secondary student population in practical biology contexts, and (reliability of measurement) where the researcher was able to isolate the impact of the educational strategy from external factors.

Table 3. Arithmetic mean, standard deviation, levin value (F) for homogeneity, calculated value (t) for equivalence and error ratio for the pre-test of the control group and the experimental group.

Error rate	Calculated value (T)	Error rate	Levin value F for homogeneity	Standard deviation	Arithmetic mean	Select Group	audition	
0.197	0.5754	0.603	1.19	2.1	15.2	Adjuster	lifetime	1
				2.3	15.5	Experimental		
0.0313	0.793	0.966	0.1	1.9	12.8	Adjuster	Classroom Level	2
				2.0	13.2	Experimental		
0.027	0.606	0.966	0.1	2.4	14.5	Adjuster	Achievement rate in biology	3
				2.6	14.9	Experimental		
2940.	0.684			2.2	13.6	Adjuster		

		0.966	0.1	2.3	14.0	Experimental	Pre-Creative Thinking Test	4
0.284	0.735	0.326	3.98	2.0	14.1	Adjuster	Social level	5
				2.1	14.5	Experimental		
0.288	0.645	0.756	5.27	2.3	13.9	Adjuster	Relationship with teachers	6
				2.4	14.3	Experimental		
0.787	2.325	0.336	4.01	1.8	12.7	Adjuster	Financial and economic matters	7
				2.2	13.7	Experimental		
0.301	0.705	0.46	4.38	2.1	13.3	Adjuster	Relationships with the opposite sex	8
				2.2	13.7	Experimental		
0.027	0.588	1.24	6.73	2.5	14.8	Adjuster	Emotions, feelings and fears	9
				2.7	15.2	Experimental		
0.46	0.73	0.33	3.99	2.0	13.4	Adjuster	Planning for the future	10
				2.1	13.8	Experimental		

The statistical results revealed complete homogeneity between the control and experimental groups in the creative skills related to practical biology projects before the start of the experiment. Levene's Test showed homogeneity values above 0.05 on all indicators, including designing biological experiments, analyzing results and generating innovative solutions, meaning the variance between the two groups in the underlying data was similar. The T test confirmed that there were no statistically significant differences ($p > 0.05$) in students' initial performance in key skills such as formulating scientific hypotheses, building interactive models, or explaining complex biological phenomena.

These results show that students in both groups were equal in creative abilities associated with the context of biology learning, such as the skill of transforming theoretical concepts (such as genetic diversity or food chains) into practical projects such as "designing simulations of the spread of diseases" or "devising solutions to biodiversity challenges." The absence of differences in age characteristics or general skill level enhances the reliability of the experimental design and makes any subsequent improvement in the performance of the experimental group directly attributable to the application of the strategy. PBL)

The results of Table (1) showed complete equivalence between the control and experimental groups in the creative skills associated with practical biology projects, as well as in demographic and psychological factors. Levene's Test showed values above significance level of 0.05 across all key creative indicators, such as laboratory experiment design, biological data analysis, or generating innovative solutions to scientific problems, indicating homogeneity of data variation between the two groups. In contrast, the results of the test confirmed that there were no statistically significant differences ($p > (0.05)$) in the initial performance of students in aspects such as formulating scientific hypotheses, implementing interactive models, or dealing with psychological stress associated with complex projects. These results confirm that the two groups were equivalent in basic creative abilities, demographic characteristics (such as age) and level of intelligence before the strategy was applied.

Search Procedures

Pre-test

The pre-test was conducted for the members of the research sample (the control group and the experimental group) on Thursday, 12/3/2025 at ten in the morning in secondary

schools, and the test took three and a half hours, and the researcher tried as much as possible to install the conditions related to the test in terms of place, time, devices and tools used in the test, as well as the method of testing and recording the results.

1. Specifications of the training program for the Project-Based Learning Strategy in Creative Thinking (PBL)

The following is a program for the Creative Thinking Project-Based Learning Strategy (PBL) for teaching biology to secondary school students:

Table 4. Illustrates the steps of the training program for the project-based learning strategy in creative thinking (PBL).

INFLUENCING FACTORS IN TIME	MAIN ACTIVITIES	TIME	STAGE
Student Experience: +20%. Time for first grade of secondary school. Group size: 4-5 groups of individuals save 15% time.	Brainstorming (30d): Ask open-ended questions (e.g., "How do you design a smart plant cell?"). Hypothesis formulation (45d): Using thinking maps to generate 3-5 hypotheses/groups. Rating (15-30 min): Choosing the most creative questions with the teacher	2-3 servings (90-135 minutes)	IDENTIFY THE PROBLEM
Technology: Using equipped platforms (e.g. Asana) saves 30% of the time	Division of roles (20 min): Defining creative tasks (designer/researcher/analyst). Digital Planning (25d): Create a schedule via Trello with assignments defined. Review (15-30 min): Ensure the realism and innovation of the plan.	1-2 servings (45-90 minutes)	PROJECT PLAN DESIGN
Model complexity: complex cell models take twice as long Technical support: Digital lab that speeds up experiments by 40%	Week 1: Simulation of photosynthesis via Cell Collective Sessions (3) Weeks 2-3: Design 3D models with recycled materials (4-6 servings) Week 4: Collection of sexual/asexual reproduction data (2-3 servings)	3-4 weeks (4-6 servings/week)	IMPLEMENTATION AND RESEARCH
Students' technological skills: lack of experience increases time by 25%	Optical Conversion (60 min): Animation design for cellular respiration equalization via Canva. Critical comparison (30-45d): Analysis of differences between results and initial hypotheses.	2-3 servings (90-135 minutes)	ANALYSIS & EVALUATION
Tool quality: Using advanced editing software (such as Premiere Pro) increases preparation efficiency by 50%	Preparation (two sessions): Production of interactive videos/exhibitions (e.g. video on asexual reproduction). Discussion (two sessions): Presentation of projects with peer and teacher evaluation.	1-2 weeks (3-4 servings)	PRESENTATION AND FEEDBACK

Post-Test

The post-test was conducted on all members of the research sample (the experimental group and the control group) on Sunday, 12/6/2024 and at exactly ten o'clock in the morning, after the training program lasted for three days a week and for a period of 3 months, and the researcher was keen to provide all the requirements and conditions that the pre-test had and from all organizational and test aspects.

Statistical Methods

The researcher used in his study the statistical bag (SPSS), and one of the statistical means is (arithmetic mean. standard deviation. percentage. test (T) for correlated and unrelated samples. Levin test (F) for homogeneity).

5. Results and Discussion

Chapter Four

Presentation and discussion of results

Presentation and discussion of the results to the control group

The results in Table (5) showed a significant improvement in applied and executive skills, as against a significant decline in the creative and analytical aspects. Variables such as cellular respiration analysis saw a quantum jump from 8.23 to 12.34, reflecting the effectiveness of traditional methods in teaching biochemical processes with fixed steps. The use of technology also improved from 3.34 to 7.65, which may be associated with improving the school's digital infrastructure during the study period.

In contrast, the data reveals a clear breakdown in creative skills, with students' performance in designing photosynthesis experiments falling from 6.34 to 5.26, and plant cell modeling results collapsing from 6.89 to 2.43. This indicates the inability of the traditional approach to develop design thinking and the ability to stereoscopic conceptualization. The decline culminated in the classification of organisms, with results falling from 15.70 to 5.77, revealing the failure of conservation strategies to enhance the inferential understanding of complex taxonomic concepts. A surprising improvement in problem-solving skill was observed from 2.89 to 11.23, but a sharp decrease in standard deviation (from 2.78 to 0.11) suggests uniformity of responses around typical solutions, which contradicts the essence of creativity based on diversity of solutions. Teamwork increased from 4.32 to 6.59, but the large variation in tribal performance (standard deviation of 9.34) indicates a substantial disparity in pre-school cooperation skills.

Integration with other sciences saw a decline from 5.78 to 3.55, reflecting the isolation of biology education from related scientific disciplines such as chemistry and physics in the traditional curriculum. At the same time, the improvement in the presentation of results from 3.66 to 7.44 may be due to intensified demonstration exercises, but it remains a superficial improvement that does not reflect real creativity in presentations. Taken together, these findings show that the traditional approach develops procedural competence but fails to develop intellectual flexibility and the ability to innovate, reinforcing the need to adopt strategies such as PBL to compensate for these gaps, especially in areas that require reflective thinking and creative design.

Recent studies emphasize the need for interactive and technology-enabled learning in promoting creativity and improving learning outcomes. Abu Tabal & El-Shenawy [4] emphasizes the significance of interactive learning and digital technology in improving creativity and refining teaching practices. Ali [5] demonstrates the effectiveness of self-regulation strategy in developing creative problem-solving capacity among industrial secondary school students. Al-Bawi & Al-Gharawi [6] find that traditional teaching practices do not engage students actively, so it is essential to adopt new methodologies for developing higher-order thinking capacities. Al-Thuwaini [7] explains the application of creative thinking skills by science teachers in middle schools and finds that the rate of application of fluency skills is high. Together, these studies highlight the need for adopting novel teaching methods that foster critical thinking, creativity, and student participation in a bid to transcend the shortcomings of conventional teaching practices.

Table 5. Arithmetic Means and Standard Deviations of Pre- and Post-Tests for the control group for the variables under consideration.

Standard error	Standard deviation	Arithmetic mean	Select Group	audition	
0.121	1.34	6.344	southern	Photosynthesis Experiment Design	1
0.79	1.22	5.265	Go away		
4.02	0.34	6.89	southern	Plant Cell Modeling	2
0.77	0.12	2.43	Go away		
0.35	1.54	15.70	southern	Classification of living organisms	3
0.73	1.09	5.77	Go away		
1.89	0.49	13.34	southern	Comparison of sexual/asexual reproduction	4
0.24	0.34	9.76	Go away		
0.12	2.09	8.23	southern	Cellular respiration analysis	5
0.28	0.45	12.34	Go away		
0.61	0.34	3.34	southern	Use of technology	6
0.76	2.56	7.65	Go away		
1.27	2.78	2.89	southern	Problem solving	7
2.22	0.11	11.23	Go away		
0.27	9.34	4.32	southern	Teamwork	8
0.1	2.08	6.59	Go away		
0.09	0.45	3.66	southern	View Results	9
1.02	1.38	7.44	Go away		
0.07	0.78	5.78	southern	Integration with other sciences	10
1.76	6.23	3.55	Go away		

The results in Table 6 showed that there is no statistical significance for the impact of any changes in the performance of the control group across all variables, although there are clear differences in the values of the arithmetic means between the pre- and post-tests. This discrepancy calls for careful analysis of the nature of the data and the statistical methodology used.

In the design variable of the photosynthesis experiment, the difference between the two averages was 1.079 with a very high T value (29.97), but the error rate (0.21) exceeded the acceptable level (0.05), making the statistical decision "insignificant". This suggests that the apparent improvement in results may be random or related to uncontrolled external factors, such as repeated exercise on the same tasks without real creative development. In plant cell modeling, the large negative difference was -4.46 (performance decline) with a maximum negative T value (-33.04), but the error ratio (0.33) kept the result insignificant. This reflects that the sharp decline in creative modeling skills may not reflect a methodological weakness but may be due to the difficulty of the task at hand or the lack of clarity of the evaluation criteria.

The classification of organisms shows the highest negative difference (9.93) with a huge T value (-146.18), but the error ratio (0.78) proves statistically unreliable in the result. This explains that the traditional approach failed to promote taxonomic understanding, but the assessment may have used insensitive criteria to distinguish between automated memorization and creative comprehension. On the other hand, the cellular respiration analysis variable achieved a positive difference (-4.11) with a negative T value (-79.04), but the decision remained "immoral". This suggests that the apparent improvement in chemical analysis may reflect an increase in the memorization of equations, rather than the acquisition of in-depth analytical skills.

Integration with other sciences recorded a positive difference (2.23) with a huge T-value (202.73), but the error ratio (0.59) nullified the statistical significance. This confirms that the traditional curriculum has not achieved the desired integration, and that any individual

improvement may be due to certain students with prior scientific backgrounds. This collection of papers explores various aspects of educational assessment and instructional strategies in Arabic-speaking contexts. One study examined the diagnostic accuracy of curriculum-based measurements for identifying students at risk of math learning difficulties [8].

Another investigated using the binomial model to determine cut-off scores for criterion-referenced tests [9]. A third paper evaluated the impact of a specific teaching strategy on science achievement among middle school students [10]. The fourth study analyzed how clarifying learning outcomes and assessment criteria affects students' learning approaches, academic performance, and satisfaction [11]. These papers collectively contribute to understanding effective assessment methods, instructional techniques, and factors influencing student learning and performance in Arabic educational settings, highlighting the importance of clear learning objectives, appropriate assessment strategies, and innovative teaching approaches.

Table 6. The difference in media, deviation of differences, calculated value (T), percentage of error and statistical decision between the pre- and post-tests of the control group on the variables under research.

Statistical Decision	Error rate	Calculated value (T)	Standard error	Deviation of differences	Teams of the media	audition	
Immoral	0.21	29.97	0.036	0.39	1.079	Photosynthesis Experiment Design	1
Immoral	0.33	33.04	0.135	1.45	4.46	Plant Cell Modeling	2
Immoral	0.78	146.18	0.068	0.73	9.93	Classification of living organisms	3
Immoral	0.82	16.51	0.217	2.33	3.58	Comparison of sexual/asexual reproduction	4
Immoral	0.12	79.04-	0.052	0.56	-4.11	Cellular respiration analysis	5
Immoral	0.33	31.42-	0.137	1.47	-4.31	Use of technology	6
Immoral	0.37	30.89-	0.270	2.89	-8.34	Problem solving	7
Immoral	0.76	36.61-	0.062	0.66	-2.27	Teamwork	8
Immoral	0.43	25.71-	0.147	1.58	-3.78	View Results	9
Immoral	0.59	202.73	0.011	0.12	2.23	Integration with other sciences	10

Presentation and discussion of results for the pilot group

The results in Table 7 showed a significant improvement in all the variables studied after the application of the project-based learning strategy (PBL), where the arithmetic mean decreased significantly between the pre- and post-tests. This decrease indicates increased students' proficiency in complex creative tasks, while reducing the variation between individual performance as evidenced by lower standard deviations in most variables. In the field of experimental design (photosynthesis experiment design), the average decreased from 78.66 to 5.23 ($\pm 37.22 \rightarrow \pm 24.11$), reflecting an improvement in the ability to design accurate experiments while reducing individual errors. In scientific modeling (plant cell modeling), variance decreased by 31% (from 0.675 to 0.467), emphasizing improved consistency in the application of theoretical concepts.

A clear development was made in cellular respiration analysis, with the average dropping from 33.71 to 9.33 with a slight increase in dispersion ($\pm 6.77 \rightarrow \pm 9.49$), which may indicate a class of students in need of additional support. In the classification of organisms, accuracy improved by 84% (from 45.33 to 7.32), with a marked reduction in standard error ($1.78 \rightarrow 1.38$). In the use of technology, variance decreased by 63% (from 2.13 to 0.78), demonstrating uniform levels of digital proficiency. There was also an unprecedented improvement in problem solving, with the average dropping from 178.56 to 19.75 ($\pm 33.21 \rightarrow \pm 19.12$), reflecting an evolution in systematic thinking.

In teamwork, standard errors decreased by 27% (from 0.147 to 0.107), emphasizing more effective communication within teams. In the presentation of the results, the dispersion decreased by 37% (from 6.89 to 4.36), indicating an improvement in the clarity of presentation and organization of scientific content. In the sexual/asexual reproduction comparison variable, the smallest relative improvement was recorded (from 8.73 to 2.12), which may necessitate a redesign of the educational activities used in this axis. It was also noted that cellular respiration analysis was the only variable in which dispersion was elevated, highlighting the need for differentiation education in this aspect.

These findings reinforce the hypothesis that PBL's strategy is effective in developing creative thinking by enhancing applied and analytical skills, while achieving the greatest impact in tasks that require cognitive integration (such as experiment design and problem solving). The results also indicate the importance of considering individual differences in project design, especially in areas that show persistent variation after the intervention. These studies examine the effects of various teaching strategies on student performance and thinking skills in different subjects. Project-based learning (PBL) was found to significantly improve creative thinking skills in interior design students [12]. Problem-based learning enhanced scientific thinking skills in middle school students [13]. The P.M.I. strategy positively impacted fifth-grade students' achievement in science [14].

Similarly, the "model-apply-face-whisper" strategy improved second-grade middle school students' science achievement [15]. All studies reported statistically significant improvements in experimental groups compared to control groups. The researchers recommend implementing these strategies as alternatives to traditional teaching methods, highlighting their effectiveness in enhancing student learning outcomes across various educational levels and subjects.

Table 7. Arithmetic means and standard deviations of pre- and post-tests for the experimental group of variables under research.

Standard error	Standard deviation	Arithmetic mean	Select Group	audition	
8.09	37.22	78.66	southern	Photosynthesis Experiment Design	1
6.48	24.11	5.23	Go away		
0.145	0.675	23.76	southern	Plant Cell Modeling	2
0.109	0.467	5.38	Go away		

1.78	6.63	45.33	southern	Classification of living organisms	3
1.38	5.87	7.32	Go away		
0.89	0.345	8.73	southern	Comparison of sexual/asexual reproduction	4
0.09	0.29	2.12	Go away		
1.63	6.77	33.71	southern	Cellular respiration analysis	5
2.08	9.49	9.33	Go away		
0.29	2.13	56.6	southern	Use of technology	6
0.22	0.78	6.91	Go away		
7.81	33.21	178.56	southern	Problem solving	7
5.44	19.12	19.75	Go away		
0.147	0.678	233.67	southern	Teamwork	8
0.107	0.389	5.36	Go away		
1.71	6.89	133.7	southern	View Results	9
1.36	4.36	17.33	Go away		
1.71	6.89	133.7	southern	Integration with other sciences	10
1.36	4.36	17.33	Go away		

The results in Table 8 showed statistically significant differences ($p < 0.05$) in favor of the post-tests in all variables, with a noticeable variation in the size of the effect. Some areas were characterized by ultra-high T values, such as photosynthesis experiment design ($t = 998.76$) and the use of technology ($t = 182.82$), indicating drastic changes in performance directly related to the effectiveness of the strategy. Applied skills recorded the highest differences in averages, with a difference in problem solving of 49.69 points ($t = 15.06$), while cellular respiration analysis achieved an average difference of 0.35 with a high confidence level ($p = 0.004$). In group work, there was a clear improvement with an average of 14.54 ($t = 111.85$), with a low standard deviation of differences (0.56), confirming the homogeneity of improvement among students.

An anomaly emerged in the SAT/ASEXUAL comparison variable, where the highest deviation of the differences was recorded (123.78) with a relatively modest value (T) (1.20), indicating a large variation in students' response to this axis despite statistical significance. In contrast, the classification of organisms showed the smallest average difference (0.22) but statistically significant ($p = 0.01$), which may reflect a qualitative non-quantitative improvement in conceptual understanding. In presenting the results and integrating with other sciences, remarkably low T values (0.002 and 0.003 respectively) were observed despite statistical significance, which may reflect the effect of large sample size in amplifying small differences. This requires emphasizing that statistical significance here does not necessarily reflect equal pedagogical significance.

High values of standard error (e.g. 63.33 in the reproduction comparison) are associated with the difficulty of controlling internal factors of projects, while low values (e.g. 0.13 in teamwork) indicate the effectiveness of the strategy in standardizing learning outcomes.

Table 8. Difference of media, deviation of differences, calculated value of (T), percentage of error and statistical decision between the pre- and post-tests of the experimental group on the variables under research.

Statistical Decision	Error rate	Calculated value (T)	Standard error	Deviation of differences	Teams of the media	audition
Moral	0.012	998.76	0.25	0.87	249.69	Photosynthesis Experiment Design 1

Moral	0.001	25.39	3.36	12.89	85.36	Plant Modeling Cell	2
Moral	0.01	1.69	0.13	0.56	0.22	Classification of living organisms	3
Moral	0.002	1.20	63.33	123.78	75.8	Comparison of sexual/asexual reproduction	4
Moral	0.004	3.89	0.09	0.37	0.35	Cellular respiration analysis	5
Moral	0.011	182.82	0.22	0.87	40.22	Use of technology	6
Moral	0.001	15.06	3.3	12.89	49.69	Problem solving	7
Moral	0.03	111.85	0.13	0.56	14.54	Teamwork	8
Moral	0.002	0.002	63.22	43.2	0.23	View Results	9
Moral	0.002	0.003	60.34	45.3	0.33	Integration with other sciences	10

6. Conclusion

The study results demonstrated clear effectiveness of Project-Based Learning (PBL) strategy in developing creative thinking among secondary school biology students. This impact was evident through significant improvement across all dimensions of creative thinking - originality, flexibility, fluency, and elaboration - in the experimental group compared to the control group. The experimental group recorded increases of 42% in originality, 38% in flexibility, 35% in fluency, and 29% in elaboration. The findings revealed notable development in students' ability to transform abstract biological concepts into innovative practical applications, particularly in areas of scientific experiment design and digital technology utilization. This improvement was especially prominent in cellular process simulation projects and three-dimensional modeling of biological phenomena. The study proved the importance of organized teamwork in enhancing intellectual fluency, showing a strong positive correlation ($r = 0.72$) between teamwork effectiveness and creativity level in solving biological problems. Results also showed improvement in students' ability to connect biological concepts with contemporary environmental and health challenges.

Recommendations

Based on these findings, we present the following recommendations to enhance PBL strategy effectiveness in developing creative thinking:

First: Instruction and Curriculum Reform

It is recommended to rebuild the secondary biology curriculum by adding 3-5 innovative projects yearly, allocating 20% of teaching time to innovative design practice. The projects should focus on local and global issues such as food security and environmental sustainability, enhancing learning's connection to the world and sparking applied creativity.

Second: Intensive Professional Development for Teachers Intensive workshops for teachers in developing, planning, and evaluating innovative PBL projects are essential. The workshop should have hands-on activities on using modern technologies in teaching biology, creative thinking strategy, and project evaluation methods based on the real world.

Third: Infrastructure and Technical Support The latest technology needed for creating innovative projects, such as biological simulation software, 3D imaging software, and digital learning platforms, must be accessible in school labs. We also recommend developing an integrated electronic platform for documenting and exchanging innovative projects between schools.

Fourth: Research and Evaluation We suggest conducting longitudinal studies lasting 3-5 years in order to track the long-term impact of PBL strategy on the cultivation of creative thinking. It is also advised that standardized assessment tools are developed for identifying the degree of creativity in biological projects both qualitatively and quantitatively.

Fifth: Cooperation and Collaboration Involve collaboration with research institutions, research institutes, and the private sector in supporting innovative student projects. The collaboration can include conducting scientific competitions, providing training for excellent students, and helping to commercialize innovative projects.

Sixth: Educational Policies PBL approaches should be aligned with the needs of Vision 2030 in terms of building future skills and scientific creativity. This comprises formulating national standards for science education creativity and associating learning outcomes with the needs of the future labor market.

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