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Exploration of Student Thinking Systems Through STEM-PjBL Project Based Learning in the Science Field

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Abstract
The complexity of science concepts which are interrelated with each other requires the competence to think systematically. Complex thinking which is the basis for critical, analytical, creative and metacognitive thinking is very important to master in responding to the challenges of the 21st century. The aim of this research is to explore students' thinking systems taught using the STEM-PjBL model. This research is quantitative descriptive research. The variables studied are students' thinking systems based on the ability to determine components that influence each other in the bioethanol synthesis and dehydrator processes. The population in the study was 17 students. Students are distributed in two semesters, namely semesters II and IV. The research uses pre-test and post-test systematic thinking ability tests as data collection techniques and tools. The test consists of 5 essay questions that assess students' systematic thinking competence, and the test used is analyzed for validity, discrimination power, and level of difficulty before use. This test was developed based on indicators of systematic thinking competency. Tests were given to students before and after carrying out project activities for making and dehydrating bioethanol. After carrying out the project, students strengthen their competence through computational simulations related to the project being carried out. The data obtained is then presented in a communicative graph. The research results showed that 35.2% had high system thinking, 29% medium, 35.6% low. These results show that the application of the STEM-PjBL model is able to foster students' systematic thinking competency.

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INTRODUCTION

Natural Sciences (IPA) is a branch of science that studies phenomena and natural occurrences in the universe through systematic observation, experimentation, and measurement (Jr & Rethwisch, 2020; Wong et al., 2020). Scientific activities in IPA include observation, hypothesis formulation, experimental design, data collection and analysis, and drawing conclusions (Akyol & Taş, 2024; Mohzana et al., 2023). All these processes are carried out systematically, controlled, and measured to produce objective and verifiable results. Critical, analytical, and creative thinking skills are essential in these activities (Hulyadi et al., 2024;

Ijirana et al., 2022). Scientific thinking in IPA involves complex cognitive processes, such as problem identification, hypothesis formulation, experimental design, data analysis, and conclusion drawing. This process requires logical, inductive, and deductive thinking skills, as well as the integration of concepts, principles, and theories to understand IPA phenomena comprehensively (Lubna et al., 2023). Scientific activities and systematic thinking in IPA produce reliable, objective, and verifiable knowledge. This knowledge can be applied to solve problems and improve the quality of human life, preparing individuals to face 21st-century challenges. Scientific thinking skills in IPA are also useful in decision-making, problem-solving, and innovation in various fields. A reliable thinking system is a fundamental competency in addressing the complexities of 21st-century problems.

In the 21st century, the challenges faced by society are increasingly complex and diverse, ranging from climate change and rapidly evolving technology to shifting social and economic dynamics. To address these challenges, a reliable thinking system becomes a fundamental competency. A reliable thinking system involves the ability to think critically, analytically, and creatively to understand and solve problems effectively (Fong et al., 2017; O'Reilly et al., 2022; Swami et al., 2014). Critical thinking involves the ability to analyze information objectively, identify biases, evaluate arguments, and draw conclusions based on available evidence. This ability is crucial for assessing the validity and reliability of information circulating in the digital age (Abrami et al., 2015). Analytical thinking is the ability to break down problems into smaller components, understand the relationships between these components, and formulate solutions based on in-depth analysis. This skill is very useful in tackling complex and multifaceted problems (Kirman-Bilgin & Kala, 2022; Pennycook et al., 2012; Swami et al., 2014). Besides these reliable thinking models, creative thinking is also essential to master in facing future complexities.

Creative thinking involves the ability to generate new ideas, view problems from various perspectives, and develop innovative solutions (Akpur, 2020). Creativity allows individuals to break free from conventional thinking patterns and find new ways to solve problems (Huang et al., 2020; Park & Lee, 2022). The rapid advancement of technology requires the ability to continuously learn and adapt. A reliable thinking system enables individuals to understand new technologies, integrate them into everyday life, and utilize them to enhance productivity and efficiency. Global issues such as climate change, energy crises, and social injustices require complex and integrated solutions (Abbass et al., 2022; Carleton & Hsiang, 2016). A reliable thinking system helps individuals and groups formulate holistic and sustainable strategies. In the information era, individuals are faced with many choices and decisions. Critical and analytical thinking skills assist in making data-driven and fact-based decisions, reducing the risk of errors, and improving the quality of outcomes (O'Reilly et al., 2022). Learning models that emphasize systematic thinking skills and scientific processes, such as PjBL, are suitable for fostering reliable thinking abilities (Baran et al., 2021; Bulu & Tanggur, 2021). The PjBL approach encourages students to engage in real projects that require problem-solving, collaboration, and innovation (Diana et al., 2021; Hulyadi et al., 2024). Through PjBL, students can develop critical, analytical, and creative thinking skills in contexts relevant to real life.

A reliable thinking system is a fundamental competency crucial for addressing the complexities of 21st-century problems. Critical, analytical, and creative thinking abilities enable individuals and groups to face challenges effectively and innovatively. Education that focuses on developing a reliable thinking system, through approaches such as PjBL and STEM integration, is key to preparing future generations to face global challenges and contribute to societal progress. In facing 21st-century challenges, developing critical and analytical thinking skills is vital for students to navigate and overcome complex global issues (Almazroui, 2023; Baran et al., 2021). This theme explores the integration of computational chemistry into STEM education through a project-based learning (PBL) approach (Saad & Zainudin, 2022). By utilizing computer simulations and hands-on projects, this method enhances students' understanding of scientific concepts and hones their problem-solving abilities (Carlgren, 2013). The synergy between computational chemistry and PBL not only strengthens theoretical knowledge but also fosters collaboration, creativity, and real-world applications, preparing students to become innovative thinkers capable of tackling contemporary scientific and technological challenges (Hulyadi et al., 2024; Muhali, 2019).

Field observations show that many learning approaches have already adopted scientific-based learning. Models such as PBL, video-assisted Blended Learning, PHET, and computational chemistry have been applied, resulting in improved students' thinking skills, but students' cognitive competence remains low. This is reflected in the lack of students' ability to connect previous knowledge with the current content being studied. Learning approaches that explore students' thinking systems have been little researched. To understand interconnected IPA content, it is necessary to delve deeper into students' thinking competencies. Developing a complex thinking system in students is important to face 21st-century challenges. The STEM-PjBL model is considered appropriate for developing students' thinking competencies.

(Agussuryani et al., 2022; Zainil et al., 2023) stated that in recent decades, STEM (Science, Technology, Engineering, and Mathematics) has undergone significant changes in line with the increasing demand for a workforce with higher-order thinking skills such as critical and analytical thinking. Initially, STEM focused on learning basic theories and applications in science and technology. However, this approach often fell short in preparing students for real-world complex challenges (Yusuf et al., 2018). The integration of Science, Technology, Engineering, and Mathematics (STEM) in education aims to enhance various skills among students, especially critical thinking. Many studies show that STEM education enhances important 21st-century skills, such as problem-solving, analytical thinking, creativity, and effective communication (Hacioglu & Gulhan, 2021; Ijirana et al., 2022; Parno et al., 2022). Research consistently shows that STEM education positively impacts students' critical thinking dispositions and skills (Agussuryani et al., 2022; Yusuf et al., 2018). STEM activities have proven to increase systematic aspects, truth-seeking, and open-mindedness in critical thinking (Ambrož et al., 2023). Additionally, problem-solving activities based on STEM have shown significant improvements in students' critical thinking tendencies. The interdisciplinary nature of STEM encourages students to approach problems from various perspectives, thereby promoting flexibility and metacognition (Lubna et al., 2023). Abstract chemistry content requires simulators to construct students' conceptions.

(Boswell et al., 2013; Calderón-Mendoza et al., 2022) stated that using simulators in chemistry learning can greatly assist students in understanding abstract concepts. Simulators allow students to visualize and manipulate chemical phenomena that might be difficult to grasp through text or static images alone. (Rakhmetova et al., 2024; Speybroeck & Meier, 2003) reported that simulators can show how molecules interact and react dynamically. This helps students understand molecular structures, chemical bonds, and complex reaction mechanisms. Simulators allow students to conduct virtual chemistry experiments. They can change variables and see the effects directly without the safety risks or material costs of a laboratory. Concepts such as atomic orbitals, bond energy, or reaction mechanisms can be explained more clearly using 3D models and animations generated by simulators (Çalik et al., 2024). With the integration of these simulators into the curriculum, teachers can stimulate students' critical and analytical thinking abilities and enhance their understanding of abstract chemistry material (Kuit & Osman, 2021).

Computational chemistry has advanced significantly since the introduction of electronic computers in the mid-20th century. At the beginning of the 21st century, the integration of computational tools in chemistry education began to significantly impact how students understand and learn complex chemistry concepts. The use of simulation and modeling software has transformed the landscape of chemistry education, offering interactive and efficient methods for studying theory and its applications (Echeverri-Jimenez & Oliver-Hoyo, 2021; McArdle et al., 2020). This approach is further strengthened by the combination of Problem-Based Learning (PBL), creating a dynamic and student-centered learning environment (Hulyadi & Muhali, 2023). Computational chemistry involves using computers to solve chemical problems through complex simulations and calculations (Rakhmetova et al., 2024). Since the introduction of electronic computers, the ability to perform calculations that were previously impossible manually has paved the way for the development of new theories and methods in chemistry (Stelz-Sullivan et al., 2022). Students can visualize and understand complex reaction mechanisms, including organic and inorganic reactions, through simulations that show step-by-step processes at the molecular level (Speybroeck & Meier, 2003; Yuen & Lau, 2022; Zhao et al., 2022

(Echeverri-Jimenez & Oliver-Hoyo, 2021; Saad & Zainudin, 2022; Snyder & Kucukkal, 2021) reports that with software such as Avogadro or Gaussian, students can build and analyze molecular structures, study molecular geometry, bonds and interactions between molecules. Computational tools enable students to study reaction kinetics and energy changes in chemical processes through simulations that provide quantitative data that supports theoretical understanding. Virtual laboratories such as ChemCollective allow students to perform experiments that cannot be performed in a physical laboratory due to time, cost, or security limitations. (Almazroui, 2023; Amin et al., 2020; Saad & Zainudin, 2022) states that PBL is a teaching method where students learn about a subject through solving complex and realistic problems. When combined with computational chemistry, this approach provides significant benefits. Students work on real projects that require the application of chemical theory using computational tools to solve problems. This helps develop analytical and problem-solving skills (Afdareza et al., 2020; Dabbagh, 2019; Kim et al., 2018). (Rodríguez-Becerra et al., 2020; Suomala & Kauttonen, 2023) stated that the integration of computational chemistry with a PBL approach offers an innovative and effective learning method in chemistry education. This not only enhances students' theoretical understanding but also develops practical and technological skills that are important for future careers. By overcoming existing challenges, the use of computational chemistry in education will continue to grow and make a significant contribution to improving the quality of STEM learning.

In the era of globalization and digitalization, critical and analytical thinking skills are very important. This topic emphasizes developing these skills through interactive and practical education. By using computational chemistry in project-based learning, students not only understand theory, but also learn to apply concepts in real-world situations, which is critical for future careers. Presenting contextual problems is expected to increase student learning motivation. The results of observations and previous research show that students' learning motivation is still low, this is proven by researchers' investigations using the question map instrument. The research results show that motivation and curiosity are still low. This is reflected in the students' ability to make complex questions which is still low (Hulyadi et al., 2023). Chemistry education students as future chemistry teacher candidates must be equipped with future competencies. Future competencies that must be possessed are the ability to think at a high level, be proficient in using and creating learning technology, be adaptive to problems faced in the surrounding environment. This competency requires the support of learning facilities that are in line with current developments. Laboratory and simulator facilities are needed to provide meaningful and innovative learning. The problem is that empirical findings in the laboratory are not studied comprehensively, which has an impact on students' low ability to interpret data. This has an impact on the emergence of misconceptions among students

(Hulyadi & Muhali, 2023). Based on these findings, it is important to apply the STEM-PjBL learning model assisted by computational chemistry to prepare future teachers who are innovative, have high HOTS abilities, and are adaptive to problems, especially dynamic environmental issues.

STEM, which is integrated with Project Based Learning (PjBL), is increasingly recognized as an important approach to prepare students to face the complexities of the 21st century (Zayyinah et al., 2022). This conceptual study explores the benefits, challenges, and theoretical foundations of STEM-PjBL, based on insights from various scientific sources (Samsudin et al., 2020). The integration of STEM with PjBL is based on Bandura's social cognitive theory, which emphasizes the interaction of cognitive, behavioral, personal, and environmental factors in learning. Self-efficacy, an important component of this theory, plays a critical role in student motivation and achievement in STEM fields. According to Bandura, self-efficacy influences the effort students put into assignments, their persistence in facing challenges, and their overall academic performance. STEM-PjBL encourages creativity by enabling students to apply interdisciplinary knowledge to real-world problems. This approach encourages innovative thinking and the ability to design and build unique solutions (Ijirana et al., 2022; Lubna et al., 2023; Parno et al., 2022). By addressing real challenges, students learn to apply scientific, technological principles , engineering, and mathematics to create practical solutions. This hands-on experience is essential for developing problem-solving skills that are highly valued in the 21st century world of work (Anggereini et al., 2023; Zainil et al., 2023; Zayyinah et al., 2022).

STEM-PjBL represents a powerful educational approach that is in line with the demands of the 21st century (Almazroui, 2023; Baran et al., 2021; Hulyadi et al., 2024; Zayyinah et al., 2022). By encouraging creativity, increasing self-efficacy, and developing essential collaborative and problem-solving skills, STEM-PjBL prepares students to navigate and contribute to an increasingly complex and technologically advanced world. However, to realize its full potential, challenges such as resource allocation, teacher training, assessment, and equity must be addressed. Future research and policy efforts should focus on these areas to support effective implementation and sustainability of STEM-PjBL initiatives. This approach encourages students to participate in projects relevant to global challenges such as climate change, global health, and renewable energy (Hunt et al., 2020; McFadgen & Huitema, 2017). By using computational chemistry tools, students can develop innovative solutions that contribute to solving global problems. This not only improves their technical skills but also makes a positive contribution to society. Previous research results show that STEM-PjBL integration has been widely carried out. Implementation of this model has been proven to be able to improve high-level thinking skills, foster environmental awareness, and motivation to learn from current world problems, namely climate change and green energy. Research that is still rarely conducted is identifying the influence of the integration of the STEM-PjBL model on systematic thinking skills.

The STEM (Science, Technology, Engineering, and Mathematics) learning model is designed to answer the challenges of the 21st century with the aim of improving critical, creative, innovative and productive thinking skills that are directly related to real conditions (Agussuryani et al., 2022; Ouyang & Xu , 2024). In this context, high-level thinking skills are very important to master. STEM education integrates science, technology, engineering, and mathematics to develop student creativity through problem solving (Stelz-Sullivan et al., 2022, 2022). This integration does not only focus on cognitive mastery but also on practical skills needed in everyday life (Lubna et al., 2023). STEM began to be applied since the second world war when technology developed rapidly. In the United States, research on STEM education began in 1969. Several non-western countries, such as Saudi Arabia and Malaysia, have also begun to adopt STEM education to improve the quality of their human resources (Ouyang &

Xu, 2024). There are three main approaches to implementing STEM education: the SILO approach, the Embedded approach, and the Integrated approach. The Integrated Approach is considered the most effective because it eliminates boundaries between STEM components and requires pedagogical training for teachers (Bryan et al., 2015; Zayyinah et al., 2022). Based on the conceptual study above, STEM-PjBL is a model that can be used to develop students' thinking systems in mastering science content that is integrated with one another. Comprehensive understanding is the key to fundamental science competencies. It is important to master comprehensive competencies to give birth to creative thinking in responding to the challenges of the 21st century.

METHOD

The research was conducted using a quantitative descriptive approach. Quantitative descriptive research is a type of research that aims to describe and analyze a phenomenon or population through the collection and analysis of quantitative data. In contrast to qualitative research which places greater emphasis on in-depth and interpretive understanding, quantitative descriptive research prioritizes measurement and making statistical generalizations about a population. This research was conducted at the Mandalika University of Education with a sample of 20 people. The variables analyzed are the effectiveness of the STEM-PjBL model assisted by computational chemistry in developing systematic thinking competence. The project in this research is based on the environmental issue of rising global temperatures due to the use of fossil fuels. The introduction of new, renewable energy that is more environmentally friendly is the topic of the project that students will work on. Making bioethanol from local NTB commodities such as cassava, sugar cane and corn is used as the basic material for making ethanol. Bioethanol synthesis activities are carried out by providing a series of treatments to improve production quality and finding potential commodities that produce bioethanol with the highest quantity and quality. The product is then subjected to a series of tests to determine the concentration and composition contained in the biethanol product. At each stage of production, discussions and reflections are carried out on each finding. At the end of the project, each group presents its findings and draws conclusions from a series of scientific activities that have been carried out. It is hoped that this series of scientific activities will be able to develop competency in thinking systematically.

Data Collection Techniques and Tools

The research uses pre-test and post-test systematic thinking ability tests as data collection techniques and tools. The test consists of 5 essay questions that assess students' systematic thinking competence, and the test used is analyzed for validity, discrimination power, and level of difficulty before use. This test was developed based on indicators of systematic thinking competency. Tests are given to students before and after carrying out bioethanol production project activities. After carrying out the project, students strengthen their competence through computational simulations related to the project being carried out.

Data analysis technique

Data collection techniques come from systematic thinking tests. In data processing, this research collected pre-test and post-test data before and after treatment. After the data is collected, data processing is assisted by the SPSS 22 program. The data analysis technique used in this research is as follows: The normality test is used to determine whether the data used is normally distributed or not. This research uses the Shapiro-Wilk normality test because the sample used is less than 50. Then, a homogeneity test is carried out to determine the level of similarity in the data variance of the population. The next test uses the N-Gain test to identify the effectiveness of the treatment given.

RESULTS AND DISCUSSION

Natural Sciences (IPA) is a field of study that is rich in complex and interrelated concepts. To understand science in depth, systematic thinking competence is needed. Systematic thinking means organizing and managing information in a logical and structured way, so that students can understand the relationship between concepts and apply them effectively in problem solving. Science includes various scientific disciplines such as physics, chemistry, biology, and geology, all of which have interrelated concepts. For example, the concept of energy in physics is closely related to the concept of chemical reactions in chemistry and metabolic processes in biology. Understanding one concept often requires understanding another concept. Many science concepts cannot be understood in isolation. Chemical content is included in concepts that are interrelated with other concepts. Chemical content is abstract and requires multiple representations, adding to the complexity of variables in understanding chemical content. In research, the complexity of chemical content is measured by varying various variables that influence certain events in a series of laboratory scientific activities. In evaluating students' thinking systems, a series of competency measurements are carried out, such as: Competence in problem context analysis, analysis of variables that influence each other in the system, complexity of the variables described, ability to narrate the relationship of each variable, ability to identify internal and external factors in the system, and misconceptions. The evaluation results are presented in Figure 1.

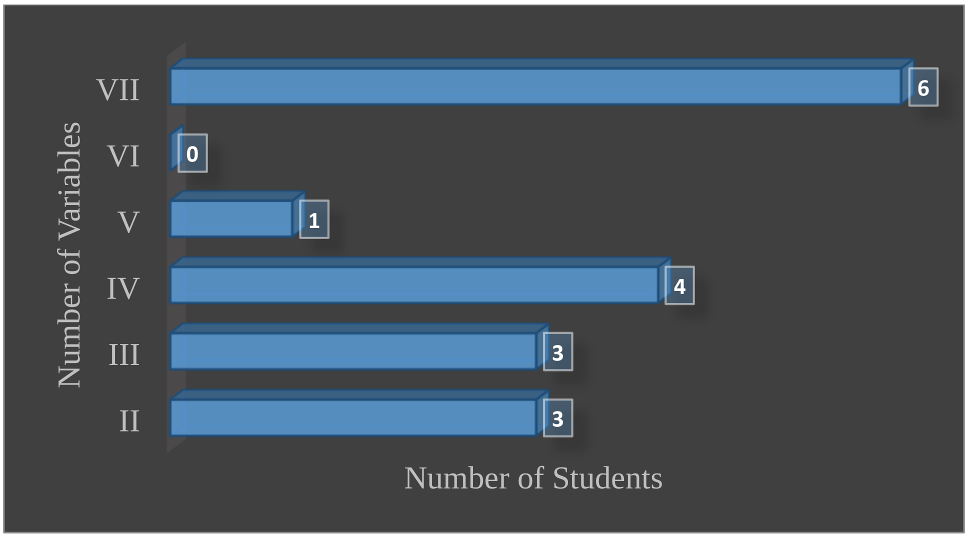

Figure 1. Complexity of student thinking

Systematic thinking involves organizing information in a structured manner, making it easier to understand and apply complex concepts. This structured approach helps students develop logical and coherent steps in solving problems (Zexian & Xuhui, 2010). Systematic thinking allows students to analyze problems by breaking them down into smaller components and identifying relationships between these components (Cabrera & Cabrera, 2023). Apart from that, systematic thinking also involves synthesis, namely combining various information and concepts to form a complete understanding (Tobón & Luna-Nemecio, 2021). In learning science, students are often faced with complex problems. Systematic thinking helps students identify problems, formulate hypotheses, design experiments, collect data, and draw conclusions based on existing data. For example, in chemistry experiments, students must follow systematic steps starting from preparing materials and tools, carrying out experiments, to analyzing the results. Concept maps are an effective tool for organizing and visualizing the relationships between science concepts (Hulyadi et al., 2023). By using concept maps, students can see how one concept is connected to other concepts and understand the overall structure of the material being studied. Project-based learning on the purification and synthesis of bioethanol from various organic materials is used to build students' complex thinking systems.

The project-based approach requires students to work on projects that require the application of various science concepts in an integrated manner. This project encourages students to think systematically in planning, implementing and evaluating the results of their work (Anggereini. et al., 2023). In this project, students are trained to design a distillation apparatus equipped with a dehirator with the hope that the bioethanol product will approach 98% bioethanol purity. It is hoped that a series of bioethanol synthesis and purification activities will foster the complexity of students' thinking. The results of the evaluation of students' thinking systems can be seen in Figure 1. The evaluation results show that the complexity of students varies. The research results show that the STEM-PjBL mode application is proven to be able to build students' thinking competence. This is indicated by the students' ability to identify facts and empirical results obtained from bioethanol synthesis and purification laboratory activities. Data was also obtained from journal analysis regarding the physicochemical characteristics of 3 components that were tested in distillation equipment and bioethanol dehydrators. The percentage of students' thinking competence was analyzed based on the complexity of variables that influence each other during the distillation and bioethanol dehydrator processes. The percentage of students' systematic thinking competency is presented in Figure 2.

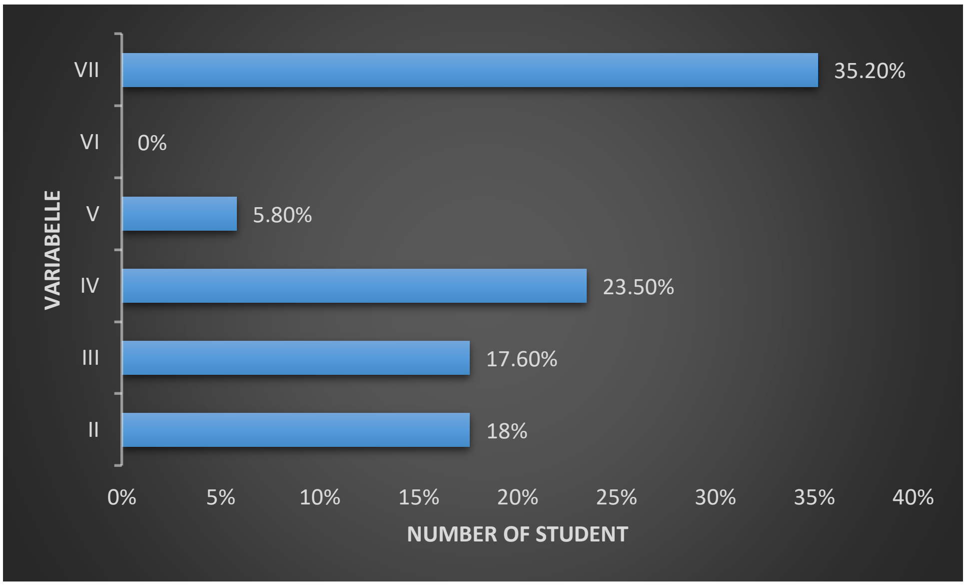

Figure 2. Percentage of students' systematic thinking competency

In learning STEM-PjBL applications, students are given real problems that must be solved using science concepts. The problem of climate change due to the use of fossil fuels is a major problem. This problem is used as a barometer for which a solution must be found. The solutions offered must pay attention to local commodities. This method encourages students to think systematically in identifying problems, searching for information, and formulating solutions (Baran et al., 2021; Parno et al., 2022). Technology can help students organize information and understand complex science concepts. For example, computer simulations can be used to model scientific processes, help students see relationships between variables, and predict outcomes based on existing data. The complexity of concepts in science learning requires systematic thinking competence (Cabrera & Cabrera, 2023). By thinking systematically, students can organize information in a logical and structured way, allowing them to understand the relationships between concepts and apply them in problem solving. A structured approach, use of concept maps, project-based approach, problem-based learning, and technology are several methods that can be used to develop systematic thinking skills in science learning. In this way, students can build a deep and comprehensive understanding of science, as well as develop the skills needed to face future challenges.

Problem-based learning (PjBL) is an educational approach that focuses on solving real-world problems actively and collaboratively. This is a student-centered method where students are presented with a problem or scenario that requires them to explore and research the topic, work in teams, and develop their understanding and problem-solving skills (Fruyt, F.D. et al., 2015). Students are presented with realistic and open-ended problems or scenarios that are relevant to the subject matter being taught (Chen, C.C. et al., 2021; Cone, N., 2014; Taub, M. et al., 2020). The problems are usually complex and require critical thinking to solve. Learning scenarios that encourage students to find solutions need to continue to be presented to generate high-level thinking abilities. This ability to think is a demand for education in the modern era which is filled with complex environmental and life problems to give birth to an adaptive and reflective generation (Ahdhianto et al., 2020; Gilewski et al., 2022; Lysaker, P.H. et al., 2020).

PjBL can train students to work in teams to analyze and understand problems. They identify what they already know, what they need to know, and potential approaches or strategies they can use to solve the problem. Students engage in independent research to gather information and knowledge related to the problem. They explore various sources such as textbooks, articles, websites, and expert opinions to gain a deeper understanding of the topic (Anazifa & Djukri, 2017; Fadilla N., et. al, 2021). Students collaborate in small groups to share their findings, insights, and ideas. They discuss different perspectives, challenge assumptions, and collectively brainstorm potential solutions or strategies. A facilitator, often a lecturer or instructor, guides the learning process by asking thought-provoking questions, providing feedback, and facilitating discussions. The facilitator's role is to support and guide students rather than provide direct answers.

PjBL can produce critical students through the application of their knowledge and critical thinking skills to propose solutions to problems. They develop hypotheses, test them, evaluate the results, and refine their solutions based on feedback and evidence. Throughout the PjBL process, students reflect on their learning experiences, challenges faced, and knowledge gained. They evaluate their problem-solving strategies, identify areas for improvement, and assess the effectiveness of their solutions. Problem-based learning promotes active learning, critical thinking, collaboration, and integration of knowledge from various disciplines. This encourages students to take ownership of their learning and develop valuable skills for real-world problem solving (Bernadetha Nadeak & Lamhot Naibaho, 2020; Bezanilla, M.J. et al. et al., 2019; Fitriani et al., 2019).

PjBL encourages students to reflect on the learning activities they have undergone. Reflection is an important component of PBL. Encourage students to reflect on their learning experiences, identify any misconceptions they may have, and explain how their understanding developed. Reflection helps students become aware of their own learning process and can encourage them to actively seek out and correct misunderstandings. (Gilewski et al., 2022; Kim, J.Y. & Lim, K.Y., 2019; Lysaker, P.H. et al., 2020) reported that PBL can help students develop metacognitive skills, which involve thinking about their own thoughts. Encourage them to reflect on their thought processes, monitor their understanding, and evaluate their learning strategies. Metacognition can help students identify and correct misconceptions by becoming aware of their own thinking patterns (Mitsea, E. et al., 2021).

Metacognitive reflection involves a person's ability to monitor and regulate their own understanding of subject matter. This includes awareness of what they understand correctly, what is still confusing, and how they can improve their understanding through appropriate strategies (Siagan, M.V. et al., 2019; Sutarto et al., 2022; Yuan, K. et al. ., 2020). (Kuvac, M.

& Koc, I., 2019) states that good metacognitive reflection can help identify misconceptions. By becoming aware of their own understanding, students are more likely to recognize discrepancies between their understanding and correct concepts. This can trigger awareness of existing misconceptions and encourage students to overcome them. (Butterfuss, R. & Kendeou, P., 2020; Pieschl, S. et al., 2021) report that strong metacognitive reflection can help overcome misconceptions. When students actively reflect on their understanding and realize the mistakes they made, they can use metacognitive strategies to change or correct their incorrect understanding. This involves careful self-monitoring, setting effective learning strategies, and using additional resources to correct misconceptions.

Bioethanol and Green Energy

Nature is a great source of energy that supports the proliferation of life on Earth. However, recently, humanity has understood the importance of preserving the energy sources available in nature that are susceptible to depletion. Recently, it has been well understood that the use of fossil fuels should be limited or the potential of other energy sources should be explored (Hunt et al., 2020; Khan, 2012; Schernikau & Smith, 2022). In this context, the concept of biofuels has emerged, which in pure form or as a mixture with petroleum products can achieve the above-mentioned objectives (Balat, 2008; Bhowmik et al., 2017; Qin et al., 2022). The potential of bioethanol as a future transportation fuel continues to be developed. Furthermore, the compatibility, advantages, and disadvantages of bioethanol as a fuel for internal combustion engines are also discussed.

Studies reveal that blending ethanol in gasoline or Motor Spirit (MS) improves important engine features such as octane number (up to 5–10%), compression ratio (up to 2%), combustion efficiency (up to 30%), and engine torque (up to 8 %) (Barua et al., 2023). The possibility of bioethanol production on a large scale has attracted global interest, and as a result, the concept of a 'biorefinery' has recently been proposed. The development of biorefineries with a 'zero-waste' approach is an important aspect for future global energy demand as well as the environment (Kamani, Eş, et al., 2019). The overall aim of this review is to analyze the potential of bioethanol as a sustainable Spirit Motor in the future (Shen, 2014). Green technology has emerged as a useful tool for producing clean fuels with the potential to minimize the impact of human activities on the environment. Currently, these fuels consist mainly of hydrocarbons obtained from crude oil. Over the last two decades, biomass has gained significant attention as a renewable feedstock for more sustainable biofuel production and has become a good candidate to replace fossil fuels. The main components of most available biomass are cellulose, hemicellulose, and lignin (Kamani, Eş, et al., 2019; Qin et al., 2022; Shen, 2014).

The bioethanol synthesis process from organic materials involves several main stages which include: pretreatment, hydrolysis, fermentation, and purification. Several stages are passed in the bioethanol synthesis process (Barua et al., 2023). First, the initial processing of the material is carried out before the bioethanol fermentation process. This process aims to change the structure of the lignocellulosic material to make it easier to hydrolyze. Pretreatment can be carried out by various methods, such as physical (grinding), chemical (using acids or bases), and biological (using enzymes or microorganisms) (Kamani, Es, et al., 2019). After pretreatment, lignocellulosic materials undergo hydrolysis to break down complex carbohydrate polymers (cellulose and hemicellulose) into simple sugars such as glucose and xylose. Hydrolysis can be carried out enzymatically using cellulase and hemicellulase enzymes, or chemically using strong acids (Mohd Yusoff et al., 2015).

(Kamani, Eş, et al., 2019; Mohd Yusoff et al., 2015) reported that the sugar produced from the hydrolysis process is then fermented by microorganisms (for example, Saccharomyces cerevisiae or Zymomonas mobilis) to produce ethanol. Fermentation conditions, such as pH, temperature, and nutrient concentration, are adjusted to be optimal for the growth of microorganisms and ethanol production. Ethanol produced from fermentation contains water and various contaminants. Therefore, a purification process is needed to obtain high purity ethanol. Distillation is a commonly used method to separate ethanol from a mixture of water and other contaminants

CONCLUSION

The STEM-PjBL learning model application has been able to foster students' system thinking. This is evident from the students' ability to connect seven interrelated variables in the synthesis and dehydration of bioethanol made from various organic materials. The research results showed that 35.2% of the students had high system thinking, 29% had medium system thinking, and 35.6% had low system thinking. These results illustrate that the STEM-PjBL model has great potential as a learning model that can train students' systematic thinking skills.

RECOMMENDATIONS

In the project design process, second and fourth-year students still need guidance and cannot be left entirely on their own. Students also need self-evaluation regarding the project activities they undertake to guide them and avoid misconceptions. It is advisable to conduct reflection at each stage of the project to achieve the desired outcomes.

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