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Project Brainstorming Learning (PjBrs-L): Integrating Structured Brainstorming into Project-Based Learning for Applied Microbiology in Biology Education

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ABSTRACT

Applied Microbiology projects require students to identify promising biological resources, formulate feasible investigations, and connect scientific evidence with possible applications. In the course context examined in this study, preliminary project activities did not consistently provide a documented process for generating and comparing alternative ideas before project selection. This study developed the Project Brainstorming Learning (PjBrs-L) model, in which structured brainstorming is the distinctive design feature linking idea exploration to project planning, STEM-oriented project work, entrepreneurial orientation, evaluation, and reflection. A Research and Development approach guided by ADDIE (Analysis, Design, Development, Implementation, and Evaluation) was used. The study involved 15 Biology Education students and three lecturers in an Applied Microbiology course at Jambi University. Product review involved three experts, while five students contributed to the interview data reported in the dissertation. Data were drawn from observations, interviews, questionnaires, expert feedback, and instructional documents, and were interpreted using iterative qualitative analysis. The resulting model comprises six stages: brainstorming; designing project steps; completing the project with lecturer monitoring; preparing reports and presentations; evaluation; and reflection. Expert feedback informed successive revisions of the academic manuscript, brainstorming guide, student worksheet, and semester learning plan. Preliminary implementation accounts describe idea generation, project planning, collaboration, experimentation, reporting, and reflection, alongside challenges involving uneven participation, limited facilities, coordination, and the need for clearer assessment guidance. The findings provide qualitative evidence of design feasibility and implementation experiences; they do not establish measured improvements in self-efficacy, creative thinking, or learning independence.

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INTRODUCTION

Applied Microbiology education asks students to connect microbiological concepts with authentic problems, experimental decisions, and the development of feasible biological products. Students may need to select locally available biological materials, formulate a problem, compare possible procedures, anticipate microbial processes, and consider the usefulness of a proposed product. These decisions require more than the completion of a project: they also require a deliberate process for generating, examining, and selecting ideas before project work begins. In this study, the instructional issue was identified in the Applied Microbiology course in the Biology Education Program at Jambi University.

Project-Based Learning (PjBL) provides a valuable framework for engaging students in authentic questions, collaborative inquiry, and the production of meaningful outputs (Kokotsaki et al., 2016; Krajcik & Shin, 2021). Existing PjBL approaches can include problem identification, planning, investigation, product development, and presentation. STEM-oriented PjBL further connects disciplinary knowledge with design and problem solving (Kelley & Knowles, 2016), while entrepreneurship-oriented projects encourage opportunity recognition and value creation (Neck et al., 2021; DeCoito & Briona, 2023). These approaches do not necessarily omit idea generation. However, the extent to which students are explicitly guided to generate several alternatives, record them, discuss their feasibility, and justify a project choice varies across implementations.

The needs analysis in the Applied Microbiology course indicated that some project groups moved from an initial problem or suggestion directly to project planning without systematically documenting alternative ideas. This was a context-specific observation rather than a claim about all PjBL implementations. In Applied Microbiology, early decisions can shape the choice of biological resources, experimental design, processing procedures, and the potential value of a product. A structured opportunity to explore and compare ideas is therefore relevant to the quality and transparency of project planning.

Brainstorming can make the early process of idea generation visible and open to discussion. Its contribution depends on the way the activity is structured and facilitated; brainstorming alone does not guarantee creative performance (Bonnardel & Didier, 2020; Gong et al., 2022). In PjBrs-L, students are guided to identify a biological problem, generate multiple alternatives without

premature evaluation, discuss and record candidate ideas, and then consider evidence, feasibility, and relevance before selecting a project. This sequence connects divergent idea generation with the convergent decisions required for project design (Runco & Acar, 2021).

The model also incorporates STEM as an approach to project implementation and an entrepreneurial mindset as an orientation toward opportunity, value, initiative, and responsibility. STEM provides a basis for connecting scientific concepts with technological tools, engineering design, and mathematical reasoning during project work (Kelley & Knowles, 2016). The entrepreneurial orientation encourages students to consider the relevance and potential use of a proposed solution without replacing the disciplinary goals of microbiology (Neck et al., 2021; DeCoito & Briona, 2023).

The distinctive contribution of PjBrs-L is therefore not the separate use of brainstorming, STEM, or entrepreneurship, all of which have appeared in educational practice. Rather, it is their deliberate connection within a six-stage sequence: structured brainstorming informs project design; project design guides STEM-oriented implementation; project evidence is communicated through reports and presentations; evaluation examines the process and product; and reflection informs subsequent learning decisions. This configuration is intended to connect early idea exploration with the decisions and evidence generated during project work.

The theoretical rationale is complementary across the stages. Constructivist perspectives inform the collaborative negotiation of ideas and the interpretation of evidence (Fosnot, 2020). Divergent-thinking principles inform the generation of alternatives during brainstorming (Runco & Acar, 2021). Social cognitive theory provides a lens for understanding students' expressed confidence and participation (Bandura, 2021; Schunk & DiBenedetto, 2020), while self-regulated learning informs project planning, progress monitoring, evaluation, and reflection (Zimmerman, 2008). These theories guide the design rationale; the present study does not claim that the corresponding psychological outcomes were measured.

Accordingly, this study aimed to develop the Project Brainstorming Learning model for Applied Microbiology, describe its expert review, and examine preliminary implementation experiences among Biology Education students. The focus is on the model's development, the revision of its supporting materials, and the opportunities and challenges observed during implementation. The study does not test causal effects on self-efficacy, creative thinking, or learning independence.

RESEARCH METHODS

This study employed a Research and Development (R&D) approach guided by the ADDIE instructional design framework: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009; Aldoobie, 2015). The work focused on the development of PjBrs-L, the review of its supporting instructional materials, and the description of its initial use in an Applied Microbiology course. Evidence from the five ADDIE phases was used for different purposes: needs-analysis evidence informed the design; expert ratings and written recommendations informed product revision; and classroom observations, interviews, open-ended responses, and learning documents informed the description of implementation. The study was descriptive and developmental; it did not include a pre–post or comparative test of the targeted student outcomes.

Research Site and Participants

The research was conducted in the Biology Education Program, Faculty of Teacher Training and Education, Jambi University, in the Applied Microbiology course. The implementation involved 15 Biology Education students enrolled in the course and three lecturers who contributed to the instructional process and course-related evaluation. The 15 students worked in project groups during the learning activities. Five students were selected at random from groups classified as having low, middle, and high levels of performance for follow-up interviews; the five interviewees are identified as R1–R5 to protect their identities. The interview sample was intended to capture varied learning experiences and was not treated as statistically representative of the full class.

Model Development Procedure

During Analysis, the course context, existing project-learning practices, student characteristics, and learning needs were examined to identify the need for a more explicit process of idea exploration before project planning. During Design, the six-stage syntax, lecturer and student activities, learning materials, assessment guidance, and supporting instruments were organized into a coherent instructional framework. During Development, the academic manuscript, brainstorming guide, student worksheet, and semester learning plan were prepared and submitted for expert review. Three validators reviewed the materials and provided ratings and written recommendations. During Implementation, PjBrs-L was used in the Applied Microbiology course over 16 scheduled meetings in accordance with the semester learning plan; each meeting was allocated 2 × 50 minutes (100 minutes). The scheduled course plan includes assessment meetings as well as learning activities. The model's six stages were implemented across the relevant learning activities rather than assigned an unsupported fixed number of minutes per stage. Evaluation was conducted continuously through review of expert feedback, observations, student

responses, and instructional documents, and the findings were used to refine the model and its supporting materials.

Research Instruments and Expert Validation

Expert validation covered four instructional products: the academic manuscript, brainstorming guide, student worksheet and lesson plan. Each product was assessed using a 20-item validation form with a five-point response scale (1 = strongly disagree/not appropriate; 2 = disagree/needs substantial revision; 3 = adequate/needs some revision; 4 = agree/appropriate; and 5 = strongly agree/very appropriate). The mean score was calculated by dividing the sum of item scores by the number of rated items; where ratings from more than one validator were combined, the denominator was the number of ratings. The validation records summarized in this article report the mean score for each review round. No additional percentage cut-off was imposed to classify feasibility; scores are presented descriptively and interpreted alongside the validators' written recommendations. The three validators were selected purposively according to relevant expertise: Validator 1 specialized in Biology, particularly microbiology; Validator 2 specialized in Biology Learning Strategies, learning-model development, critical thinking, and Higher Order Thinking Skills (HOTS) in Biology Education; and Validator 3 had expertise in Biology and learning. Their role was to review the conceptual accuracy, instructional coherence, content relevance, clarity, and usability of the four products. The study's qualitative implementation evidence, rather than outcome scores, was used to describe students' experiences; self-efficacy, creative thinking, and learning independence were not quantitatively measured in this article.

Data Collection Techniques and Sources

Data were collected from students, lecturers, expert validators, and instructional documents using classroom observation, semi-structured interviews, open-ended student responses, expert-validation forms, and document analysis. Observation records were used to describe participation, group interaction, project planning, implementation, reporting, evaluation, and reflection. Interviews with R1–R5 explored students' perceptions of the six learning stages, perceived benefits, and implementation challenges. Open-ended responses provided additional accounts of the learning experience. Expert-validation forms and written comments documented judgments and recommendations concerning the four instructional products. Document analysis covered the academic manuscript, brainstorming guide, student worksheet, lesson plan, project plans, logbooks, reports, and other available student work. Findings from observations, interviews, student responses, validator feedback, and documents were compared to identify convergent patterns and differences across sources and methods.

Data Analysis

Qualitative data were analyzed iteratively using data condensation, data display, and conclusion drawing and verification (Miles et al., 2020). The researcher conducted the initial coding of interview notes, observation records, open-ended responses, and documents according to meaningful units related to the learning stages and implementation experiences. Similar initial codes were grouped into broader categories, such as idea generation, project planning, collaboration, resource constraints, scientific reporting, assessment, and reflection. These categories were then organized into themes and compared across the five interview respondents and the other data sources. The interpretation was checked against the original records and documentary evidence so that themes remained grounded in the available data. No inter-coder reliability coefficient or formal member-checking procedure is claimed. Credibility was supported through comparison of data from different sources and collection methods. Expert ratings were summarized descriptively by review round, while written recommendations were examined to identify revisions required for each product. The analysis describes development and implementation experiences; it does not establish causal effects on student outcomes.

RESEARCH RESULT

Results of Needs Analysis and Development of the Project Brainstorming Learning Model

The results are presented in five parts: needs analysis, development of the PjBrs-L model, expert validation and product revision, implementation in the Applied Microbiology course, and qualitative evidence from students' learning experiences. The needs analysis identified a specific instructional issue: some groups moved to a project choice without documenting a systematic exploration of alternative ideas. This issue was important in Applied Microbiology because early choices determine the biological materials, procedures, experimental design, and potential application considered by each group. The model was therefore designed to make idea generation and selection explicit before students proceeded to project planning.

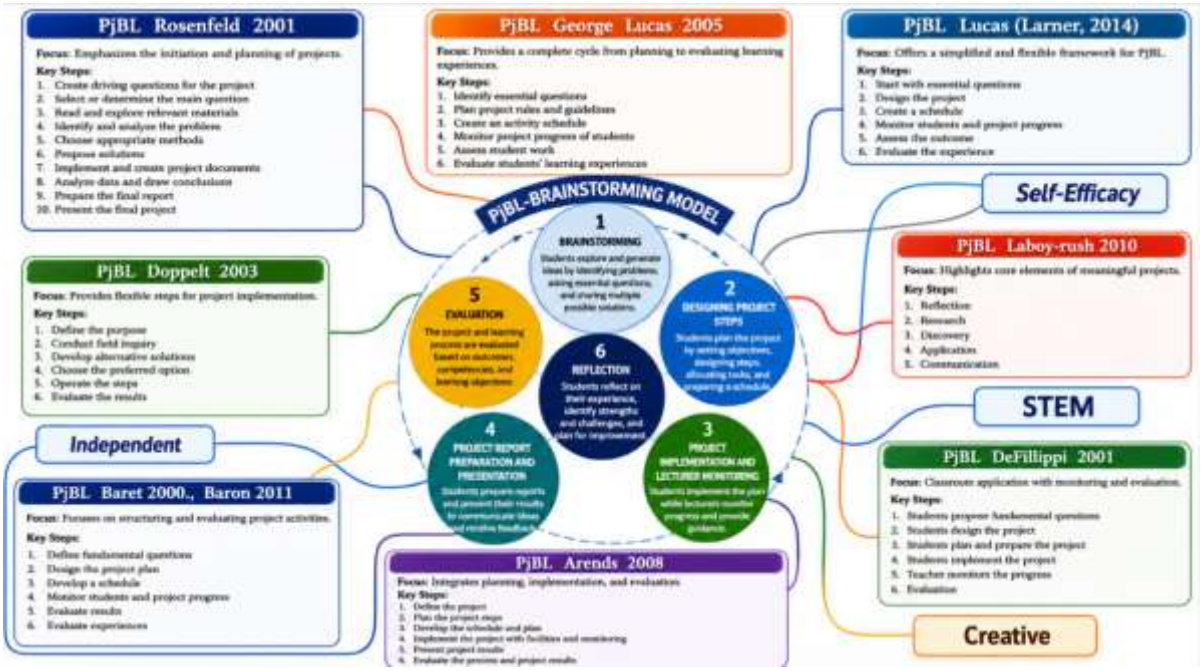


Figure 1. Results of the PjBL Model ReconstructionProject Brainstorming Learning

Figure 1 shows the process of reconstructing the PjBL syntax into Project Brainstorming Learning. The main change lies in the addition of a phase brainstorming which functions as a means of exploring ideas before students design a project. This stage is expected to facilitate the development of creative thinking, self-efficacy and learning independence.

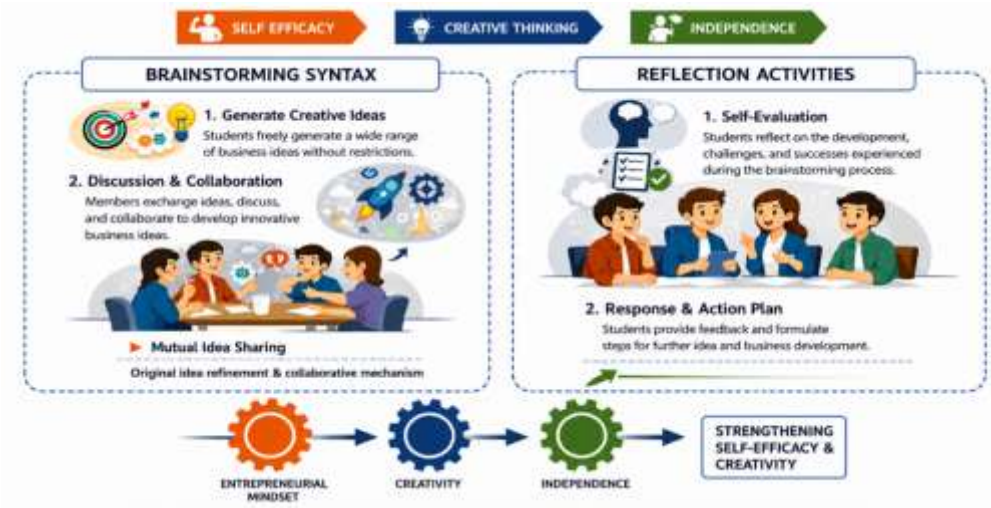


Figure 2. Novelty Model Project Brainstorming Learning

Figure 2 illustrates the model's proposed contribution: structured brainstorming is positioned as the core innovation, while STEM integration supports the application of disciplinary knowledge during project work and the entrepreneurial mindset orients students toward opportunity recognition, value, initiative, and responsibility. The novelty is therefore in the configuration and sequence of the components, rather than in claiming that each component is individually new.

Feasibility of the Project Brainstorming Learning Model

Four instructional products were reviewed: the academic manuscript, brainstorming guide, student worksheet, and lesson plan. Each product was assessed using a 20-item form scored on a five-point scale. The validation records show the same pattern across the four products: a mean score of 2.00 in the first review, 3.00 in the second review, and 4.00 in the third review. These values are mean scores on the 1–5 scale, not percentages. The progression indicates that the products received higher ratings after successive revisions. Because the study did not establish a separate numerical cut-off for feasibility, the scores are reported descriptively rather than converted into categories such as "feasible" or "very feasible." The written recommendations were used alongside the scores to guide revisions.

Across the three review rounds, the consolidated mean score for each instructional product, calculated across three validators and 20 items per product, increased from 2.00 to 3.00 and then to 4.00 on the five-point scale (Table 1). The review process was therefore iterative: the first round identified aspects requiring substantial clarification; the second round indicated improvement while retaining areas for refinement; and the third round reflected stronger ratings after revision. The validators' comments emphasized the need for clearer and more operational instructions, stronger alignment among objectives, content, learning activities and assessment, and more explicit examples and rubrics. These recommendations informed revisions to the academic manuscript, brainstorming guide, student worksheet, and lesson plan. The final mean score is presented as an expert rating, not as evidence of student learning gains.

Table 1. Mean Expert Validation Scores for the Instructional Products

Instructional product	Review 1 mean	Review 2 mean	Review 3 mean
Academic manuscript	2.00	3.00	4.00
Brainstorming guide	2.00	3.00	4.00
Student worksheet	2.00	3.00	4.00
Lesson plan	2.00	3.00	4.00

Implementation of Project Brainstorming Learning

PjBrs-L was implemented in the Applied Microbiology course over 16 scheduled meetings, with each meeting allocated 2 × 50 minutes according to the lesson plan. The six stages—brainstorming, designing project steps, completing the project with lecturer monitoring, preparing reports and presentations, evaluation, and reflection—were enacted across the relevant course activities. The lesson plan specifies the course sequence and meeting allocation; it does not prescribe a separate fixed duration for each model stage. Observation and student accounts indicated that students engaged in idea discussion, project planning, experimental or product-related activities, reporting, evaluation, and reflection. At the same time, implementation revealed

uneven participation, difficulties in coordination, limited laboratory resources, time and cost constraints, and a need for clearer reporting and assessment guidance.

Table 2. Student Perceptions of the Implementation of Project Brainstorming Learning Syntax

Syntax	Respondent	Researcher-Generated Summary of Interview Accounts	Tree Theme
Brainstorming	R1	Students work in groups with their respective roles, using logbooks to record the process and progress of the project.	Collaboration and Documentation
	R2	Students are divided into groups, create activity proposals, and fill out logbooks to guide the project work process.	Planning and Structure
	R3	Students designed a kombucha tea experiment from lindur leaves, learned to manage time, and analyzed data.	Creative Thinking and Analysis
	R4	Field observations in mangrove forests to identify plants that have the potential to become products.	Field Observation and Potential
	R5	Initial discussions focused on selecting project topics and assigning roles while assessing the potential of lindur leaf products based on references.	Problem Identification & Scientific References
Designing a Project	R1	Division of tasks within the group, but facing the challenge of less active members.	Group Work Challenges
	R2	Preparation of activity proposals to plan projects systematically.	Project Planning
	R3	Experimental design with limited tools and materials in the laboratory.	Limited Resources
	R4	Planning of natural talc powder project, including sampling and processing.	Utilization of Natural Materials
	R5	Designing the experimental flow and preparing supporting instruments, including a literature review to ensure proper procedures.	Literature-Based Planning
Completing the Project	R1	The project is running under the guidance of lecturers, logbooks are used to monitor progress.	The Role of Lecturers and Monitoring
	R2	The project requires a relatively large amount of time and cost.	Time and Cost Constraints
	R3	Group coordination becomes a challenge, especially if communication is less than effective.	Communication and Coordination
	R4	Testing and production processes are hampered by limited laboratory access.	Limited Facilities
	R5	The experiment was carried out in stages, but some procedures had to be repeated due to data inconsistencies.	Data Validation & Replication
Reports & Presentations	R1	Project reports are recorded in a logbook and checked by the lecturer.	Documentation and Evaluation
	R2	Students compile proposal reports and project results as part of the assignment.	Scientific Reporting

	R3	Preparation of reports and presentation of project results in a scientific and systematic manner.	Presentation Skills
	R4	Preparation of a complete report and presentation in front of the class.	Scientific Communication
	R5	The report is prepared with an emphasis on data analysis and revisions based on lecturer input before the presentation.	Feedback-Based Improvement
Evaluation	R1	The lecturer provides solutions and suggestions based on the logbook for project improvement.	Lecturer Feedback
	R2	Project evaluation is carried out through assessment of proposals and final results.	Outcome-Based Assessment
	R3	Evaluation of limitations of tools and materials, as well as group performance.	Performance Evaluation
	R4	Evaluate individuals within the group to ensure fair contributions.	Fairness in Assessment
	R5	Evaluation includes consistency of process, quality of analysis, and ability to apply scientific concepts in the project.	Process Evaluation & Analysis
Reflection	R1	Teamwork is essential, but challenges arise from less active members.	The Importance of Collaboration
	R2	PjBL trains problem-solving and teamwork skills, but requires improved planning.	Collaborative Learning
	R3	PjBL helps to understand the real-life applications of microbiology, despite the obstacles.	Practical Applications
	R4	PjBL provides hands-on experience and trains responsibility, but needs improvement in time management and facilities.	Field Experience
	R5	PjBL improves conceptual understanding and learning independence, but requires the support of more complete laboratory facilities.	Independence & Facility Needs

Table 2 presents researcher-generated summaries of interview accounts from five students (R1–R5), rather than verbatim quotations. The five respondents were selected at random from students representing low, middle, and high performance levels, from the 15 students who participated in the course. Their accounts are organized by the six stages of PjBrs-L and are interpreted together with observation records and available learning documents. The summaries are used to illustrate the range of experiences, not to imply that every student expressed the same view.

Qualitative Evidence from the Initial Implementation of PjBrs-L

The qualitative evidence indicates that students experienced both enabling features and practical constraints during implementation. In the brainstorming stage, students discussed

possible project topics and considered biological resources, although participation was not always equal. During project design, groups prepared proposals and planned procedures, but some needed clearer guidance on objectives, task allocation, and experimental steps. During project completion, lecturer monitoring and logbooks supported progress documentation, while limited facilities, coordination difficulties, and repeated procedures constrained some groups. Reporting and presentation activities provided opportunities to communicate project processes and findings, although students needed more consistent report formats and clearer assessment criteria. Evaluation and reflection were undertaken, but students did not always use rubrics or provide detailed reflections. These findings are based on the interview summaries in Table 2, implementation observations summarized in Table 3, and available project documents.

Table 3. Qualitative Evidence from the Initial Implementation of PjBrs-L

Model Syntax	Researcher Analysis (Trial Results)
Brainstorming (Mindset: self-efficacy, creative thinking, independence)	Students appeared enthusiastic about the discussion, but some remained hesitant to share their initial ideas. This highlights the need to strengthen their understanding of the importance of divergent thinking. Some students lacked strong confidence when expressing their initial project ideas.
Designing project steps	Students were able to develop a well-structured project plan, but the module instructions needed to be clarified to make each step easier to understand. Some students were confused about formulating project objectives and still needed concrete examples.
Completing projects and lecturer monitoring (STEM Integration)	The completion process went well, with students appearing actively engaged in the experiments and calculations (physics/engineering concepts). However, several groups still encountered challenges in interdisciplinary integration (S-T-E-M), indicating the need for additional guidance.
Create project reports and presentations	Students appeared to have difficulty compiling systematic reports. Presentations went well, but needed training in scientific communication. Report formats were not yet uniform, and there was confusion regarding which sections should be reported.
Evaluation	The evaluation process has been underway, but students do not yet fully understand the assessment mechanism. The assessment rubric has not been optimally utilized by students as a tool for self-reflection. This indicates the need for training in the use of rubrics and evaluative indicators.
Reflection	While most students were able to reflect on their learning experiences, some still presented their reflections in a normative manner. This indicates the need for a more structured reflection guide to explore experiences in depth.

Table 3 summarizes the researcher's analysis of implementation evidence across the six stages. The evidence shows that brainstorming created a designated space for idea sharing, but some students remained hesitant; project planning supported systematic preparation, although instructions required clarification; and project completion involved applied work, although the connection among STEM components was not equally explicit in every group. Reporting, evaluation, and reflection were carried out, but students benefited from more explicit templates,

rubrics, and prompts. The observations identify areas for improving facilitation and supporting materials rather than demonstrating measurable changes in the targeted competencies.

Tabel 4. Operational description of the six-stage PjBrs-L syntax

Stage	Lecturer facilitation	Student activity / output	Assessment focus
1. Brainstorming	Present an authentic biological problem; establish rules for respectful idea generation; prompt and document discussion.	Identify the problem, generate alternatives, discuss ideas, and record candidate project ideas. Output: idea list and initial rationale.	Participation, diversity of ideas, relevance to the problem.
2. Designing project steps	Guide feasibility checks, objective formulation, task allocation, timeline, and selection of materials.	Select and justify a feasible idea; prepare project plan/proposal, roles, timeline, and required resources.	Alignment of objectives, feasibility, planning and role clarity.
3. Completing the project (monitoring)	Monitor progress through check-ins/logbooks; ask probing questions and support safe, evidence-based STEM work.	Conduct project activities/experiments, collect and analyze evidence, revise procedures, document progress. Output: project/product and logbook/data.	Process documentation, use of evidence, STEM connections, collaboration.
4. Reports and presentations	Provide report structure and criteria; facilitate presentation and constructive feedback.	Prepare a scientific report and present methods, results, limitations, and product/solution.	Accuracy, organization, interpretation, and scientific communication.
5. Evaluation	Explain criteria/rubrics; assess process and product and provide actionable feedback.	Use criteria to assess project outcomes and contributions; identify strengths and areas for improvement.	Use of rubric, evidence-based judgment, individual/group contribution.
6. Reflection	Prompt reflection on decisions, learning, teamwork, obstacles, and next steps.	Reflect on the process and outcomes; identify learning and a concrete improvement action. Output: reflection/action plan.	Depth of reflection, self-monitoring, and realistic next steps.

The lesson plan allocates 2 × 50 minutes for each of the 16 scheduled meetings. The six model stages are distributed across the relevant course activities; the lesson plan does not assign a separate fixed number of minutes to each stage, so no stage-specific duration is inferred.

DISCUSSION

Project Brainstorming Learning as a Conceptual Development of Project Based Learning

The implementation evidence suggests that the most distinctive feature of PjBrs-L was the explicit opportunity for students to explore and record possible project ideas before selecting a direction. The interview summaries show that early discussions involved choosing project topics,

identifying biological resources, and considering the relevance of possible products. These activities were followed by proposal preparation, task allocation, and experimental planning. The sequence illustrates how idea exploration was connected to subsequent project decisions in this Applied Microbiology course. It does not imply that all existing PjBL models lack brainstorming; rather, PjBrs-L makes the process an explicit and documented stage within the model's syntax.

This sequence is consistent with constructivist views of learning, in which students develop and refine understanding through discussion, interpretation, and engagement with meaningful problems (Fosnot, 2020). The brainstorming stage draws on divergent-thinking principles by encouraging students to consider more than one alternative before evaluating feasibility (Runco & Acar, 2021). Project design then provides a convergent decision point: students justify a selected idea, formulate objectives, allocate responsibilities, and prepare a plan. Thus, the contribution of PjBrs-L is the connection between open idea generation and evidence-informed project selection, rather than the addition of an isolated discussion activity.

The later stages extend this connection into project work. STEM integration provides a framework for applying microbiological knowledge alongside relevant technological, engineering, and mathematical considerations during project implementation (Kelley & Knowles, 2016). The entrepreneurial orientation encourages students to consider opportunity, potential value, and responsibility when discussing the relevance of a product or solution (Neck et al., 2021). Reports and presentations make the process and evidence communicable, while evaluation and reflection provide opportunities to review decisions and identify improvements. The study documents these design relationships and implementation experiences; it does not compare PjBrs-L experimentally with separate PjBL, STEM-PjBL, or entrepreneurship-based models.

These findings extend previous research showing that the effectiveness of PjBL in developing 21st-century skills can be enhanced when learners are given the opportunity to explore ideas more openly before entering the project implementation phase (Krajcik & Shin, 2021; Kokotsaki et al., 2016). Therefore, Project Brainstorming Learningcan be seen as a form of PjBL reconstruction that accommodates the need for developing Creative Thinking and learning independence more explicitly. The theoretical principles are distributed across the model rather than attached to brainstorming alone. Table 5 summarizes how the learning theories and design principles inform each stage and the learning opportunities that the stage is intended to provide. These are design intentions and interpretive links, not measured effects.

Table 5. Theoretical Alignment of the Six PjBrs-L Stages

PjBrs-L stage	Theoretical basis / design principle	Intended learning opportunity
1. Brainstorming	Divergent thinking and constructivist learning (Fosnot, 2020; Runco & Acar, 2021)	Generate, discuss, and record alternative ideas related to an authentic biological problem.
2. Designing project steps	Self-regulated learning: goal setting and planning (Zimmerman, 2008)	Select a feasible idea, formulate objectives, allocate roles, and plan materials and procedures.
3. Completing the project with lecturer monitoring	Constructivist inquiry and integrated STEM learning (Fosnot, 2020; Kelley & Knowles, 2016)	Apply concepts, conduct project activities, use evidence, monitor progress, and revise procedures.
4. Preparing reports and presentations	Social construction of understanding and scientific communication	Organize evidence, explain procedures and findings, and communicate limitations and decisions.
5. Evaluation	Self-regulated learning and evidence-based judgment (Zimmerman, 2008)	Review the process and product against criteria and identify aspects requiring improvement.
6. Reflection	Metacognitive monitoring and self-regulated learning (Zimmerman, 2008)	Review decisions and learning experiences and identify realistic next steps.

Brainstorming and Students' Expressed Confidence

Some students participated actively in brainstorming, whereas others were hesitant to share preliminary ideas. This observation is relevant to self-efficacy theory, which explains how beliefs about personal capability can shape engagement with challenging tasks (Bandura, 2021; Schunk & DiBenedetto, 2020). However, self-efficacy was not measured quantitatively or through a validated pre–post assessment in this study. The findings therefore describe students' participation and expressed experiences; they do not demonstrate an increase in self-efficacy. The structured discussion may provide a supportive opportunity for students to contribute ideas, but this possibility requires further investigation using an appropriate measure.

The interview and observation evidence also indicates that students generated and discussed project alternatives, but the quality of ideas was not scored using a creative-thinking rubric in this article. Accordingly, the findings cannot establish changes in fluency, flexibility, originality, elaboration, or creative-thinking self-efficacy. The role of brainstorming in PjBrs-L should be interpreted as providing structured practice in idea generation and comparison. Future studies could examine whether repeated participation in this stage is associated with measurable changes in creative-thinking performance.

STEM Integration and Entrepreneurial Orientation in Project Work

Project planning, information seeking, task allocation, resource management, and reflection are activities that are conceptually consistent with self-regulated learning (Zimmerman, 2008). In

the present study, students prepared project proposals, divided responsibilities, used logbooks to document progress, and reviewed project outcomes. These activities provide examples of opportunities to practice planning and monitoring during project work. Nevertheless, the qualitative records do not establish that students' learning independence increased, and the study did not administer a reported pre–post measure of this construct.

STEM-oriented project activities required students to relate microbiological concepts to procedures, materials, and, where relevant, technological or quantitative considerations. The implementation records also show that some groups had difficulty making the connections among STEM components explicit and experienced limitations in laboratory access, materials, and coordination. The entrepreneurial orientation provided a prompt to consider the potential relevance and value of biological products, but entrepreneurial mindset was not measured as an outcome. These findings support a cautious interpretation: STEM integration and entrepreneurial orientation are design features of PjBrs-L that may make project decisions more contextual, while their implementation quality depends on resources, guidance, and students' preparation.

Theoretical and Practical Implications of the Project Brainstorming Learning Model

The findings of this study have important theoretical implications for the development of project-based learning models. To date, most research on PjBL has focused on the relationship between projects and cognitive learning outcomes. The study's contribution to Biology Education is a context-sensitive PjBL development that places structured idea exploration before project design in an Applied Microbiology course. The model links that stage to STEM-oriented project implementation, an entrepreneurial orientation, scientific communication, evaluation, and reflection. The findings offer an account of expert review and preliminary implementation, including both enabling features and constraints. Transfer to other biology courses may be possible where students must select biological problems, resources, and procedures, but it should be examined in further studies because course content, facilities, student characteristics, and project requirements may differ. In other words, the phase brainstorming is an important component that needs to be integrated into a project-based learning model to optimize the development of Creative Thinking, self-efficacy, and learning independence. From a practical perspective, the model Project Brainstorming Learning provides lecturers with an alternative way to design learning that is more oriented toward developing 21st-century competencies. The developed syntax enables students to have a more active, reflective, and meaningful learning experience. Furthermore, the integration of STEM and entrepreneurial mindset making learning more relevant to the needs of the workplace and the challenges of modern society. This study has several limitations. It involved a

small group of 15 students in one Applied Microbiology course and relied primarily on qualitative implementation evidence and expert review. It did not include pre–post measurement or a comparison group, and therefore cannot determine whether PjBrs-L improves self-efficacy, creative thinking, or learning independence. The findings should be interpreted within the instructional context in which the model was developed and implemented.

CONCLUSION

This study developed Project Brainstorming Learning (PjBrs-L) for an Applied Microbiology course in Biology Education and examined its expert review and preliminary implementation. The model comprises six connected stages: brainstorming, designing project steps, completing the project with lecturer monitoring, preparing reports and presentations, evaluation, and reflection. Its distinctive contribution is to position structured and documented idea exploration before project planning and to connect that process with STEM-oriented project work and an entrepreneurial orientation. Expert ratings increased across three review rounds for the academic manuscript, brainstorming guide, student worksheet, and lesson plan, while student accounts and observations identified both opportunities for idea sharing and challenges involving participation, resources, coordination, reporting, and assessment. The study did not measure changes in self-efficacy, creative thinking, or learning independence; therefore, no effectiveness claim is made for these outcomes. Further research should test the model with explicit outcome measures, comparative designs, and implementation across different Biology Education contexts.

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The authors declare that there is no conflict of interest regarding the publication of this paper.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Budiarti, R. S.: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Validation, Visualization, Writing – Original Draft, Project administration, and Writing – Review & Editing. **Hakim, M. A. R.:** Conceptualization, Methodology, Supervision, Validation, Formal analysis, Writing – Review & Editing, and Project administration.

DECLARATION OF THE USE OF AI

During the preparation of this manuscript, the authors used OpenAI ChatGPT Pro (GPT-5.5) to improve the clarity, academic language, grammar, and readability of the manuscript. The AI tool was used solely for language refinement and editorial assistance and did not contribute to the research design, data collection, data analysis, interpretation of results, or scientific conclusions. All AI-generated suggestions were carefully reviewed, revised, and verified by the authors, who take full responsibility for the accuracy, originality, and integrity of the content of this publication.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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