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Article

Integrated Project Based Learning (PjBL) with STEM and Field Study in Elemental Chemistry Learning

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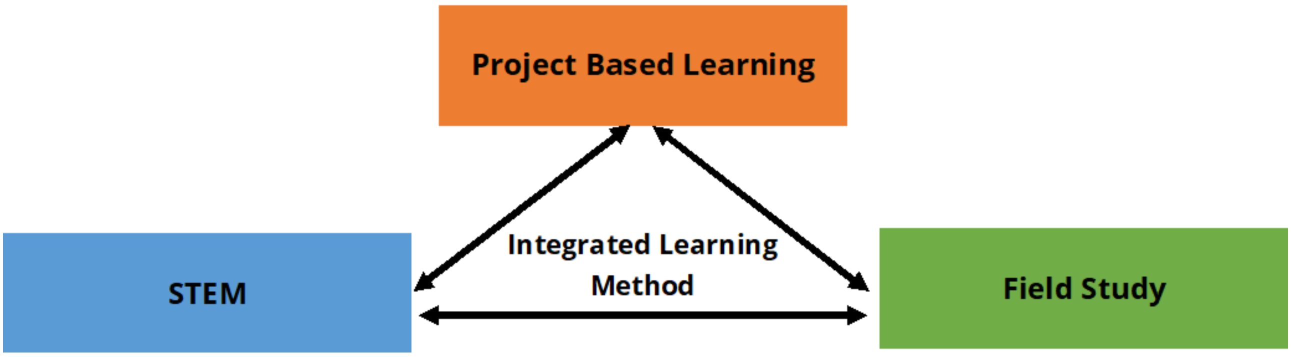
Abstract

This research investigates the effectiveness of a project-based learning (PjBL) model integrated with Science, Technology, Engineering, and Mathematics (STEM) in enhancing students critical thinking and field study skills in Elemental Chemistry. The study aims to assess how this integrated approach influences student learning activities, including engagement with scientific literature, teamwork, cognitive skills enhancement, and the development of teaching materials for independent discovery. A mixed-methods approach was used, combining statistical analysis of quantitative data with qualitative insights from observation sheets, interviews, and student worksheets. The curriculum included soft skill training in sampling teak sawdust (Tectona grandis) and synthesizing oxalic acid, Ca, Ba, and Mg-oxalic compounds in the lab. Results showed significant improvement in student grades in the Elemental Chemistry course, with average scores in the good category ranging from 71.05% to 79.55%, indicating the PjBL model is effective. Furthermore, the development of an Elemental Chemistry learning kit specifically designed for the PjBL approach effectively enhanced student thinking skills, as evidenced by their achievements in STEM-related tasks, highlighting the potential of integrated learning method in improving educational outcomes in higher education chemistry courses.

Keywords: *field study, elemental chemistry, PjBL, STEM*

Graphical Abstract



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Introduction

Technological advancement has revolutionized educational paradigms, necessitating the integration of collaborative skills in technology-driven learning environments. This shift underscores the need for educational systems to adapt and embrace these evolving expectations [1]. A pivotal approach in this context is project-based learning (PjBL), recognized for enhancing engagement and developing crucial skills in students[2]. This model, particularly when combined with STEM (Science, Technology, Engineering, and Mathematics) education, is argued to significantly bolster creative thinking abilities in learners[3,4].

Furthermore, a field study is an educational approach that engages directly with the surrounding environment, offering students enhanced opportunities to acquire competencies through direct observation of their natural surroundings[5]. This method, for instance, involves taking students to the actual sites of learning, thereby enriching their capacity to grasp the educational content more effectively[6]. Syardiansah (2018) describe field study as a pedagogical technique that employs hands-on data collection, including observation, interviews, note-taking, and posing diverse questions[7]. Such methods are becoming increasingly vital in preparing students as competent contributors in the technologically advanced era[2]. Echoing this, Binkley (2012) emphasizes the importance of developing collaborative and technological competencies in students[8]. The essential skills expected of graduates include creative thinking and innovation, critical problem-solving, and metacognitive abilities; effective communication and collaboration skills; a profound understanding of information technology advancements and communication literacy; and life and career skills, encompassing personal and social responsibilities[9].

In the context of Elemental Chemistry education, the application of PjBL promises to cultivate independence and active learning in students. This model not only applies existing knowledge but also hones critical thinking, attitudes, and practical skills[10]. The STEM-PjBL model represents an integrated approach, balancing various factors across different stages of learning[11,12].

Our research focuses on the application of these innovative teaching methods in an Elemental Chemistry course. It explores the efficacy of a blended learning model combining STEM and PjBL, supplemented by field studies, in enhancing student learning outcomes. This study was conducted by a team of three lecturers, supported by data collectors, administrative staff, data processors, laboratory assistants, and tutors.

Experimental Section

Time and place of research

This study was conducted during the odd semester of the 2022/2023 academic year and targeted students enrolled in the Basic Chemistry course within the Chemistry Program at Universitas Jambi. The population for this research comprised all students registered for this course. Specifically, two classes were involved: Class A, consisting of 30 students, served as the experimental group, and Class B, also comprising 30 students, functioned as the control group. The research activities were conducted in various locations, including the Chemistry Laboratory of the Faculty of Science and Technology (FST), lecture room 03 on the 2nd floor of FST at Mendalo Campus of Universitas Jambi, and the CV. Tri Tunggal Sawmill in Pasir Panjang Village, Danau Teluk District, Jambi City.

Method

This study employs a blended Research and Development (R&D) approach, integrating both quantitative and qualitative methodologies to comprehensively investigate educational practices. The following steps outline the learning design model used in conducting research.

Identify learning objectives

Determine the abilities or competencies of students to be achieved in learning in accordance with the syllabus in the established curriculum. Furthermore, the learning objectives referred to the learning indicators are analyzed.

Instructional Analysis

Analyzing learning that focuses on determining the relevant skills and knowledge needed by students to achieve competencies and learning objectives.

Analysis

Survey in the Chemistry Undergraduate Study Program. Analysis of the needs for the potential and problems of learning Elemental Chemistry occurred in the Chemistry Undergraduate Study Program, Faculty of Science and Technology (FST), Jambi University, was carried out to get a real description according to needs. The description was obtained through direct observation during the research team was carrying out the learning.

Learning Problems. Student critical thinking ability is still relatively low, so students only understand the lecture material but have not been able to explore the information conveyed by the lecturer. Based on this, process improvements will be made to improve student critical thinking skills in the learning process. Therefore, Elemental Chemistry courses need to be designed as well as possible for project-based learning. Solving the abstract problem of the lecture material used a project-based learning model to build student activity in learning.

Potential Chemistry Undergraduate Study Program. The readiness of the Chemistry Undergraduate Study Program, FST Universitas Jambi in implementing project-based learning is considered quite ready. This is evidenced by the availability of learning facilities on campus, both in terms of complete facilities in the lecture hall and in the Chemistry Laboratory. In addition, the location of the field study is CV. Tri Tunggal Sawmill in Pasir Panjang Village.

Formulate learning objectives

The formulation of online learning objectives is based on Graduate Learning Outcomes (LO) and Course Learning Outcomes (CLO).

Developing assessment instruments

This action is conducted to develop an assessment tool to measure the level of achievement of student competencies set in the learning objectives. The instruments used were observation, interview sheets, and student worksheets.

Developing learning strategies

The learning design in this study used a project-based learning model in the Elemental Chemistry course at the Chemistry Undergraduate Study Program, FST Universitas Jambi. The learning implementation was carried out with offline and online blended learning using the Chemistry Laboratory, Lecture Room and the Sawmill Location of CV Tri Tunggal in Pasir Panjang Village.

Developing learning plans and selecting teaching materials

The preparation of semester learning plan contains the following characteristics:

- Students make decisions, and create frameworks,
- There is a problem whose solution is not predetermined,
- Students design processes to achieve results,
- Students regularly review what they are doing,
- The final result is a product and evaluated for its quality, and
- The class has an atmosphere that tolerates mistakes and changes.

Design and develop formative evaluation

Stages of formative evaluation. After the design of project-based online learning teaching materials has been developed, the next step is to design and conduct formative evaluations. A formative evaluation was conducted to collect data related to the strengths and weaknesses of teaching materials in project-based online learning. The results of the formative evaluation process can be used as input for improving the blended learning draft (Figure 1).

There are four stages of formative evaluation that can be performed to develop project-based online learning teaching materials, namely:

- Individual evaluation
- Small group evaluation
- Evaluation of survey results at the Field Study Site
- Evaluation of all determined aspects.

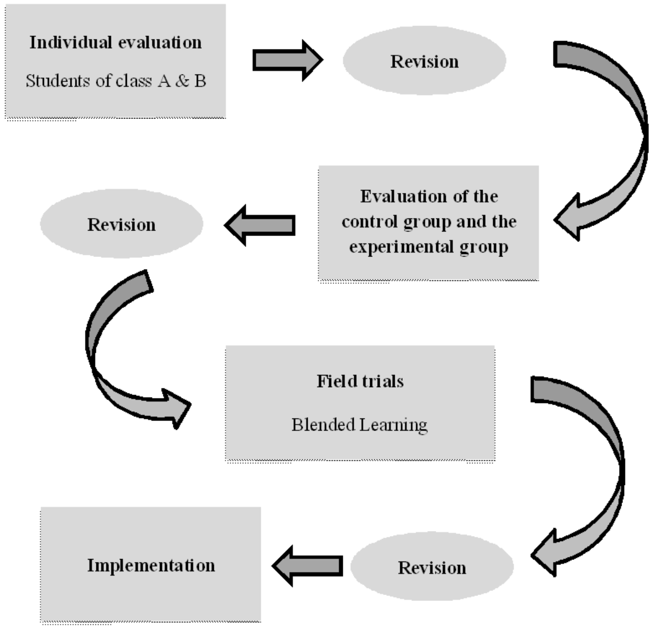

Figure 1. Design of formative evaluation procedures.

Validation by a team of experts

The learning design had been validated by a team of experts. This is important to perform it before this product is tested on the target or user, namely, students. The expert team are lecturers who are in accordance with their respective fields of expertise.

Implementation of formative evaluation stages

- **Phase I (individual evaluation)**

This is a necessary step in implementing a formative evaluation. This evaluation is carried out through direct contact with one or three prospective students who use project-based online learning materials to obtain input about the attractiveness of learning.

- **Phase II (evaluation of control and experimental groups)**

Evaluation of the control and experimental groups was carried out by testing the teaching materials against the control (without field study) experimental group, using project-based blended learning consisting of 30 students. This evaluation is carried out to obtain input that can be used to improve the quality of learning.

- **Phase III (field trial)**

The field evaluation is a trial of teaching materials in project-based online learning to a large group of prospective learning users before the teaching materials are used in real learning situations.

Revise the draft of learning tools

At this revision stage, the products developed (semester learning plan using project-based learning models, blended learning teaching materials (online and offline) and student worksheets) underwent improvements in accordance with the validation stages given in product trials to students.

Design and develop summative evaluations

In the final stage, the researcher provided a summative evaluation sheet that involved an independent assessor, in this case the lecturer of the teaching team. The summative evaluation sheet was designed by the researchers and validated by a team of experts.

Data type

The types of data in this study are qualitative and quantitative data from the results of student learning evaluations using project-based online learning teaching materials.

Data Collection Instruments

The instrument used in collecting data in the study was an observation sheet on online learning. Observations made by researchers through observations using google form and manual questionnaires, which examine the extent of the role of learning tools developed by blended learning in Elemental Chemistry courses and student activities. Furthermore, the Student Worksheet contains work guidelines on material synthesis and student learning evaluation questions.

Research Design

This STEM-integrated project-based learning is carried out to improve student critical thinking skills. The application of project-based learning with a blended learning system is needed to improve student learning outcomes.

Implementation observation data STEM integrated PjBL

Observational data are used to collect data on the implementation of the STEM-integrated PjBL learning model using the field study method by adding the scores of each statement. The PjBL implementation criteria used are presented in Table 1.

Result and Discussion

This research was conducted using a control and an experimental class. Before the learning process was carried out, preliminary data observations were carried out first on students who acted as subjects in the study. Based on the observations made in the learning process in the Elemental Chemistry course before and after using the PjBL-STEM learning model through the field study method, it can be observed that activities arose in students.

Research on project-based learning has also been carried out by Ngatijo et al. (2022), by integrating project-based learning integrated with STEAM on the development of student life skills in the Inorganic Chemistry III course. This study obtained satisfactory results in which the implementation of the project-based learning model is integrated with STEAM. There is a significant value that there is a match between the use of the learning model applied to the development of student life skills. Although the rest is influenced by external variables, project-based learning can help students develop their skills[13].

In accordance with this, Astuti et al. (2019) also argue that the project-based learning model integrated with STEM can increase the mastery of concepts and activities in learning through practice questions on mathematical formulas and improve analysis in solving problems given in the implementation of learning[14]. The STEM-integrated learning model can prepare the character of independent learning and influence high-order thinking skills[15].

In general, elemental chemistry learning systematically includes the existence, properties, manufacture, and use of each essential element and compound in the periodic table of elements. By applying the innovation of the PjBL-STEM learning model, the discussion of the topic of elemental chemistry can be deepened utilizing the waste in the surrounding environment. In this study, a synthesis of compounds was carried out in the laboratory using raw material for teak wood saw waste which was sampled directly from the sawmill. The synthesized compounds are then analyzed for their elements so that students can understand the existence, nature, procurement and manufacture and uses of each of these elements and compounds. Based on the observations in the research carried out, the data can be presented in Table 2 in the form of data on student observation assessments in the implementation of learning.

Table 1. Criteria for critical thinking

No.	Percentage (%)	Criteria
1.	81-100	Very good
2.	61-80	Good
3.	41-69	Enough
4.	21-40	Less

Table 2. Data on the results of student observation assessments

No	Statement	Preliminary data %	Before action %	After action %
1	Observing student democracy	54.05	70.27	83.78
2	Interest in filling out the given project student-worksheet	40.54	62.16	81.08
3	Enthusiasm in asking	5.41	10.81	18.92
4	Enthusiasm in answering questions	13.51	21.62	37.84
5	Note the explanation	45.95	67.57	86.49
6	Carry out the tasks of the activities given during the learning process	32.43	45.95	67.57
7	Active in project-based learning activities	67.57	72.97	86.49
8	Responding to opinions expressed by other students	5.41	13.51	16.22
9	Trying to solve the problem given and found in the project	16.22	32.43	51.35
10	Enthusiastic in implementing project-based learning	54.05	64.22	70.27
	Average	33.51	46.22	60.00

It can be seen from Table 2, which are data from the observation assessment of students who were given action before and after being given action that the implementation of the use of the PjBL-STEM learning model went well. Based on the observations, it can be observed that during the implementation of the research before the action is undertaken and after the action, the use of the project learning model always increased, although not too much. Thus, the observations of students who have been observed during the research can be said to provide positive values and can support the realization of learning objectives for students in the Elemental Chemistry course.

The purpose of implementing the field study learning method is to disseminate information and experience from more capable and competent parties to students who are research subjects so that the abilities and mindset of students who take part in field study activities are further improved. This can be seen from the increase in student abilities and competencies before participating in the field study compared to after participating in the field study.

Observational data obtained from the assessment of observations made on the implementation of the STEM-integrated PjBL learning model are presented in Table 3. Observations on the implementation of the STEM-integrated PjBL learning model reveal that it performs well across the six PjBL learning steps, with successive percentages of 78.57%, 75.13%, 72.04%, 79.50%, 71.05%, and 79.55%.

Table 3. Data on the results of student observation assessments

No	PjBL Steps	Percentage (%)	Category
1	Determining the basic question	78.57	Good
2	Designing a project plan	75.13	Good
3	Making a schedule	72.04	Good
4	Monitoring project progress	79.50	Good
5	Testing results	71.05	Good
6	Evaluating experience	79.55	Good

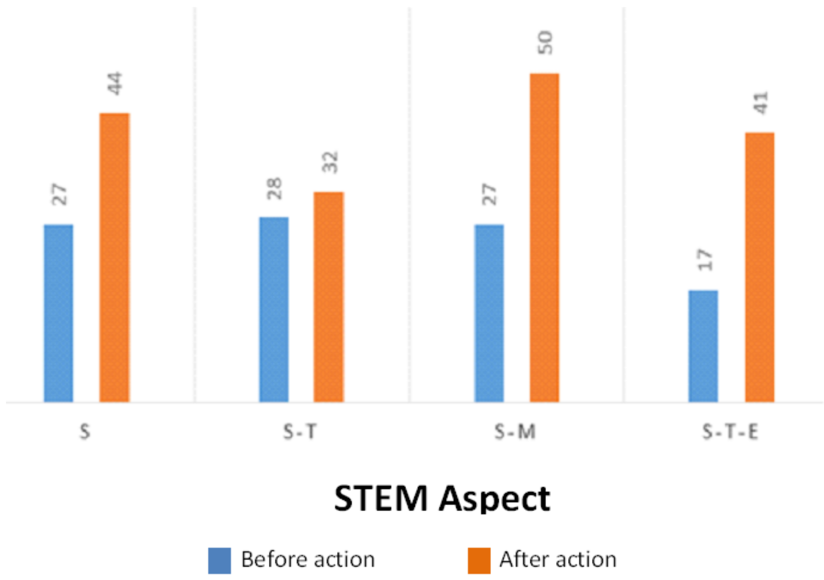

Figure 2. Percentage of observations based on STEM aspects.

STEM means to provide practical reinforcement in learning that integrates science, technology, engineering, and mathematics by focusing on solving problems in the life around them[3]. In accordance with this statement, the results of research conducted by previous studies show that the results of applying STEM in the learning process can help develop knowledge and thinking patterns in problem-solving. The application of STEM in the implementation of the learning process can help improve students' critical thinking skills. Critical thinking is a reflective way of thinking that focuses on making decisions about what to believe and what to do[4].

Research on the integration of STEM in PjBL is still rarely conducted. The results of research conducted by Xu, et al. (2023) revealed that STEM-integrated PjBL can increase interest in learning, the learning process becomes more meaningful, and able to assist in solving the problems found[16]. In addition, STEM in the PjBL model provides challenges and motivates because it can train critical thinking, analysis and improve higher-order thinking skills for students[17,18]. Thus, through learning using STEM, students know science and technology that can be used as provisions in real life and can solve problems encountered in their daily lives[19]. Figure 2 describes the improvement in STEM aspects combined with science questions given by lecturers to students. The cohesiveness of these questions covered various aspects: science alone (S), science and technology (S-T), science and mathematics (S-M), and science combined with technology and engineering (S-T-E)[20]. The result shows that the achievement of the Science-mathematics (S-M) indicator was 50%. While the lowest achievement was in the science and technology aspect of 32%. The achievement of improving the STEM aspect greatly affects the scientific attitude of students.

Conclusions

In conclusion, the integrated project-based learning with STEM and field study significantly enhanced student performance in the Elemental Chemistry course of a Chemistry Undergraduate Program Universitas Jambi, evidenced by high average scores ranging from 71% to 80%. The learning tools developed specifically for Elemental Chemistry were highly effective in this educational approach. There was also a notable improvement in students' thinking skills, demonstrated by a 50% increase in science-mathematical achievements during project implementation. Furthermore, the study successfully integrated theoretical knowledge with practical application, exemplified by the innovative use of teak sawn wood waste, which was synthesized into multifunctional compounds.

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