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Development of General Chemistry Teaching Materials Using the PjBL-STEM Model to Enhance Students' Creative Thinking Skills

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Abstract

Thinking creatively is a crucial higher-order skill that students must acquire when they graduate from university. This necessitates lecturers designing and developing learning processes that actively engage students while fostering their creative thinking abilities. This study aims to develop and validate general chemistry teaching materials on organic compounds and reactions using the PjBL-STEM model and evaluate their effectiveness in improving students' creative thinking skills. The study employed the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model. The teaching materials were designed as comprehensive books that adhered to the PjBL-STEM framework. Effectiveness was measured by analyzing improvements in students' creative thinking abilities through quantitative testing. The results demonstrate that the PjBL-STEM-based teaching materials are valid and feasible for implementation. Their effectiveness in enhancing students' creative thinking abilities was statistically significant (t-count = 32.488; p = 0.000), with an average improvement of 42.725 ± 8.317. The development of PjBL-STEM-based teaching materials offers a valuable tool for chemistry education, effectively promoting creative thinking skills among students. This approach provides a practical framework for lecturers to design innovative, student-centered learning strategies.

Keywords: creative thinking, PjBL, STEM, teaching materials

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1. Introduction

Since the emergence of a global movement calling for a new learning model for the 21st century, there has been a growing view that formal education must be transformed. These changes are important in bringing about new forms of learning needed to address complex global challenges. The change referred to is not a change in curriculum content, but a change in pedagogy, which is a change in action from simple action to comprehensive action and the transition from traditional teaching to technology-based teaching (Afandi et al., 2016).

The identification of student competencies that need to be developed is essential in the 21st century. Students must hone skills and improve learning to overcome global challenges, such as critical thinking skills, and the ability to communicate effectively, innovate, and solve problems through negotiation and collaboration (Panggabean et al., 2021).

General chemistry courses are a tool for achieving goals and training students to have thinking skills. One of the things that needs to be developed in chemistry learning is critical thinking skills, in accordance with the goals of chemistry education. Chemistry material and critical thinking skills are two things that cannot be separated, because chemical material is understood through critical thinking and vice versa critical thinking can be trained through learning chemistry (Purba et al., 2022).

Critical thinking skills are one of the most important goals at any level of education. Critical thinking skills cannot develop along with the physical development of each individual. This ability is related to the ability to identify, analyze, and solve problems creatively and logically to produce the right considerations and decisions (Fakhriyah, 2014). Critical thinking skills or abilities are very important for students because by having critical thinking skills students can act rationally and choose the best choices for themselves. The abilities and critical thinking skills possessed by each individual are certainly different, depending on the exercises that are often carried out to develop them (Purba et al, 2021).

Creative thinking abilities are one of the most important goals at all levels of education. This skill is related to the ability to identify, analyze, and solve problems creatively and logically to produce the right considerations and decisions (Fakhriyah, 2014). Creative thinking is an intellectual process that actively and skillfully conceptualizes, applications, analyzes, synthesizes, and evaluates information collected or resulting from observation, experience, reflection, reasoning, or communication, to guide beliefs and actions. This be obtained from can observations, experiences, induction deduction processes, or communication (Anggriani et al., 2018).

Creative thinking is self-regulation in deciding something that produces interpretation, analysis, evaluation, and inference, as well as exposure using evidence, concepts, methodologies, criteria, or contextual considerations on which decisions are made (Nuryanti et al, 2018). People who think creatively ideally have several basic criteria or elements abbreviated as FRISCO (Focus, Reason, Inference, Situation, Clarity, and Overview) (Fridanianti et al., 2018).

An educator including lecturers is also required to be able to design learning that is oriented towards active student involvement and is expected to stimulate students to be able to think critically and be able to solve the problems they face (Purba et al, 2021). Strategies to improve critical thinking skills are very urgent for students because they are related to life skills competencies for students after completing their studies at the university. Critical thinking skills are very important for a student to have, which at any time can be used as a basis for solving problems. This includes scientific activities such as asking questions, making statements, choosing the right choices, and making decisions in chemical experiments (Sutiani et al, 2021).

The principle of 21st-century learning uses a learner-centered learning approach, in which the teacher/lecturer acts as a facilitator. 21st-century learning emphasizes the ability of students to formulate problems, find out from various sources, think analytically, critically, creatively, and collaborate and collaborate in solving problems (Suratno et al., 2020). The selection of models and approaches to informal learning can train scientific literacy skills and student learning outcomes. The model and approach chosen is the project-based learning model with the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach (STEAM-PjBL Approach) (Rusmansyah et al, 2021). Project Based Learning (PjBL) is an ideal model to complement 21st-century educational goals because it involves the 4C principles of Critical thinking, Communication, Collaboration, and Creativity (Rusydiana et al., 2021).

PjBL has great potential to provide a more interesting and meaningful learning experience for students so that PjBL becomes a learning model that supports the 2013 curriculum (Wahyu, 2016). In PjBL, students collaboratively determine their learning process, conduct research, and create projects that reflect their knowledge. This approach enhances their skills in using technology, communication, and problem-solving. Through PjBL, students deepen their understanding of science concepts and tend to better retain and comprehend information gained from implementing the projects (Dewi, 2015).

Several studies have also shown that the application of PjBL is effectively used in learning (Jazimah & Septianingsih, 2021), is able to increase student learning activities and achievements (Sitaresmi et al, 2017), improves creative thinking skills (Sari et al, 2019), increases the ability communication (Melinda & Zainil, 2020), improve critical and creative thinking skills (Putri et al, 2015; Ananda et al., 2021), improve collaboration skills and learning outcomes (Pratiwi et al., 2018), improve literacy skills (Rizkamariana et al, 2019), as well as being able to increase student HOTS (Higher Order Thinking Skill). (Sambite et al, 2019); (Londa & Domu, 2020); (Rusydiana et al., 2021).

To enhance student engagement, creativity, innovation, problem-solving skills, and other cognitive benefits, use teaching materials in the form of interesting modules (Rusmansyah et al., 2021). Interactive learning media that can be used can be in the form of electronic modules (Makuasa et al., 2024). Therefore, to accommodate the students' needs the learning process needs to provide the learning model and the teaching materials that support 21st-century learning (Pramasdyahsari et al., 2023).

Critical thinking skills are essential for students to succeed in addressing challenges, problems, and careers in the 21st century. The rapid development of science and technology requires educators to prepare students who can think critically and competently across various fields. The fields needed to tackle these challenges are Science, Technology, Engineering, and Mathematics (STEM), which involve critical thinking, analysis, and collaboration. Through STEM, students integrate processes and concepts in real-world contexts, developing skills and competencies necessary for college, career, and life (Rachmawati et al., 2017).

The STEM approach integrates these disciplines to develop essential 21st-century skills. It significantly impacts academic achievement by linking learning to real-world situations, allowing students to connect scientific concepts to their daily lives. Through STEM, students focus not just on memorizing facts but on understanding how scientific concepts relate to everyday experiences (Irmita, 2018). Several studies also show that the STEM approach can improve students' critical thinking skills (Lestari et al., 2018); (Ariyatun & Octavianelis, 2020); (Santoso & Arif, 2021); (Allanta & Puspita 2021); (Fadlina et al, 2021), improve skills think creatively (Fitriyah & Ramadani, 2021), and be able to improve student learning outcomes (Melina, 2022); (Rahayu & Sutarno 2021).

This study highlights the importance of developing innovative learning methods, such as PjBL-STEM-based teaching materials, to improve students' creative thinking skills. Building on previous research that applied the STEM approach to enhance students' creative thinking abilities, the researcher focused on developing a general chemistry textbook using the PjBL-STEM model to foster students' creativity.

2. Research Method

This research is a type of research and development (R&D), which is a type of research that produces products instead of testing a theory and is a process used to develop and validate educational products and test the effectiveness of these products (Sugiyono, 2020). This study used books based on the PjBL-STEM model as the teaching material.

The development model used refers to the ADDIE development model. The procedure is carried out through several stages, including: (1) Analysis, including field studies (student needs analysis) and literature studies, which are conducting analysis to collect information related to student needs and reviewing literature related to the products developed; (2) Design, including identifying objectives and designing learning models, which is the stage carried out to identify objectives and design PjBL-STEM learning models in the learning of compounds and organic reactions to be developed; (3) Development, including developing instruments and validating instruments for the development of PjBL-STEM learning models in the learning of compounds and organic reactions. This stage of development is a stage to realize the design into a product that is ready to be implemented; (4) Implementation, applying general chemistry learning media using a web-based learning model to students such as applying the developed product, which is the PjBL-STEM learning model on learning compounds and organic reactions; and (5) Evaluation, including analyzing and evaluating the use and implementation of the PjBL-STEM learning model on students' critical thinking skills, which is conducting an evaluation by analyzing the PjBL-STEM learning model on compound learning and organic reactions to students' creative thinking skills.

Data collection techniques in this study include: (1) Interviews, used to gather preliminary data on problems to be studied and inform product trials during validation with expert validators and field trials, aimed at improving teaching materials based on the PjBL-STEM model for organic compounds and reactions; (2) Validation sheets, used to collect expert validation data on the teaching materials based on the PjBL-STEM model for the development of organic compounds and reactions; and (3) Instruments test, designed to gather data on students' creative thinking abilities in learning organic compounds and reactions, with tests organized according to achievement competencies in essay/description form.

The research data were analyzed in stages to determine the feasibility (validity) and effectiveness of the developed learning. The feasibility (validity) of teaching materials based on the PjBL-STEM model was analyzed based on the results of expert validation by considering input, comments, and suggestions from expert validators. The effectiveness of teaching materials based on the PjBL-STEM model is obtained from the results of tests of students' creative thinking skills.

The effectiveness test was analyzed from increasing students' creative thinking skills using the t-test or paired sample t-test approach with the help of the SPSS program. The feasibility (validity) of general chemistry teaching materials based on the PjBL-STEM model on the learning of compounds and organic reactions developed is evaluated and assessed by expert validators based on the feasibility of the material and the feasibility of the media.

The research was conducted on one class containing 40 students as a sample. So that the implementation of the teaching materials produced was carried out on 40 students (1 class) and carried out in 3 (three) stages including: (1) the initial stage, which is the initial test (pretest) before students are given learning actions, (2) the second stage, the action or learning process where students utilize the general chemistry teaching materials based on the PjBL-STEM model that has been produced in learning organic compounds and reactions, and (3) the third stage, the final test (posttest) after all learning materials have been taught.

3. Result and Discussion

The product developed in this research and development is a general chemistry teaching material (book) based on the PjBL-STEM model on organic compounds and reactions, to facilitate lecturers and students in the learning process and improve students' creative thinking skills in learning organic compounds and reactions. The outcome is a collection of book prototypes based on PjBL-STEM that can be further developed to meet the needs of general chemistry books using the PjBL-STEM model to enhance students' creative thinking skills. The book (teaching material) contains references to PjBL-STEM and critical thinking, as well as a sub-topic about organic compounds and reaction and posttest questions.

Figure 1. Cover Book

The validation or feasibility of teaching materials is assessed by expert validators in their fields. General chemistry teaching materials (books) based on the PjBL-STEM model that is produced and has been declared valid (feasible) based on the assessment of expert validators are then implemented by students to analyze the effectiveness of teaching materials in improving students' creative thinking abilities.

3.1. Product Validity

The feasibility (validity) of teaching materials for general chemistry courses based on the STEM PjBL model on the material on organic compounds and reactions that have been developed, is analyzed based on the validation or evaluation results sheet carried out by a team of expert validators on the aspects of material feasibility and media feasibility (design).

Table 1 shows the results of the assessment of the expert material validator team and the average total score obtained was 4.60 or stated to meet the valid criteria. Thus, it is concluded that the general chemistry teaching material based on the PjBL-STEM model is valid from the material aspect so that it is suitable for application in the learning process of organic compounds and reactions.

Table 1. Product Validation Results on Material Aspects

Assessment Aspects	Average Score	Criteria
Content material	4.63	Valid
Presentation of material	4.42	Valid
Language	4.44	Valid
Use of learning models	4.93	Valid
Evaluation and assessment	4.56	Valid
Total average	**4.60**	**Valid**

Table 2 shows the results of the assessment of the expert media validator team (design) which obtained an average total score of 4.66 or stated that it has met the valid criteria. Thus, it is concluded that the general chemistry teaching materials based on the PjBL-STEM model are valid from the media aspect (design) so that they are suitable for application in the learning process of organic compounds and reactions.

Table 2. Product Validation Results on Media (Design) Aspects

Assessment Aspects	Average Score	Criteria
Graphics	4.61	Valid
Language	4.75	Valid
Total average	**4.68**	**Valid**

3.2. Achievement of Students' Creative Thinking Abilities

The achievement of students' creative thinking skills is obtained through test instruments given before (pretest) and after utilizing general chemistry teaching materials based on the PjBL-STEM model (posttest). The implementation of the teaching materials produced was carried out on 40 students and was carried out in three stages including: (1) the initial stage, which is the initial test (pretest) before students were given action, (2) the second stage, the learning process where students utilize general chemistry teaching materials based on the PjBL-STEM model on organic compounds and reactions that have been produced, and (3) the third stage, the final test (posttest).

Table 3. Achievement of Students' Creative Thinking Abilities

	Pretest	Posttest
N	40	40
Minimum	35	75
Maximum	55	98
Mean	46.18	88.90
Std. Deviation	4.402	4.960
KS test	0.136	0.128
Sig.	0.061	0.097

Table 3 shows the achievement of the pretest results of students' creative thinking abilities before being given the action, the average pretest was 46.18 ± 4.402 and the data was normally distributed ($p = 0.061$). After being given the action by utilizing general chemistry teaching materials based on the PjBL-STEM model, the posttest results obtained an average score of students' creative thinking abilities of 88.90 ± 4.960, and the data was normally distributed ($p = 0.097$).

3.3. Product Effectiveness

The effectiveness of the product in the form of general chemistry teaching materials based on the PjBL-STEM model on the material of organic compounds and reactions that have been produced is analyzed from the increase in the achievement of students' creative thinking skills in completing the test instrument. The effectiveness of increasing students' creative thinking skills is analyzed using the paired sample t-test approach using the SPSS program.

Table 4. Product Effectiveness Test Results (Teaching Materials)

	Paired Differences		t	sig
	Mean	***Std. Dev***		
Posttest -Pretest	42.725	8.317	32.488	0.000

Table 4 shows the results of the analysis of the improvement of creative thinking skills students with the difference in the average value of student's creative thinking skills (posttest-pretest) amounted to 42.725 ± 8.317 and the results of hypothesis testing obtained the value of t-count of 32.488 with a probability (sig.) of $0.000 < 0.05$. Thus, concluded that the implementation of general chemistry teaching materials based on the PjBL-STEM model that is produced is significantly proven to be effective in improving the ability of students to think creatively. Students' creative thinking skills in learning organic compounds and reactions.

The product developed in this study is a teaching material for general chemistry courses based on the PjBL-STEM model on organic compounds and reactions. The teaching material was developed by referring to the ADDIE development model and designed based on learning indicators on organic compounds and reactions, using PjBL and STEM learning steps (syntax). The teaching material that has been developed is then evaluated and reviewed by a team of expert validators to assess the feasibility of the teaching material based on the feasibility aspect of the material and the feasibility aspect of the media (design). The results of the expert validator team's assessment of the general chemistry teaching material based on the PjBL-STEM model that was developed have been declared valid so that it is worthy of being implemented in the learning process. The feasibility (validity) of the teaching material is qualitatively met based on the results of the analysis of the validation sheet that has been filled in by the expert material validator team with an average total score of 4.60 (valid) and the results of the assessment of the expert media/design validator team with an average total score of 4.68 (valid), according to the standards according to the *Badan Standar Nasional Pendidikan* (BSNP) with modifications according to teaching materials at the university level.

In the implementation stage, the use of general chemistry teaching materials based on the PjBL-STEM model in the chemistry learning process on organic compounds and reactions has also proven to be effective in improving students' creative thinking skills. The effectiveness of implementing teaching materials based on the PjBL-STEM model was statistically fulfilled based on the results of the evaluation of creative thinking skills through test instruments completed by students, both on pretest data before being given action, and on posttest data after being given learning action, with an average difference in the score of increasing students' creative thinking skills of 42,725 ± 8,317. Students' responses to the general chemistry teaching materials based on the PjBL-STEM model produced were also very positive.

In addition, hypothesis testing was carried out to ensure the significance of the increase. The calculated t-count obtained was 32.488 with a probability level (sig.) of 0.000. Since this probability value is smaller than 0.05, the test results show that the increase in students' creative thinking skills is statistically significant.

Thus, it can be concluded that the implementation of general chemistry teaching materials based on the PjBL-STEM model is proven effective in improving students' creative thinking skills. This improvement is particularly observed in learning that focuses on the topic of organic compounds and reactions. The effectiveness of this teaching material reflects the great potential of the PjBL-STEM model in supporting the development of higher-order thinking skills, such as creative thinking, in the context of chemistry learning.

The findings of this research and development also have implications for lecturers that to improve the achievement of learning outcomes, especially students' creative thinking skills, one can design and develop innovative learning, one of which is by developing teaching materials based on the PjBL-STEM model. Through this general chemistry teaching material based on the PjBL-STEM model, it can help students improve understanding, and mastery as well as train and improve students' creative thinking abilities.

4. Conclusion

This study successfully produced teaching materials in the form of a general chemistry book based on the PjBL-STEM model on organic compounds and reactions, which was developed through the ADDIE development model. Based on the analysis of the validation sheet filled in by a team of expert validators, it can be concluded that this teaching material has been declared valid and suitable for use in learning, both in terms of the feasibility of material content, presentation, language, use of learning models, evaluation, assessment, and graphic feasibility in accordance with BSNP standards, with appropriate modifications for the college level. In addition, the application of this teaching material proved effective in improving students' creative thinking skills, with an average increase in pretest-posttest scores of 42.725 ± 8.317, which was supported by significant statistical testing results ($p = 0.000 < 0.05$). The development of PjBL-STEM-based teaching materials can be an effective alternative to learning chemistry, especially in improving students' creative thinking skills. Therefore, it is important to conduct further development and testing of this teaching material in other classes to ensure wider effectiveness. This research also encourages the development of other teaching materials that use the PjBL-STEM model in chemistry courses and other disciplines and can be a reference for lecturers and development researchers to create more interactive and project-based learning.

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