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University Students' Understanding of Intermolecular Forces: A Comparison of First & Third-Year Students

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Abstract: The study aims to analyze chemistry education students' understanding of intermolecular forces more deeply in 2021 (third-year) and 2023 (first-year). This type of research is descriptive research, and the technique used to collect data is a test and interview. Students encountered difficulties connecting types of Intermolecular Forces (IMFs) and molecular examples. Students' understanding of hydrogen bonding is higher than that of dipole-dipole, induced dipole, and London (dispersion) forces. This study implies that third-year chemistry education students demonstrated superior mastery of intermolecular forces than first-year students.
Keywords: Comparison of students' understanding, chemistry teaching, chemistry teaching

INTRODUCTION

Intermolecular forces (IMFs) comprise atoms, ions, and molecules that interact, and there are representations of phenomena at the macroscopic, symbolic, and microscopic levels (Johnstone, 1991). Intermolecular interaction is the most crucial concept for chemistry education students, particularly those taking general chemistry (Baldock et al., 2021), to understand and even predict the physical properties of macroscopic systems. The difference in boiling point and melting point of substances results from this difference. The path that connects the molecular structure to the properties of a substance requires a long chain of inferences. Ideally, a student should be able to construct and then use the structure (by understanding that the shape and distribution of electrons in the molecule determine the molecule's polarity) to make inferences about the interactions between molecules (intermolecular forces) that govern physical and chemical properties (Cooper et al., 2015) to intermolecular forces encompass concepts involving representative phenomena at macroscopic, symbolic, and microscopic levels. A comprehensive understanding of any chemical topic relies on students' ability to integrate these three interconnected levels, which can be illustrated in the form of a triangle.

Understanding chemical concepts is part of the results of the chemistry learning process. In addition, as the center of science, concepts in chemistry are the basis for the development of science, technology, and industry. Based on previous research, misconceptions experienced by students occur in several chemical concepts, including the concept of forces between molecules. Cooper et al. (2015) found that the first and second years of general chemistry showed surprising results; namely, 55% of students stated that intermolecular forces occur within molecules. Only 10-30% of students understand that intermolecular forces occur between molecules. Even more surprising is that 59% of students must consistently state that intermolecular forces are within or between forces. Another study also found the same misconception that intermolecular forces occur within molecules. Students assume hydrogen bonds involve hydrogen atoms, occurring when a C atom binds to an H atom in the molecule.

Misconceptions about intermolecular forces also occurred among chemistry education students at one of the universities in Malang in 2021 (third-year) and 2023 (first-year). This is evidenced by the question regarding the comparison between two compounds that have the highest boiling point, where students are asked to explain the differences in the factors that affect the boiling point, such as the functional group factor (Hydrogen Bond), Molar mass factor (Van der Waals Dispersion Force), steric factor (Van der Waals Dispersion Force), polarity factor (Van der Waals Dipole-Dipole Force), atomic size factor (Van der Waals Dispersion Force). From the results of interviews, some students still have difficulty understanding the concept of intermolecular forces. From these problems, the topic of chemistry education students' understanding of intermolecular forces in 2021 (third-year) and 2023 (first-year) needs to be analyzed more deeply. Through this research, it is hoped that it can be known to what extent chemistry education students understand the concept of intermolecular forces.

This study aimed to determine the levels of understanding and misconception experienced by chemistry education students about intermolecular forces. Most students still did not have a coherent and stable understanding of intermolecular forces as interactions between molecules. The same thing was also reported by Schmidt et al. (2009), who concluded that misconceptions often occurred about intermolecular forces and that students' understanding of intermolecular forces was insufficient. Taagepera & Noori (2000) also noted students' misconceptions about the physical properties of organic compounds topic. From such reality, it is possible that the prospective chemistry teachers also face difficulty and even experience misconceptions about the concept, even though the concept has been delivered during Senior High School and in Basic Chemistry courses.

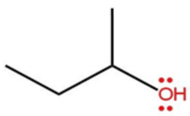
METHOD

This descriptive research aims to describe the ability of first-year (2021) and third-year (2023) students to understand and solve problems with intermolecular forces. This study used short-answer and multiple-choice questions and interview techniques to collect data. It involved 20 Chemistry Education students at a public university in East Java, with 10 students for each cohort. The test is used to determine chemistry students' understanding of intermolecular forces, while interviews validate the answers written by students on the answer sheet. The interview results confirmed students' knowledge of the intermolecular forces from the written test.

Instrument

The questions in the test are divided into two parts, part A and part B. The inquiries in part A were created separately, while part B was adopted from Musawwa et al. (2018). Questions 1-5 in part A required students to identify boiling points from the molecules' examples. In part B, students were asked to determine the type of IMFs from the examples of the molecules.

Table 1. Question in part A

No.	Questions
1.	Which compound has the highest boiling point? A.  B. 
2.	Which compound has the highest boiling point? A.  B. 
3.	Which compound has the highest boiling point? A.  B. 
4.	Which compound has the highest boiling point? A. CH_4 B. $CHCl_3$
5.	Which compound has the highest boiling point? A. Br_2 B. I_2

Students group answers based on the answer choices for each question number. After grouping, the total number of answers for each question is calculated for each question with a variety of answer choices. Analysis of a combination of students' correct answers will show students' understanding of intermolecular forces. Meanwhile, analysis of a combination of wrong answers will provide data about where students made mistakes in understanding the material on intermolecular forces. A multiple-choice test was applied to determine the levels of understanding and misconception of prospective chemistry teachers related to the concept of intermolecular forces.

Table 2. Question in part B

No.	Questions
1.	Which interactions might occur between two chloromethanes? [A] London dispersion force [B] Dipole-induced dipole [C] Momentary dipole-induced dipole [D] Dipole-dipole [E] Hydrogen bond
2.	Which interactions might occur between I_2 and other polar molecules? [A] London dispersion force [B] Momentary dipole-induced dipole. [C] Dipole – dipole [D] Hydrogen bond. [E] A and B correct
3.	Which interactions might occur between dichloromethane and chloromethane? [A] London dispersion force [B] Dipole-induced dipole [C] Dipole – dipole [D] Hydrogen bond [E] A and B correct
4.	What interactions occur between molecules (F_2) composed of atoms with high electronegativity (F)? [A] London dispersion force [B] Dipole-induced dipole [C] Dipole – dipole [D] Hydrogen bond [E] Covalent bond
5.	What interactions occur when Cl_2 has dissolved in chloromethane solution? [A] London dispersion force [B] Dipole-induced dipole [C] Dipole – dipole [D] Hydrogen bond [E] Covalent bond
6.	Which interactions might occur between H_2O and HF? [A] London dispersion force [B] Dipole-induced dipole [C] Dipole – dipole [D] Hydrogen bond [E] Covalent bond
7.	What interactions occur between methane containing H atoms [A] London dispersion force [B] Dipole-induced dipole [C] Dipole-dipole [D] Hydrogen bond [E] Covalent bond
8.	In which of the following compound(s) is hydrogen bonding likely to occur between the same molecules? [A] CH_4 [B] $CHCl_3$ [C] CH_3F [D] CH_3OH [E] H_2
9.	Which hydrogen bond is the strongest? [A] H_2O – HF [B] H_2O – H_2O [C] HCl – HBr [D] HF – HCl [E] H_2 – H_2O
10.	Which molecular forces below are the strongest? [A] CH_3Cl – I_2 [B] F_2 – F_2 [C] $CHCl_3$ – CF_4 [D] CH_4 – H_2O [E] CH_3OH – H_2O

RESULTS AND DISCUSSION

The purpose of question 1 is to determine the understanding of chemistry education first-year and third-year students regarding the influence of functional groups on boiling points. It was found that third-year students could understand the problems better than first-year students. This is proven by 100% of third-year students who answered correctly, while only 50% of first-year students answered correctly. Some first-year students seem unaware that a functional group can affect a molecule's boiling point. Different functional groups with the same carbon atoms will have different boiling points. The correct concept is that "the boiling point of alcohol is higher than ether due to the presence of hydrogen bonds, which results in the strength of the force between alcohol molecules higher than ether, which only has a dipole-dipole force and London force."

The purpose of question number 2 is to determine students' understanding of the effect of carbon chain length on boiling point. Again, 100% of third-year students answered correctly, with only 50% for first-year students. Several first-year students assume that the most volatile compounds are the compounds with the highest boiling points and molar masses. They incorrectly believed that the higher the hydrocarbon compound's molar mass, the lower its boiling point was due to the weaker the bonds between hydrocarbon molecules compounds and their nonpolar character. They failed to recognize that the van der Waals forces exist in non-polar molecules. The knowledge of third-year students for the first two questions is classified as very high, while first-year students are classified as intermediate.

The aim of question number 3 is to determine the student's understanding of the influence of steric effects/number of branches on carbon chains with the same functional group on boiling point. 70% of third-year students answered the question correctly, while only 20% of first-year students. In this question, the level of understanding of third-year students is relatively high, while that of first-year students is relatively low. They failed to realize that the size of the iodine atom is greater than the bromine atom, so the valence electron in the iodine atom is weakly bound by the nucleus more than the bromine atom. Hence, iodine atoms are more easily polarized.

Question 4's purpose is to determine the students' understanding of the effect of molecular weight on boiling point. Eighty percent of third-year students answered the question correctly, while 40 percent of first-year students were relatively intermediate. Question number 5 shows a dipole-induced dipole interaction between the polar molecule chloromethane and the nonpolar molecule Cl_2. The percentage of correct answers is 20% from the first year, which shows the level of student understanding at the low level, and 50% from the third year, which shows the level of student understanding at the intermediate level. In number 6, the interaction formed between H_2O and HF is hydrogen interaction. The electronegative atoms and the visible H atoms in both molecules indicate the two molecules' propensity to form hydrogen bonds. A hydrogen interaction or bond is a primary attraction between hydrogen (H) atoms that bond covalently to a more electronegative atom or group (DeFever et al., 2015). The student understanding of this problem reached 70% from the first year, which means their understanding was high, and a score of 100% or perfect from the third year, which means their understanding was very high. In question number 7, the interaction between the methane molecules is London dispersion forces because methane is a nonpolar molecule. The correctness of the answer in number 7 is quite low, 20% from first-year students and intermediate, 50% from third-year students.

Another type of question (part B) that emphasizes students to predict molecular examples of the IMFs is correctly demonstrated by 63.33% of third-year students and 33.33% of first-year students. The elevated percentage of successful third-year students responding to the questions is unsurprising, given the number of courses they have completed. The result of this study also implies the necessity to consider how we represent chemical phenomena to students. The representations provided to pupils influence the characteristics highlighted to them and the probability that they will make accurate predictions about chemical properties (Farheen & Lewis, 2021; Nelsen et al., 2024).

CONCLUSIONS

This study found that third-year chemistry education students demonstrated a better mastery of intermolecular forces than first-year students. This phenomenon is understandable because they have completed more chemistry courses. Further studies to deeply uncover students' understanding of intermolecular forces should be carried out from another perspective published by previous researchers, such as tactile models (Bromfield Lee & Beggs, 2021), visual representations (Patron et al., 2021) and other forms of instruments.

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Women in Chemistry: Exploring Their Contributions to the Development of Chemical Science

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Abstract: The role of women in chemistry has undergone significant changes throughout history despite facing various social and cultural challenges. In the past, men dominated chemistry, and female scientists' contributions were often overlooked or minimized. However, over time, women have increasingly demonstrated their outstanding contributions to the development of chemistry. Names like Marie Curie, who won two Nobels in physics and chemistry, and Rosalind Franklin, who was instrumental in the discovery of the structure of DNA, are undeniable proof that women have a crucial role to play in the advancement of chemistry. However, gender stereotypes and social norms often limit women's career options in science, and the influence of an academic environment that does not always support gender equality hinders their potential to develop fully. In addition, women are often faced with dual challenges, such as the double burden of managing a scientific career and family responsibilities. Based on these challenges, developing more inclusive and supportive policies and strategies is imperative to enable more women to engage in chemistry. In addition, creating a flexible work environment that prioritizes work-life balance will help reduce barriers for women in developing a career in chemistry. This research aims to trace the long journey of women in chemistry, identify the obstacles they face, and explore solutions and steps that can be taken to realize gender equality in this field. With these steps, it can be ensured that the full potential of women in chemistry can be realized so that they can contribute to advancing global science and technology more broadly.

Keywords: Chemistry, Contribution, Women

INTRODUCTION

Chemistry is one of the branches of natural science that has played a vital role in understanding natural phenomena and creating solutions to various global challenges. Over time, chemistry developments have broadened our horizons about matter and its reactions and provided the basis for innovations in areas such as health, energy, the environment, and materials technology. However, suppose you trace the history of the development of this science. In that case, the narrative of women's contributions is often on the periphery or even neglected, even though they have made no less essential contributions than their male counterparts (Rossiter, 1993).

One example of a monumental contribution comes from Marie Curie, the first woman to receive the Nobel Prize and the only one to win the Nobel Prize in two different fields, physics and chemistry. Her work on radioactivity paved the way for research in the nuclear and medical fields (Curie, 1904). On the other hand, Rosalind Franklin became a key figure in unraveling the structure of DNA, although recognition of her contribution only came years after her death (Mielczarek, 2006). Not only them, but many other female chemists, such as Dorothy Hodgkin's contributions to protein crystallography have also changed how we understand molecular processes (Hodgkin, 1965).

Unfortunately, women's contributions to chemistry often face various structural and cultural barriers. Gender discrimination, limited access to education, and minimal recognition of their work are challenges faced throughout history (Rossiter, 1993). Even in the modern era, despite increasing awareness of the importance of diversity and inclusiveness, women still face challenges in obtaining equal representation in the fields of science, technology, engineering, and mathematics (STEM).

This article aims to explore the contributions of female chemists to the development of chemistry, focusing on their achievements, scientific impact, and challenges. In addition, this research will also explore how their roles can inspire the younger generation, especially women, to engage in science. By highlighting their contributions and struggles, this article not only appreciates the role of women in the history of chemistry but also encourages society to continue to support diversity and gender equality in the world of science.

METHOD

This research uses a *literature* study method (*Library Research*) with the SALSA procedure (*Search, Appraisal, Synthesis, and Analysis*). This method was chosen because it allows researchers to collect and review relevant information from various previously published sources to provide a comprehensive overview of the topic under study. The first stage in this procedure, namely *Search*, was to search for related articles using keywords such as "Women in Chemistry" and "Contributions of Women to Chemistry" through academic databases such as Google Scholar, Scopus, etc. After the literature data is collected, the next step is carried out, namely *Appraisal*. At this stage, the journal's reputation, validity, and relevance of the articles obtained were assessed. This assessment aims to ensure that the literature used in the research is of good quality and has strong relevance to the topic discussed. The next stage is *Synthesis*. This stage is done by organizing the information that has been found into a more structured form so that it can be identified from the reputation of the journal obtained to some crucial things in the article such as the name of the person discussed, his contribution, significance, to the conclusion of the article. The last stage is *analysis*. This stage is done by identifying the content of the information that has been compiled previously. This stage functions in making firm conclusions, providing new views, and supporting the main arguments in the article to be made. This identification aims to make the article capable of providing a clear and complete understanding of the topic being discussed.

RESULTS AND DISCUSSION

The first woman elected a Fellow of the Royal Society provides a comprehensive overview of the life and scientific achievements of Dame Kathleen Lonsdale FRS (1903-1971), a leading crystallographer. Lonsdale made significant contributions to the analysis of crystal structures, mainly using X-ray crystallography. She was instrumental in confirming the planar structure of benzene, which had a broad impact on organic chemistry. He discussed his advances in crystallography, especially methods of analyzing organic compounds and molecular structures in depth. In addition to her scientific contributions, Lonsdale was a leading figure in promoting women in science and as a peace activist, serving as a role model for the next generation of female scientists. Her work was honored with numerous awards and recognitions, including being named *Dame Commander of the British Empire* and a rare hexagonal diamond named Lonsdaleite named after her. Kathleen Lonsdale demonstrates her scientific brilliance and her dedication to social issues. It is an essential resource for understanding the historical development of crystallography and the role of women in science in the early 20th century (Wilson, 2021).

Her contribution to radiology and the development of radiotherapy, especially in applying radiation for cancer treatment, made Marie Curie famous in this field. In addition, Marie Curie is also renowned in the field of chemistry, especially for her discovery of radioactive elements such as radium and polonium, as well as her intensive research into the chemical properties of radiation. She even received the Nobel Prize in Chemistry in 1911 for contributing to the isolation of pure radium, cementing her position as a pioneer in radioactive chemistry. In addition to receiving two Nobel Prizes in Physics and Chemistry, Curie became essential in opening up opportunities for women in previously male-dominated fields of science. Marie Curie also contributed to the establishment of Radium in Paris, which later became the center of radiation research and treatment of cancer. In addition, her efforts in World War I introduced a mobile radiography unit to help treat wounded soldiers, eventually training more than 150 radiologists. Her achievements have made her a role model for future female scientists, particularly in radiobiology and radiotherapy (Gasinska, 2016).

In addition, one of the female luminaries in the field of chemistry is Professor Malika Jeffries-EL, a chemist and professor at Boston University known for her innovative research in developing organic semiconductors. With more than 50 peer-reviewed publications and over 200 conference presentations, Jeffries-EL not only contributes to scientific advancement but also plays an active role in promoting diversity in science. Professor Malika Jeffries-EL is a *Fellow of the American Chemical Society* and *the Royal Society of Chemistry and* the recipient of numerous awards recognizing her efforts in increasing the participation of women scientists and marginalized groups in the chemical sciences. The role of women in chemical science is not only limited to research but also includes teaching and advocacy. Professor Jeffries-EL, for example, is committed to encouraging students from underrepresented groups to pursue STEM degrees. She is active in various professional organizations and has significantly supported women in science through mentoring and advocacy (Jeffries-el, 2024).

In the interview, Jeffries-EL emphasized the importance of creating support networks for women starting their careers in chemical research, including finding mentors and sponsors who can help them develop professionally. In addition, the challenges women face in this field are often related to the *systematic* bias that still exists in the scientific community. Jeffries-EL underscores the need for awareness of this bias and encourages institutions to provide bias training to reviewers and conference organizers. With these actions, it is hoped that a more inclusive environment will be created for women scientists to shine and contribute to their full potential. Overall, the contribution of women in chemistry is significant and growing. With figures like Professor Malika Jeffries-EL leading the way, the future of the field promises more innovation and diversity. Women serve as researchers, educators, mentors, and advocates, shaping the next generation of scientists and ensuring that their voices are heard in every aspect of chemistry research (Jeffries-el, 2024).

Rosalind Franklin made an essential contribution to understanding the structure of DNA through her meticulous X-ray fractionation technique. Through careful experimentation, Franklin managed to photograph DNA in two forms, namely form A (drier) and form B (wetter). Her diffraction photography, especially Photo 51, became the key for James Watson and Francis Crick to determine the double helix structure of DNA. Her findings cleared up the confusion in previous X-ray diffraction observations that showed a mixture of A and B forms of DNA. In addition, Franklin was the first scientist to provide accurate measurements for the diameter of the helix, the number of bases per turn of the helix, and the antiparallel orientation of the DNA strand, which was the foundation of Watson and Crick's DNA model. He conducted an in-depth analysis of the structure of DNA, discovering that DNA has a double helix shape with a backbone consisting of sugars and phosphates that protect the nitrogenous base pairs on the inside. Unfortunately, despite the importance of her data, Franklin did not receive the recognition she deserved during her lifetime, as she died several years before Watson, Crick, and Wilkins received the Nobel Prize in 1962 (Elkin, 2003).

Dorothy Mary Hodgkin is a British female chemist who contributed greatly to the field of science, especially in biochemistry and medicine. Dorothy Hodgkin is known as a scientist who succeeded in developing protein crystallography. Some of her influential discoveries in the field of science were the determination of the structure of penicillin that Ernst Boris Chain and Edward Abraham had previously researched and then the determination of the structure of vitamin B12, which earned her the Nobel Prize in Chemistry in 1964. In 1969, after 35 years of research and five years after receiving the Nobel Prize, Hodgkin could decipher the structure of insulin. He could interpret the structure of vitamin B12 and other complex molecules using X-rays, including penicillin and insulin. The structure of penicillin, for example, allows scientists to understand how antibiotics work to design new antibiotics that are more effective against bacterial infections. The same goes for insulin; understanding its structure allows further research into diabetes therapy, which is now an essential treatment for millions of people with diabetes (Butler, 2023).

Hodgkin was one of the pioneers in the field of modern structural biochemistry. Hodgkin studied the technique of X-ray crystallography, a method used to determine the three-dimensional structure of biomolecules. Hodgkin is one of the pioneers in the field of modern structural biochemistry. The X-ray crystallography technique he developed and perfected became the primary method for determining the structure of biological molecules. Today, this method is used to understand many essential molecules, including proteins and enzymes, which form the basis of a wide range of research in pharmaceuticals, medicine, and biotechnology. The X-ray crystallography method developed by Hodgkin is an advanced technology for analyzing complex molecules. This method is the basis for many modern research instruments, including drug and vaccine research. This technology has even been further developed with methods such as cryo-electron microscopy (Butler, 2023).

The next female chemist was Carolyn Bertozzi, a chemist who contributed to the creation and development of bioorthogonal chemistry and its application to understanding the role of carbohydrates in biology. Carolyn created the Staudinger ligation and the concept of azide as a strong functional group for bioorthogonal chemistry. Carolyn's development of bioorthogonal chemistry can overcome the significant challenge of applying chemical reactions in biological environments, which is generally difficult due to various reactive groups in cells. In the study of glycans, this innovation enables direct detection and manipulation of glycans in living cells, which was previously difficult. In addition, Carolyn's technique also opens up opportunities for new glycan-based therapies, especially in the treatment of intractable cancers. The technology also enables molecular labeling with high specificity, potentially improving therapeutic efficacy. In addition, Carolyn and her trainees have applied this technique to glycoscience to identify and visualize glycans on living cells and support the development of chemical synthesis methods for glycoproteins and other related molecules (Kramer et al., 2023).

Asima Chatterjee, an Indian organic chemist, is recognized for her contributions to organic compounds and medicinal plant chemistry research, especially in alkaloids and plant-derived bioactive compounds. Chatterjee conducted in-depth research on alkaloids, which are organic nitrogen compounds found in many plants and have many medical benefits. He successfully isolated and understood the chemical structures of alkaloids from several medicinal plants common in India. His research laid the foundation for developing new medicines derived from natural materials. One of his most remarkable contributions was his research on developing anti-malarial compounds. Chatterjee researched plants native to India to find compounds effective against malaria, a widespread tropical disease. This discovery was crucial as it helped develop safer and more effective anti-malarial drugs. Her research also laid the foundation for further exploration of the potential of plants in medicine and provided great inspiration for women scientists. In addition to her scientific contributions, Chatterjee was a professor and mentor to many students, especially in India. Chatterjee became a pioneer in natural product chemistry in India. Her research encouraged the continued study of chemical compounds from traditional Indian plants, which later became the foundation for much research in pharmacology and medicinal chemistry in India and the world (De, 2015).

Professor Tricia Breen Carmichael is an influential female scientist in nanotechnology and modern electronic materials. With a Doctor of Philosophy (Ph.D.) from the University of Windsor in 1996, she continued her academic career through post-doctoral research at MIT and Harvard University, two of the world's leading institutions. Professor Carmichael's career took off when he joined the IBM TJ Watson Research Center, where he focused on developing organic electronics, a rapidly emerging field.

His research has led to significant innovations such as novel electronic textiles, wearable electroluminescent fabrics, and soft, stretchable light-emitting devices. One of his most outstanding achievements was the development of the first transparent butyl rubber for next-generation devices (Carmichael, 1996).

Currently, Professor Carmichael leads an interdisciplinary research program on stretchable and wearable electronic devices. He is also actively promoting equality, diversity, and inclusion in academia as editor-in-chief of the Flexible and Printed Electronics journal and director of equality, diversity, and inclusion for the Canadian Chemical Society. Her dedication to EDI (Equality, Diversity, and Inclusion) has been recognized through numerous awards, including the Mary Lou Dietz Equity Leadership Award. Despite facing challenges as a woman in a male-dominated field of science, Professor Carmichael remains optimistic and hopes to create a more inclusive academic environment where the term "women in chemistry" is no longer relevant. Through her dedication to research that is relevant to the needs of society and her fight for gender equality in the world of science, she has become an inspirational figure to many. Therefore, Professor Tricia Breen Carmichael is a successful scientist and an ideal example of a leader committed to creating positive change in the global scientific community (Carmichael, 1996).

Dr. Ritika Gautam-Singh is a prominent chemical scientist in biological inorganic chemistry. She is an Assistant Professor at the Indian Institute of Technology (IIT) in Kanpur, India, where she leads research on metal-based drug development for medical therapy, synthetic immunotherapy, and diagnostics. His primary focus is on utilizing metal-ligand interactions to create molecules that can disrupt metal homeostasis in cells, which has great potential in addressing various diseases, including cancer, neurodegenerative disorders, microbial infections, and metabolic and autoimmune syndromes. His research combines coordination chemistry, proteomics, and metabolomics to create highly specific and compelling therapeutics (Kanpur, 2024).

Dr. Ritika did her undergraduate studies at Banaras Hindu University and IIT Delhi and continued her doctoral studies at the University of Arizona, USA. She was also a research fellow at The Scripps Research Institute California before returning to India in 2019 to form her research group. Her dedication is recognized globally, with awards such as Royal Society of Chemistry Emerging Investigator and American Chemical Society Rising Star in 2023. She was appointed Associate of the Indian Academy of Sciences in 2024. As one of the inspiring female figures in chemistry, Dr. Ritika drives scientific innovation and showcases women's vital role in advancing science globally (Kanpur, 2024).

The following female chemists are Helma Wennemers, Christina Moberg, and Luisa De Cola. They discuss the contribution of women in chemistry and portray the current state of gender equality in science, especially in STEM (Science, Technology, Engineering, and Mathematics). Although the contribution of women in chemistry is increasing, data shows that they are still underrepresented. Data from UNESCO shows that only 28% of researchers worldwide are women, with disparities across countries. Countries such as Germany and France have a relatively low number of female researchers compared to Eastern European countries such as Lithuania and Latvia, which have gender equality in research. In addition, there is a decline in the number of women in research careers. This phenomenon is called the '*leaky pipeline*' where women leave science careers after higher education, often due to a lack of career flexibility, particularly for those with family responsibilities (D'Andola, 2016).

In this regard, social media and support communities play an important role in helping women in science to share experiences and discuss gender issues despite the risk of attacks from "trolls" or gender-based harassment. Barriers that limit women to high-level careers in research should be removed to maximize potential for innovation and creativity. To increase the representation of women in science, efforts can be made, such as training and mentoring programs, supporting policies for researchers with families, and countering the gender bias within academia. Organizations such as the Athena SWAN Charter and the Daphne Jackson Trust are examples of initiatives supporting women in research (D'Andola, 2016).

CONCLUSIONS

Women have made significant contributions to the field of chemistry despite the social and cultural challenges they have faced. Figures such as Marie Curie, Rosalind Franklin, and other female scientists have played an essential role in the advancement of chemistry. Despite progress, there are still gender stereotypes and structural barriers that limit women's participation. Therefore, there is a need for more inclusive policies and supportive work environments to encourage more women to engage in science, and there is an importance of support and policies to increase women's representation in STEM fields.

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Profile of Junior High School Students' Problem-Solving Ability on The Topic of Human Relationship to Ecosystems Through The Role-playing Method

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Abstract: This research aims to elucidate the problem-solving capabilities of junior high school students about human relationships with ecosystems, particularly river ecosystems, utilising the role-playing method within a debate framework among represented professional groups. This study involved 25 seventh-grade students from an MTs Negeri in Malang Regency. Students were grouped to simulate various occupations, including physicians, government representatives, scientists, and environmental advocates. Data was gathered using LKPD responses, observation forms, and interview protocols. The data analysis indicates that the environmental volunteer profession group scored the highest on the LKPD, scoring 94. Additionally, as assessed by observation, the average percentage derived from the student problem-solving skill profile was 85%, categorised as very good. The interview results indicated that students responded positively to the learning activities.

Keywords: Role-playing method, problem Solving, River pollution

INTRODUCTION

Education in Indonesia is experiencing development in line with the changing times. 21st-century skills are one of the aspects of focus in learning using the Merdeka Curriculum, with the hope that they can equip students to face the challenges of the 21st century. The National Education Association (NEA, 2012) states that there are 18 21st-century skills that students need to master. Learning and innovation skills are one of the skills that encompass 4 aspects commonly known as the 4Cs: communication, collaboration, critical thinking, and creativity. One of the skills included in the essential thinking element is problem-solving ability (Partnership for 21st Century Learning, 2009).

Problems are conditions that can be experienced by someone anytime and anywhere in their life. Therefore, it is important to master problem-solving skills to help overcome challenges. Problem-solving ability is the student's capacity to seek solutions to a problem based on their knowledge, understanding, and abilities (Koswara et al., 2019). Problem-solving activities are a process that requires logical thinking to find a solution to a problem. Students can solve problems by applying their knowledge in new situations. According to Polya (1957), problem-solving ability consists of 4 stages, namely: (1) Understand the Problem, (2) Device a Plan, (3) Carry Out the Plan, (4) Look Back. Problem-solving ability has the following criteria: understanding the problem, planning problem-solving strategies, implementing problem-solving strategies, analysing results, and concluding problem-solving (Runi, 2021). Several factors that influence problem-solving ability include the environment, learning media, learning strategies, critical thinking, the material presented, the complexity of the material, students' initial abilities, and motivation (Vega Artinta et al., 2021).

The 2022 PISA report shows Indonesia has an average science proficiency score of 383. The average science proficiency score remains low (OCDE, 2023). The research conducted by Ermawan & Fauziah (2023) regarding students' problem-solving abilities in science subjects found that students' problem-solving skills are still low. This result was obtained because students were not yet able to understand the given problems, making it difficult to plan and determine solutions to the problems. In addition, the low problem-solving abilities of students may also be due to the use of conventional teaching methods and lectures that still dominate science instruction in the classroom, making students less trained to face complex and diverse problems (Monika et al., 2022). Therefore, innovation in science education is urgently needed to improve students' problem-solving skills, which are still low.

Students' low problem-solving skills can be improved using the role-playing method (Runi, 2021). Role-playing is a learning method that conditions students to participate directly in the learning process and serves as a tool to understand other people's perspectives (Lewin, 1948). The role-playing method's benefits are that students gain different learning experiences and a new learning atmosphere. It also makes students more active and think creatively (Iftita et al., 2023). Role-playing can be used in the classroom in many ways. This method can enhance the efficiency of academic learning by depicting current events or social conditions (Chesler & Fox, 1966). Some skills and abilities that can be developed through role-playing include self-confidence, teamwork, a sense of responsibility and leadership in learning, peer learning/teaching, and creative problem-solving, which would be difficult to develop if only using conventional learning methods (Craciun, 2010).

The role-playing method has proven effective in achieving learning outcomes in three main aspects of learning: affective, cognitive, and behavioural. Learning by placing students in specific roles can train empathy and perspective-taking. Research (Acharya et al., 2019) shows that applying the role-playing method is more effective than learning with conventional methods. Several studies have reported that role-playing positively impacts student learning; the role-playing method allows students to gain a deeper understanding of an issue. Several studies have found that role-playing games significantly impact student learning; the role-playing method allows students to obtain a deeper grasp of a topic and encourages their interest in studying the problem further (Hidayati & Pardjono, 2018). The employment of role-playing strategies might strengthen students' problem-solving abilities, especially on the link between living things and their surroundings (Ismawati et al., 2016). The application of the role-playing method in school learning activities should be linked to events or difficulties around the pupils (Iftita et al., 2023). The issue of environmental contamination is related to occurrences and natural symptoms that can arise owing to numerous factors. Problems relating to environmental contamination can readily be noticed around the pupils. For example, home, agricultural, and industrial waste are disposed of in waterways (Rahayu et al., 2021).

Based on the explanation above, the author is encouraged to examine how the problem-solving abilities of students in science disciplines, mainly connected to the issue of river pollution, utilise the role-playing learning technique. This study intends to describe students' problem-solving abilities and answers after participating in learning activities using the role-playing method on the link between humans and ecosystems sub-topic.

METHOD

This descriptive research occurred at a public Islamic junior high school in Malang Regency in the second term of the 2023/2024 academic year. This study involved 25 seventh-grade students. The study commences with developing instruments designed to assess students' problem-solving abilities, encompassing instructional modules, student worksheets, and observation sheets. Before utilising the research instruments, they are validated by specialist faculty members at the university. Furthermore, an interview guideline is employed to assess students' responses following their engagement in learning through the role-playing method. The specifics of the research instruments used are presented in Table 1.

Table 1. Research Instruments

Research objective	Instrument	Data	Participant
Students' problem-solving abilities profile	Students' worksheet (LKPD)	1) Problem topic 2) Response regarding the problem 3) Causes of the problems 4) Preventive measures that can be taken 5) Preventive measures that can be taken by collaborating with other professions 6) Conclusion of the discussed issue	25 students
	Observation sheet	Observation sheets are assessed using a Likert scale and problem-solving indicators: 1) Understanding of the problem 2) Problem analysis 3) Solution planning 4) Execution of solution 5) Conclusion and reflection	4 observers
Students' responses	Interview guidelines	Interview questions: 1) Students feelings 2) Students' confidence before participating in learning activities using the role-playing method 3) Students' self-confidence after participating in learning activities using the role-playing method 4) The difficulties experienced by students during the learning activities using the role-playing method 5) Suggestions related to the learning that has been conducted	4 students

The implementation of learning to assess students' problem-solving abilities using the role-playing method is divided into two sessions with procedures. During the learning process, both in the first and second meetings, 4 observers attended to collect observational data on students' problem-solving abilities. The role-playing learning with a debate scenario was conducted following the procedure outlined in Table 2.

Table 2. Role Playing Procedures for Meeting 2

No.	Activities
1.	Students alternately present the topic of the issues discussed based on the images presented in the LKPD.
2.	The student conveyed their group's response regarding the topic discussed.
3.	The student presented the group's argument regarding the causes of river pollution issues.
3.	The student presented the group's argument regarding the causes of river pollution issues.
4.	The student presented their group's arguments regarding preventive measures that can be taken to address the issue of river pollution.
5.	The student presented their group's argument regarding preventive measures that can be taken by collaborating with other professions.
6.	The student presented the group's argument regarding the conclusion of the discussed environmental pollution issue.

Indicators of problem-solving ability include understanding the problem, analysing the problem, planning the solution, implementing the solution, drawing conclusions, and reflecting (Polya, 1957). The formula used to calculate the level of achievement in students' problem-solving abilities is as follows (Yuanari, 2011).

$$Score = \frac{Obtained\ score}{Maximum\ score} \times 100$$

The results of calculating students' problem-solving ability scores are then classified as problem-solving ability according to (Bwefar et al., 2019).

Table 3. Problem-Solving abilities indicators

Indicators	Observation	LKPD
Problem understanding	2 statements	2 statements
Problem analysis	2 statements	1 statement
Solution planning	2 statements	1 statement
Execution of the solution	2 statements	1 statement
Conclusion and reflection	2 statements	2 statements

After conducting the learning activities, the data results from the LKPD are presented as percentages for each indicator in graphical form, and the answers to the LKPD completed by the students are transcribed. The interview results are transcribed and grouped based on the responses that emerged. Meanwhile, the data from the observation sheets are presented in tables based on each indicator's percentage results and then described. Data is analysed using triangulation techniques, which involve comparing research results from data collection that vary from the same data source or subject (Alfansyur & Mariyani, 2020). Data on students' problem-solving abilities were obtained from LKPD answers and observation sheets, which were then compared to determine the profile of students' problem-solving skills.

Table 4. Category of Problem-Solving Abilities

Interval	Criteria
81-100	Excellent
61-80	Good
41-60	Moderate
21-40	weak
0-20	Poor

RESULTS AND DISCUSSION

Description of Students' Problem-Solving Abilities

The profile of students' problem-solving abilities is reflected in the outcomes of their LKPD responses. The scores of the students' LKPD answers, completed in groups, are shown in Table 5.

Table 5. Students' LKPD Score

No.	Professional Role in Role-Playing	Score
1.	Doctor	93
2.	Scientist	91
3.	Government official	91
4.	Environmental volunteers	94

Based on the students' LKPD answers, it is known that the group of doctors received a score of 93, the group of scientists received a score of 91, the group of government officials received a score of 91, and the group of environmental volunteers received a score of 94. Based on the scores obtained, the problem-solving abilities of each group fall into the excellent category (Bwefar et al., 2019). Students can answer each question well. As an introduction, two images showing cause and effect are presented, from which it can be inferred that the topic to be discussed in the lesson using the role-playing method with a debate scenario is "The Impact of Humans on River Pollution." In the section on student responses related to the discussed issue, students were able to convey their group's response regarding the problem of river pollution. In the section on the causes of river pollution, students can clearly mention several activities that lead to river pollution. In questions related to prevention efforts to address river pollution issues from the perspective of the assigned profession, students can design prevention efforts that align with the assigned profession. Next, in the mitigation efforts that can be collaborated with other professions, students can design effective mitigation strategies. In the conclusion section, students can conclude the discussed topic of river pollution issues.

The students' problem-solving abilities can be observed through their responses in the LKPD. Although they answer the LKPD adequately, several points require further clarification. Answers related to the subject of the problem and the student's responses to it fall under the problem-solving indicator, which is understanding the issue. Through this indicator, it is anticipated that students will be able to articulate the presented problem and identify its key elements. Students are asked to ascertain the topic of the problem through two related images: one of a person throwing rubbish into a river and another of a polluted river. However, some groups do not concentrate on human influence but solely on river pollution. For instance, the response from the group of medical professionals is as follows:

"*Pollution of the river by garbage*"

Based on the answer above, it is evident that the students still struggle to comprehend the cause-and-effect relationship depicted in the image. In contrast, the more accurate response comes from the following group of scientists:

"*The impact of humans on river ecosystem pollution.*"

The answers above indicate that the group of medical professionals still cannot comprehend the presented problem, whereas the scientists already understand it. This aligns with research (Chiang & Lee, 2016), which suggests that low problem-solving ability in students may arise from not fully grasping the issue at hand. The limited capacity of students to understand a problem may stem from their insufficient conceptual understanding. Students often struggle with the fundamental concepts of the issues presented (Price et al., 2021). Furthermore, their low comprehension can also be attributed to a lack of attention to the problems presented (Tan et al., 2023). Students tend to be less meticulous in examining the relationship between the two images provided, often concentrating on only one, which results in inaccuracies in identifying the problem topic.

In the section on group responses to the issue, several similar answers were noted, primarily concerns regarding river pollution caused by humans dumping waste into the river. A notable response comes from a doctor:

"*River pollution is a serious problem that affects human health and the environment. In 2016, based on data from the Ministry of Environment and Forestry, out % of 140 rivers in 34 provinces, 73.24% were in a polluted status. The pollution of these rivers can affect water quality and impact public health.*"

Through the above answer, it is known that the ability of the medical profession group to understand issues is classified as good because they use data from polluted rivers and can see from the perspective of their profession, which is related to human health. Through the above answer, the ability of the medical professional group to understand the issues is excellent. This can be influenced by the group's understanding of the medical profession's role and the availability of sources or references related to the profession and the issues presented (Ermawan & Fauziah, 2023).

The next indicator of problem-solving ability is analysing the problem. This indicator can be seen through the students' group answers to the causes of river pollution problems. In this section, students can convey the causes of river pollution but have not yet approached it from the perspective of the portrayed profession. For example, in the following response from a scientist profession:

"*Because many residents throw waste into the river, it can cause floods, etc.*"

Based on this answer, the student's response has not yet adopted the viewpoint of a scientist. Scientists are expected to possess a broader knowledge base than the general public. When students can view the issue of river pollution from a scientific perspective, they can relate it to the inadequate waste management tools or technologies in Indonesia, which contributes to river pollution being a significant problem in the country. This may stem from students being less familiar with the roles of the professions being portrayed (Aura et al., 2023). Furthermore, monotonous learning and the limited availability of books make students accustomed to viewing problems in a general manner (Castro, 2023).

The next indicator of problem-solving is planning a solution. In this planning phase, students design solutions according to their profession. Students can devise preventive measures to address river pollution based on the responses gathered. Through the solution planning indicators, students' ability to create solutions relevant to the profession they are portraying is evident. Here is the answer from the group of scientists that aligns with the scientists' perspective.

"*Creating trash bins based on their types, creating nets provided around the river area, building channels for waste so that it does not mix with river water.*"

Based on the answer, it can be seen that students can design preventive measures from a scientific perspective related to developing and producing something. The preventive measure of creating nets around the river is a creative prevention effort that is still rarely applied in daily life. When asked why such an effort was being designed, the group of professional scientists argued that most people throw trash from above the river or bridge. Through the designed preventive measures, it is hoped that the waste thrown away will not fall into the river, thus preventing river pollution. Students can explain the reasons for creating detailed problem-solving solutions because the issues discussed are related to their daily lives, allowing them to plan preventive measures based on observed facts. (Chesler & Fox, 1966). The appropriate topic to be used in learning activities with the role-playing method is a topic that is related to or close to the student's daily lives.

The students' answers regarding preventive efforts that can be undertaken in collaboration with other professions aim to consider various possible solutions to address river pollution. Based on the students' answers, the group of doctors collaborates with the group of scientists, and the group of government professionals works with environmental volunteers. The collaboration formed is a variation and desire of the students themselves. Through this collaboration, new variations of preventive efforts emerged, carried out by government professionals working with volunteers as follows.

"*Agreeing with the government and volunteers to tackle river waste by directly engaging in the area to set an example for the community.*"

Based on that answer, it is known that the government profession wants to collaborate with environmental volunteers by directly participating in river cleaning activities to set an example for the community. After being asked further about the plan made, the students opined that the government should be able to set an example for its community. According to research (Permata & Sandri, 2020), group work is one factor that can support students' ability to plan a solution. Because the learning is conducted in groups and there is collaboration, students can plan diverse and creative solutions to problems.

The conclusion of the topic on the impact of humans on river pollution is that cooperation between various parties is necessary to address the issue of river pollution. All professional groups can conclude the discussed issue well. Students' problem-solving abilities can be classified as good if they can conclude the presented problems accurately (Rahmayani & Fadly, 2022). In this case, students can conclude that the issue of river pollution discussed requires cooperation among various parties to be resolved.

Students' problem-solving ability is evident in the learning process and outcomes. Based on the results obtained, it is known that the group of environmental volunteer professionals received the highest scores. This may be influenced by good cooperation among groups. The improvement in students' problem-solving skills will enhance their mindset. Thus, by using appropriate problem-solving skills, students can develop concrete and more apparent ideas. These skills help students face and simplify complex problems, making them easier to understand and solve (Pratiwi & Musdi, 2021). In the context of role-playing learning, most students can understand the presented problems. However, they are less accurate in designing problem-solving solutions and still find it challenging to solve problems according to their roles.

Based on the description related to student responses in the LKPD, it is known that the following factors influence students' problem-solving abilities using the role-playing method: 1) some groups are still unable to understand and solve the problem because they only pay attention to the problem in general; 2) some groups have difficulty finding information related to the profession they are portraying, making it hard to plan problem-solving solutions; 3) each group plans and implements problem-solving strategies by working together or discussing within the group to obtain more accurate answers; 4) cooperation between groups can influence students' problem-solving abilities.

Besides the LKPD answers, students' problem-solving abilities are assessed through observation sheets. Based on the percentage results of the observation sheet, it is known that the problem understanding indicator received a score of 91% with good criteria. On the problem analysis indicator, a score of 81% was achieved with good criteria. The solution planning indicator received a score of 87% with good criteria. The implementation solution indicator received a score of 84% with good criteria. Meanwhile, the conclusion and reflection indicator received a score of 81% with a good criterion. Observation of students' problem-solving abilities showed an average score of 85% with excellent criteria (Bwefar et al., 2019).

Through the results of the observation sheet above, it can be seen that students' problem-solving abilities fall into the excellent category, with the highest percentage on the problem-understanding indicator. In contrast, the lowest percentage is on the problem analysis, conclusion, and reflection indicators, which received the same percentage. The problem-understanding indicator, the basic indicator of problem-solving ability, is already good because it has received the highest percentage. Meanwhile, the problem planning indicator, which produced a low percentage, may be due to students being confused about making plans that align with their profession.

The conclusion and reflection indicators also received a low percentage, although still within the good category. In this section, students can draw good conclusions about the learning. However, the low percentage results were obtained from the observer's observations, with notes provided by the observer regarding the reflection section that has not been fully implemented. Thus, this can affect the percentage of the conclusion and reflection indicators. The reflection stage was not maximally implemented due to time constraints in the learning process. One of the drawbacks of the role-playing method is that it requires a considerable amount of learning time, which can affect the problem-solving stage that cannot be maximally completed (Sari et al., 2019).

The difference in LKPD answer results can be caused by varying levels of cooperation among group members. In group activities, the role of each group member is crucial to achieving optimal results (Wiria & Alberida, 2023). As seen from the learning process, students' problem-solving ability can be determined through observation sheets, with the observation results related to the student's self-confidence in presenting the answers they have written in the LKPD. Thus, even though the answers on the LKPD received good results, they were not conveyed well when observed. Based on the results of the LKPD answers and observation sheets, it is known that students' problem-solving abilities encompass all indicators and fall into the excellent category (Bwefar et al., 2019). Although it falls within the excellent category, the problem analysis and conclusion indicators received lower scores than the others. This is due to the student's lack of understanding of the presented problems or the lack of learning related to problem-solving, so the students are not yet accustomed to solving problems, especially environmental pollution issues. Both external and internal factors influence students' problem-solving abilities. These internal factors include the cognitive abilities and interests possessed by the students. At the same time, the external factors include the learning environment created, the motivation provided by teachers, and the models/methods of teaching used (Bhadargade et al., 2020).

Students Responses Regarding Learning Using the Role-Playing Method

Students' responses regarding the learning experiences obtained after participating in lessons using the role-playing method can be seen through the interview results presented in Table 6.

Table 6. Students Responses Recorded from The Interview

No.	Question	Answer
1.	Feelings after the learning	Happy, because they can express their opinion.
2.	The courage to express opinions before participating in learning activities using the role-playing method.	Lack of confidence in one's own opinion
3.	The courage to express opinions after participating in learning activities using role-playing.	It is more daring because it involves playing a profession in groups.
4.	Cooperation among group members	There are group members who did not participate in the group discussion.
5.	Difficulties during learning	Adjusting the answers to match the portrayed profession
6.	Suggestion	• The debate is conducted one by one. • Be more patient with friends. • Done in front of the class, not sitting.

Through the results of the interviews, it was found that the majority of students stated they enjoyed learning using the role-playing method because it allowed them to express their opinions in class, unlike learning with conventional methods, which made students less interested in voicing their opinions or asking questions during class. In line with the research (Khamouja et al., 2023), the role-playing method can encourage students to be more interested in learning activities. Additionally, students' confidence also increased compared to when using conventional teaching methods such as lectures. Based on the results of student interviews, students' confidence in expressing their opinions increased because they role-played a profession and learning was conducted in groups. Several studies state that role-playing can influence students' confidence in learning activities or expressing opinions during the classroom learning (Dohaney et al., 2018; Steube et al., 2024). Based on the results of student interviews, it was found that in each group, group members did not participate in the discussion, which could lead to less optimal answers (Fadillah, 2023). Although students responded positively to the learning that had been conducted, they expressed some difficulties during the learning activities using the role-playing method. Most students stated that the obstacles encountered during the learning process using the role-playing method were the difficulty in adjusting their answers to the portrayed profession. Additionally, students provided suggestions regarding the teaching methods that had been implemented.

The interview results show that students respond well to the learning process using the implemented role-playing method. It is evident from how the students answered the questions posed. In addition, students also stated that they enjoyed gaining experience through role-playing learning because it allowed them to solve problems from the perspective of other professions. In addition to problem-solving skills, students gain the courage to express their opinions after participating in role-playing learning, as in groups, making them feel more confident in expressing their views. The role-playing method is enjoyable engaging, and can foster student interaction. Through this method, the skills and abilities that can be developed include teamwork, leadership in the learning process, responsibility, peer learning/teaching, self-confidence, and creative problem-solving (Craciun, 2010). Although there are difficulties in role-playing activities, such as the adjustment between opinions and the professions portrayed by students, they can overcome these by effectively expressing their views and participating in the learning activities.

CONCLUSIONS

Based on the results obtained, it is known that the group of environmental volunteer professionals received the highest problem-solving ability score, 94. Meanwhile, the average observation result was 85%, an excellent category. Through interviews related to learning using role-playing, positive responses were received from students, indicating that the learning activities can help train students' problem-solving abilities and that students can see the efforts to solve a problem from the perspective of different people or professions. However, some group members did not participate in the group discussion. Based on the research, students' problem-solving abilities can be influenced by the teaching methods applied and cooperation in group activities. Therefore, students' problem-solving abilities in science education can be enhanced through role-playing methods, making learning activities more varied and creating new learning experiences for students.

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Learning Approach for Enhancing Students' Creativity

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Abstract: Creativity is an ability that students must have to face the challenges of the 21st century. In education, creativity is needed to help students understand abstract concepts, solve problems and create innovative ideas. This article aims to identify various effective learning approach strategies to stimulate students' creativity and create an inspiring and productive learning atmosphere. The Search, Appraisal, Synthesis and Analysis (SALSA) approach is used. The results show that several methods, such as mind mapping, Project-Based Learning (PjBL), critical thinking, and guided inquiry, positively impact student creativity. PjBL was considered the most effective of all the methods studied due to its holistic and contextual approach, providing meaningful and in-depth learning experiences. This study recommends the implementation of PjBL, supported by other strategies such as mind mapping, to create innovative learning relevant to students' needs.

Keywords: creativity; project-based learning; mind mapping; inquiry; critical thinking.

INTRODUCTION

Creativity is an individual's ability to use imagination and possibilities gained from interaction with ideas, other people and the environment to make new and meaningful connections and results. Once a person is faced with a game or problem that requires creative thinking to solve, the person cannot solve it because it only dwells on one way out, and then there is someone who can help him through a way that he did not think of (Bara, 2012). Education today emphasises the importance of creativity as one of the 21st-century skills. Students are not only required to master knowledge but also to think critically and creatively. Many conventional learning models focus more on direct teaching and memorisation, limiting the space for students to explore new ideas and think creatively. In the context of chemistry education, these barriers become more complex. Abstract chemistry concepts make students less motivated and can affect students' cognitive achievement. Chemistry is a science that seeks answers to the what, why, and how of natural phenomena related to composition, structure and properties, changes, and dynamics (Simatupang, 2021). Previous studies have shown that the lecture method still dominates classroom learning and can accommodate students' needs to think creatively and actively. As a result, many students find it challenging to understand the material, especially when learning is not connected to real-life contexts.

To overcome these problems, various innovative learning strategies have been developed. One of the most discussed methods is Project-Based Learning (PjBL), which has been proven effective in increasing student engagement and creativity. In addition, technologies such as augmented reality (AR) are also being integrated into learning to help students understand abstract concepts more visually and interactively. A diverse learning approach strategy can be an effective tool to enhance creativity. Through innovative and interactive methods, students are encouraged to think outside the box, explore new ideas and collaborate with their peers. Therefore, this article aims to identify various effective learning strategies to stimulate students' creativity and create an inspiring and productive learning atmosphere based on literature analysis from several related journals. By understanding and applying the right approaches, it is hoped that we can equip the younger generation with creative thinking skills that will be useful in their future lives.

METHOD

This research uses a systematic research method with the Search, Appraisal, Synthesis and Analysis (SALSA) approach (Grant & Booth, 2009). The research stages were carried out as follows:

Search

The literature search process was conducted through various academic databases, such as SINTA, Scopus, and Garuda, using keywords such as "creativity learning strategy" and "inquiry creativity development strategy". The search focused on Indonesian and English journal articles published between 2015-2024.

Appraisal

This process was conducted by applying inclusion and exclusion criteria. Selected articles focused on learning strategies, had clear research methods, addressed creativity development, and were published in accredited journals. Conversely, articles without full-text access, publications outside the timeframe, non-research articles, and sources with low methodological quality were excluded from the review.

Synthesis

This process includes mapping the main themes of learning strategies, identifying the characteristics of each approach, comparative analysis of creativity development strategies, and classification of methods based on creativity indicators.

Analysis

The analysis stage is the final stage, which includes narrative analysis of strategy comparison, critical interpretation of the effectiveness of each approach, identification of strengths and limitations, and synthesis of strategy development recommendations. Conclusions were drawn based on the available empirical evidence. The entire research process upholds the ethical principles of scientific publication by applying accurate citations, avoiding plagiarism, making objective interpretations, and respecting the work of previous researchers.

RESULTS AND DISCUSSION

Through a literature search, several learning models, including Project Based Learning (PjBL), Augmented Reality (AR), Problem-Based Learning (PBL), STEM-PjBL, Mind Mapping, and Cooperative Learning, increased student creativity. A summary of the articles is described in Table 1 below:

Table 1. Learning method analysis result

Author	Findings
(Fatmawati, F., et al. 2022)	The research method used in this study is Classroom Action Research (PTK), which aims to improve student learning creativity through the application of the Project Based Learning (PjBL) learning model. The results showed an increase of 14% from cycle I to cycle II, indicating that the application of the Project Learning (PjBL) learning model succeeded in increasing student learning creativity in class V SD Negeri 34/I Teratai.
(Setiawaty, S., et al. 2024)	The learning method is inquiry-based, where students go through several stages, such as observation, proposing problems, formulating hypotheses, and collecting and analysing data. Then, the Technology Acceptance Model (TAM) was used to evaluate students' acceptance of AR media. The results obtained by the average N-Gain of science process skills in the experimental class reached 0.57, higher than the control class, which only reached 0.40. The post-test score showed higher results in the experimental class (6.58) than in the control class (5.37), indicating that AR media effectively improves students' understanding of science skills.
(Rohani, A. 2023)	The research method used is standardised measurement through tests and questionnaires on students. Three tests were used: the critical thinking questionnaire, learning style inventory, and creativity test. The results showed that critical thinking has a significant positive relationship with creativity, where students who are better at critical thinking tend to be more creative.
(Purwati, P., et al. 2018)	The study used a quasi-experimental method conducted at the National Health Analyst Academy Surakarta using two regular classes B level 2. The average score for guided inquiry learning was higher than modified free inquiry. For students with high creativity, the average score for guided inquiry learning is 88, while in modified free inquiry, it is 82.
(Hidayah, N., et al. 2015)	The research method used was Classroom Action Research (PTK), which observed and analysed changes in learning activities, verbal creativity, and student learning outcomes in class X MIA C SMA Negeri 1 Kebumen in the 2013/2014 academic year. This study showed that guided inquiry learning assisted by LKS can increase student activity during the learning process. Student creativity in the high creativity category increased by 15% (from 48% to 63%).
(Lou, S. J., et al. 2017)	The research method used was a quasi-experimental design. The teaching experiment was conducted for six weeks, focusing on using project-based learning (PBL) integrated into STEM (science, technology, engineering and math) activities. The study's results were increased student creativity. Students showed a deeper understanding and application of STEM knowledge).
(Zakarya, et al. 2024)	The research method used was a qualitative approach with data collection techniques through observation, in-depth interviews, and document analysis. The results show that mind mapping enhances students' creativity through concept visualisation, problem-solving, and critical thinking skills development. Students who used mind mapping proved that it helps them organise ideas non-linearly and build associations between ideas that enrich their creativity.
(Aziz, R. et al. 2023)	This study involved quantitative and qualitative mixed methods, with a sequential explanatory approach conducted in two stages to examine the effect of classroom climate on student creativity. Regression analysis revealed that classroom activities influence students' creativity with R=0.532R=0.532R=0.532 and R2=0.283R^2=0.283R2=0.283 (p<0.001). This means that about 28.3% of the variation in students' creativity can be explained by classroom activities.
(MAN 3 Central Jakarta. 2023)	The research method used was an experiment with the Cooperative Learning model through a guided inquiry approach. The results showed that applying the Cooperative Learning model with a guided inquiry approach and applying the chemistry experiment method significantly improved students' interest, creativity, and understanding in learning redox reactions. The data obtained indicated that about 90.6% of students showed interest and felt helped by this method, with student creativity scores reaching an average of 95 for the resulting video project.

Various learning strategies can be applied to improve student creativity. One is the mind mapping method, where students are given space to think creatively and explore new ideas in a structured way that makes it easier to understand learning concepts. This mind mapping method has proven that students can better organise ideas non-linearly and build associations between ideas that enrich their creativity (Zakarya, Hafidz, Martaputu, 2022). This method focuses on understanding concepts and stimulates students' overall creative power. Designing mind maps allows students to utilise colours, images, and keywords to link ideas in unlimited ways.

The following method is project-based learning; students in one class are grouped to work on a project. Students must build their content knowledge and demonstrate new understandings through various forms of representation. Project-based learning can develop creativity by developing initiatives to produce new skills through research activities to work on and complete a learning project.

The application of the following learning method is inquiry-based with the media, augmented reality (AR), which effectively improves students' science process skills. The inquiry stages, such as observation, problem formulation, and data analysis, are combined with evaluating technology acceptance using the Technology Acceptance Model (TAM). The results showed that the average N-Gain of science process skills in the experimental class (0.57) was higher than that of the control class (0.40). In addition, the post-test score of the experimental class (6.58) was also higher than that of the control class (5.37), confirming that the use of AR was able to improve students' understanding of science skills significantly (Setiawaty et al., 2024).

The following method is critical thinking, which has a significant positive relationship with creativity. Students who are better at critical thinking tend to be more creative (Rohani, 2023). Critical thinking emphasises the importance of developing skills and providing opportunities for students to explore diverse learning styles to enhance their creativity and support more optimal learning outcomes.

Furthermore, the guided inquiry method and modified free inquiry method show that there is a significant influence between the use of guided inquiry methods and modified free inquiry methods on student creativity. Both contribute to improved learning outcomes. Based on the results of the Mann-Whitney test, it was found that learning with guided inquiry methods and modified free inquiry affected cognitive and affective learning outcomes but did not affect psychomotor learning outcomes. Quantitatively, cognitive learning outcomes show differences between the two methods. The average cognitive score for the guided inquiry class was 87.31 (Purwati et al., 2018), while the modified free inquiry class was 82.35, with a score distribution that tends to be better in the guided inquiry class at a high score interval (93-100) (Aziz et al., 2025).

Next is the guided inquiry learning model with LKS, which has been proven to increase student activities, creativity, and learning outcomes in the classroom. The quality and success of learning can be seen from students' activeness, creativity, and learning outcomes. Based on observations, questionnaires, and interviews in previous research, the inquiry learning model can increase student activity and creativity, improving learning outcomes, including knowledge, attitudes, and skills (Hidayah et al., 2015). This model is believed to be effective in overcoming the problem of chemistry learning in classrooms with low creativity, according to Barrow's research, (2010) (Barrow, 2010), which shows that the inquiry steps can inspire students to be more creative.

Then, the final research method is an experiment with a model of Cooperative Learning. This model significantly shows increased students' interest, creativity, and understanding in learning redox reactions. The data obtained indicated that around 90.6% of students showed interest and felt helped by this method, with students' creativity scores reaching an average of 95 for the resulting video project (MAN 3 Jakarta Pusat, 2023).

These learning methods can complement each other to create creative and productive learning. Just as mind mapping can help students design projects in PjBL or as a reflection tool in guided inquiry, critical thinking methods can be integrated into all methods to encourage students to explore different learning styles. However, of the above methods, the Project-Based Learning method has the most significant impact on increasing student creativity because this method provides an approach that combines the development of creativity with 21st-century skills such as collaboration, problem-solving, and critical thinking.

This PjBL method allows students to actively learn through authentic projects relevant to their lives actively, thereby increasing engagement and understanding of concepts. Additionally, PjBL encourages students to integrate theory with practice, allowing them to explore creative ideas while applying the knowledge they have learned. With a wide range of research supporting its effectiveness, PjBL enhances student creativity, creates more meaningful learning experiences, and broadly impacts learning outcomes.

Student creativity can increase from 63% to 81.8% through PjBL (Fatmawati et al, 2022). In addition, the STEM-PjBL model also significantly impacts students' understanding of concepts and critical thinking skills, as evidenced by the results of statistical tests. The average score on the "imagination" aspect increased from 26.68 to 28.28, and the "curiosity" score from 28.70 to 30.45 in the STEM-PjBL model (Lou et al., 2017).

This shows that PjBL can provide consistent results in various aspects of learning, including creativity. However, the challenges in PjBL are the need for more time, good group coordination, and a very strategic role of teachers as facilitators. Therefore, to maximise the impact of PjBL, teachers need to provide clear guidance, use tools such as mind mapping for planning, and integrate technologies such as augmented reality (AR) to help visualise complex concepts.

CONCLUSIONS

The most effective learning strategy to enhance students' creativity is Project- Based Learning (PjBL). Although various methods such as mind mapping, critical thinking, and guided inquiry also contribute positively to stimulating creativity, PjBL provides the most significant impact. This method combines creativity development with 21stcentury skills, such as collaboration, problem-solving, and critical thinking, allowing students to learn through real projects relevant to their lives. PjBL enriches students' learning experience by integrating theory and practice and increases engagement and deep understanding of concepts. Involving students in the project creation process gives them the space to explore creative ideas and solve real challenges, thus improving the overall quality of learning outcomes. Therefore, PjBL is proven to be a comprehensive and impactful learning approach that enhances students' creativity, creates a more meaningful learning experience, and supports achieving more optimal learning outcomes.

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Student Worksheet of Light and Optics for STEM-Based Problem-Based Learning: Critical Thinking Skills Perspective

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Abstract: This study investigates the effectiveness of student worksheets in an integrated Problem-Based Learning model using the STEM approach on light and optical materials towards improving the critical thinking skills of eighth-grade students of SMPN 1 Kepanjen. Student worksheets were developed using the 4D model of Thiagarajan (1974). This study was a pre-experimental design using a one-group pretest-posttest. The research instruments were critical thinking ability tests and questionnaires. The paired sample t-test results showed a significant difference in students' critical thinking skills before and after learning on the STEM-based Problem-Based Learning student worksheet. Supported by an N-Gain score of 48.14%, the developed students' worksheet effectively improves students' critical thinking skills.

Keywords: high level of thinking, media for STEM education, science teaching, innovative worksheet

INTRODUCTION

The world's science and technology are experiencing rapid progress in the fields of education, information, communication, economics, and technology (Redhana, 2019). That progress can have a positive impact on students. These advances help students overcome the challenges of 21st-century learning by recognising their critical and creative thinking, communication, collaboration, and scientific literacy skills (Miyarso, 2019). The transition from the national curriculum to the 2013 curriculum is one of Indonesia's efforts to prepare students for 21st-century learning.

Based on the results of the 2018 Program for International Student Assessment (PISA) survey initiated by the Organization for Economic Co-operation and Development (OECD) in March 2019, Indonesian students were ranked 72nd out of 78 countries, with an average score of 371 in literacy aspect and ranked 70th with an average score of 389 on the science aspect. The score of students in Indonesia is still relatively low compared to the OECD average of 487 in the literacy aspect and 489 in the science aspect (Schleicher, 2019). The literacy aspect shows the ability of students to build knowledge, think critically, and make the right decisions. The science aspect shows the ability of students to identify accurate explanations of known scientific phenomena, use that knowledge in identifying simple cases, and determine whether a conclusion is valid based on the data presented (Schleicher, 2019). PISA results show that students in Indonesia have lower critical thinking skills in both literacy and science aspects compared to countries that participate in PISA. This phenomena lead to a need for boostering students soft skills including creativity (Nafiah et al., 2025), problem solving (Rohmah et al., 2025) and others required skills.

Skills in investigation and problem-solving are still hampered in science learning. Emphasis on memorising concepts without involving students in the process of finding, understanding, and developing concepts is still carried out in science learning (Rahmawati et al., 2020). This causes low critical thinking skills in students. Students' critical thinking skills are considered important in order to clarify their understanding of the subject matter. Besides that, critical thinking skills will help students in social life and careers (Widodo, 2021). Students' critical thinking skills are the ability to solve students' problems through their knowledge and intellectual abilities. Critical thinking ability is the ability to solve problems sensibly according to logical steps, and the results of solving these problems are more efficient (Utami et al., 2017). Interviews with teachers of SMPN 1 Kepanjen show that students' critical thinking skills in science subjects, especially light and optics, are relatively low. This is supported by the large number of students with learning outcomes below the KKM. The method used to learn science is assignments and lectures. The teacher uses the learning model recommended in the 2013 curriculum, discovery learning. However, the model is not implemented optimally.

Students assume that learning science is difficult to understand. They also feel that the learning tools used are boring. The material in the book is conveyed to students without a search and investigation process, so it can only be remembered and memorized in the mind. This makes students feel not actively involved, so there is no interaction between teachers and students in learning. Besides that, learning is only focused on teachers, and students are not trained to think critically when finding and formulating something. Studies regarding the profile of Indonesian students' critical thinking is still unsatisfied (Dewi et al., 2020; Rahmadhani & Novita, 2018).

As stated above, one of the causes of the problem of learning science is the lack of appropriate learning tools. Student Worksheets can be a solution to improving students' critical thinking skills. A student worksheet is a collection of sheets containing the steps taken by students. Student worksheets are a form of teaching materials that complement or support the implementation of the Learning Plan (RPP) (Prastowo, 2014). Student worksheets serve as tools that make it easier for students and teachers during learning (Abdurrahman, 2015). The advantages of using worksheets for learning are that they increase efficiency and motivation, encourage active learning based on experience and are consistent with learner-centred learning (Ibrahim et al., 2017). Student worksheets, widely used by teachers, are still inadequate for building students' critical thinking skills. Besides, student worksheets do not emphasise the practical learning experience, so students are less motivated to learn. Other research Afiyanti et al. (2022) has found that using work-based chemical balance teaching materials and scientific approaches (BA-KK-KPI) can effectively improve student learning outcomes.

In this study, a student worksheet (LKPD) was developed based on Problem Based Learning (PBL) integrated in Science, Technology, Engineering, and Mathematics (STEM) as a means of improving students' critical thinking skills. Problem-Based Learning uses constructivist principles to encourage the application of prior knowledge, collaborative learning, and active engagement. The beginning of PBL activities is that a small group of students analyse problems, identify relevant facts, and apply knowledge and experience to solve problems (Seibert, 2021; Zhou, 2018). According to Arends, PBL steps are: (1) problem orientation; (2) organise students in learning; (3) independent or group investigations; (4) develop and produce works; and (5) analyze and evaluate problem-solving activities (Shofiyah & Wulandari, 2018). Problems in PBL activities must be problems or situations relevant to a particular activity that include missing information or unclear answers such as unstructured case studies (Miner-romanoff et al., 2019).

This PBL-based LKPD will be integrated with the STEM approach. The National Research Council explains aspects of STEM, namely: (1) Science is a unit of knowledge that is accumulated through scientific research processes that can produce new knowledge; (2) Technology consists of all systems of processes, people, knowledge, organizations, and devices that create and operate them; (3) Engineering is a collection of knowledge related to design and creation; (4) Mathematics is a field that examines patterns and relationships in quantities, numbers, and spaces and is used in science, engineering, and technology (Council, 2014).

STEM is an approach that links various fields of science. Science requires mathematics to process data, while technology and techniques are the application of knowledge about science (Afriana et al., 2016). STEM is an effective way of facilitating and maintaining the integration of science, technology, mathematics, and engineering (Estapa & Tank, 2017). In the context of STEM, PBL is very suitable as the main pedagogy for STEM learning (Odell et al., 2019). Efforts to improve students' soft skills is a need for science teaching in this era. In their review, Nafiah et al. (2025) suggested to emply project-based learning (PjBL) for improving students' creativity.

The results of the study prove that STEM-based teaching materials have an effective impact on student learning outcomes both in terms of knowledge, skills or attitudes (Izzah et al., 2021). In another study, PBL-based worksheets that are integrated with green chemistry and ethnoscience are useful for increasing students' thinking skills in three thinking domains, namely cognitive, psychomotor, and affective (Sudarmin et al., 2019). Besides that, in other studies regarding the application of the PBL model combined with STEM-based LKPD related to environmental pollution materials, it can improve students' critical thinking skills (Hasanah et al., 2021). Therefore, in order to improve students' critical thinking skills on light materials and optical instruments, it is necessary to develop a student worksheet with an integrated PBL model with a STEM approach.

METHOD

This type of research is a pre-experimental design and uses a one-group pretest-posttest. This design is designed to examine the impact on students' critical thinking skills when using STEM-integrated PBL-based worksheets. The research was conducted at SMPN 1 Kepanjen Malang Regency involving 30 students of class VIII F as the experimental class. The first step of this research is preparation by preparing research instruments in the form of teaching materials, evaluation questions, and lesson plans. The RPP used is based on light materials and optical instruments. 30 multiple choice questions were used as evaluation questions. Prior to the study, an analysis was conducted on evaluation questions with empirical validation. Based on empirical validation with SPSS 25, 16 valid questions were obtained, and Cronbach's Alpha value was 0.831 > 0.60, so the questions were declared reliable. Only 16 valid questions were used as instruments for data collection.

The teaching materials used are LKPD based on the STEM integrated PBL model. LKPD is prepared using a 4-D (four D) development model. Thiagarajan et al. (1974) with a pre-experimental design. The 4-D development model consists of 4 main steps are Define, Design, Develop, and Disseminate.(Thiagarajan et al., 1974). The steps performed are based on the 4D model of Thiagarajan et al. (1974) as follows: (1) define, in this step a preliminary study is carried out by means of a literature study and needs analysis; (2) design, in this step the researcher develops the initial product in the form of LKPD and test instruments that are in accordance with the material; (3) develop, in this step validation and readability tests are carried out; (4) disseminate, in this step the LKPD is distributed and the effectiveness is carried out using a one-group pretest-posttest design as a measurement of critical thinking skills. The last step of this research is processing and analyzing research data to prove the research hypothesis.

The research instruments are tests and questionnaires. All instruments go through an analysis process first by testing the validity and reliability. The data acquisition technique used is a test technique. The test technique consists of pretest-posttest questions to measure critical thinking skills and a questionnaire to measure the readability of the developed teaching materials. The analysis used in this research is descriptive analysis and inference. Inference analysis was carried out using normality and homogeneity tests. To test the effectiveness of learning using STEM-based PBL-based worksheets on students' critical thinking, a t-test was conducted with a paired sample t-test and a significance level of 0.05.

RESULTS AND DISCUSSION

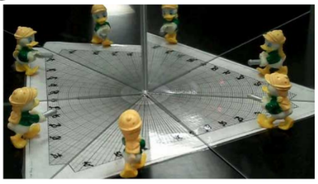
The STEM-based PBL-based LKPD is used for light and optical materials. Student worksheets consists of student worksheets for students and for teachers. The students' worksheets are equipped with a problem orientation in the form of an orientation article or video, a list of learning resources, experiments, and evaluations. One of the advantages of this worksheets is that it contains PBL syntax equipped with STEM aspects at each step that students take during learning. Besides that, simple experiments can be carried out either in the classroom or at home. This supports students to explore their knowledge through problem orientation and integrate it with the findings of the experiment. In the student worksheets, the teacher's handbook is equipped with an answer key for each syntax and assessment guide.

The front page shows the material's title, the author's name, and the model and approach used. An example of the contents of the student worksheets is shown in Figure 1.

Percobaan 3

Alat/bahan	Jumlah
Cermin datar kecil	2 buah
Plester perekat	1 buah
Busur derajat	1 buah
Penjepit kertas atau benda kecil lain	1 buah

Langkah Percobaan



Gambar 3 susunan alat dan bahan pada cermin bersudut
(Sumber: fisikabc.com)

1. Susunlah alat dan bahan seperti gambar di atas!
2. Aturlah sudut yang dibentuk kedua cermin sebesar 120^0!
3. Letakkan penjepit kertas di antara kedua cermin seperti pada gambar!
4. Hitunglah berapa jumlah bayangan yang terbentuk pada gambar! Mengapa bayangan yang terbentuk lebih dari satu?
5. Jika sudut antar cermin diubah menjadi 90^0, berapakah jumlah bayangan yang terbentuk? Apakah hubungan dari sudut kedua cermin? Jika sudut yang dibentuk lebih kecil, maka jumlah bayangan yang terbentuk lebih sedikit atau lebih banyak?

Figure 1. An example of the contents of the student worksheets

Figure 1 is the content of the STEM-integrated PBL-based student worksheets used in this study. Not only the questions that are displayed, but students worksheets also displays initial questions that are in accordance with problem orientation and experimental instructions equipped with lighter questions that encourage students to think critically and provide more real experience in finding concepts in the material through investigation. The student worksheets validation data that supports this research are presented in table 1. Besides that, the table of the results of the teacher and student readability questionnaires is presented in table 1. The two data then become a reference for the feasibility of the student worksheets to be used in learning.

Table 1. STEM-integrated PBL-based student worksheets validation

Rated aspect	Percentage	Criteria
Material Validation		
- Suitability - PBL model - STEM approach - Concept truth - Language standard	91,36%	very suitable
Media Validation		
- Design and layout - Hyperlink	92,86%	very suitable
Mean	92,11%	very suitable

Table 1 is the result of the worksheet validation by the validator, the instructor. The validation aspect is in the form of material and media validation using a questionnaire. Suitability is assessed by KD, GPA and learning objectives. The PBL model is presented with the syntax in the student worksheets. There are also applications of each aspect of the STEM approach. Designs and layouts are judged on the selection of colors, text, and the proportions of each design element. The student worksheet is equipped with a hyperlink to the list of reading sources and a QR code for problem orientation.

Table 2. STEM-integrated PBL-based LKPD readability questionnaire

Rated aspect	Percentage	Criteria
Legibility by teacher		
- Readability and display - Learning and materials	76,21%	suitable
Legibility by students		
Readability	83,81%	very suitable
Mean	80,01%	very suitable

The steps in the LKPD are adapted to the PBL model which has the following syntax: (1) problem orientation; (2) organizing in learning; (3) self-investigation; (4) presenting the work; and (5) evaluation (Shofiyah & Wulandari, 2018). At the stage of problem orientation and organization for learning to get a value of 4 out of a maximum value of 5. This can be due to the problems posed according to real life, but it would be better if the problems were obtained by the students directly. Organizing for learning in the form of an invitation to literacy in several trusted sources. It will be better if organizing can be an opportunity for students to discuss in groups so that they can develop their critical thinking skills. Grouping is a feature of cooperative learning (Wulandari et al., 2017).

Based on the feasibility test, the PBL-STEM-based LKPD meets the printing feasibility standard. The assessment standard by the National Education Standardization Agency (BSNP) states that the feasibility standard of printed materials can be assessed from the aspect of content, presentation, and language (BSNP, 2014). Aspects of the presentation of learning is considered very feasible. This proves that the content of the learning media is systematically arranged with the right order of presentation.

The results of the readability questionnaire showed that the developed student worksheet was easy to understand in its use for students to think critically. According to the teacher, the worksheet can promote students' critical thinking skills in terms of critical thinking supported by the student worksheet. The teacher thinks that the aspects of the student worksheet are in accordance with the PBL model and the STEM approach. Students appreciate that the student worksheet is easy to use with language that is easy to understand. In addition, the student worksheet makes it easier for students to learn independently. This is in accordance with the advantages of using student worksheet for learning, increasing efficiency and motivation, promoting active learning based on experience, and being consistent with learner-centered learning. (Ibrahim et al., 2017). Based on the results of the questionnaire, the student worksheet developed is very suitable for use in learning.

Validation and reliability tests were conducted on pretest-posttest questions to measure students' critical thinking skills. The results of the expert validation of the instrument are shown in Table 3. In addition, the bivariate Pearson correlation test was conducted to test the validation of the test questions.

Table 3. The expert validation of the test questions

Rated aspect	Percentage	Criteria
Content suitability	99,33%	very suitable
Language standard	92,67%	very suitable
Mean	96%	very suitable

Table 3 is the result of a validation test of the questionnaire by experts. The validation aspect is the appropriateness of the content and language used. Conformity is seen from the GPA, question indicators, Bloom taxonomy, and critical thinking indicators on test questions. Sentences in questions use language that is easy for students to understand and free of ambiguity. After expert validation, an empirical test is conducted on the questions. The sample from the empirical test was 50 students of class IX SMPN 1 Kepanjen who were randomly selected. The results of the empirical test are the results of bivariate Pearson correlation and Cronbach's alpha.

Based on the results of the Pearson bivariate correlation, out of the 30 questions developed, it is known that 19 questions are valid and 11 questions are invalid. Valid questions are based on the results of $r_{count} > r_{table}$ (0.279). Invalid questions are based on the results of $r_{count} < r_{table}$ (0.279). From these results, 19 valid questions were tested for Cronbach's alpha reliability. The reliability test results of 19 valid questions have an alpha value of 0.831. This means that the developed questions are in the high reliability category and can be used as research instruments. The study was conducted in class VIII F of SMPN 1 Kepanjen to investigate the effectiveness of using LKPD through the pretest and posttest results. The results of the pretest and posttest of the use of STEM-based PBL-based worksheets on light and optical materials are shown in Table 4.

Table 4. Pretest and posttest of the use of STEM-PBL based worksheets

Test Type	Total Students	Mean	Standard Deviation	Minimum Value	Maximum Value
Pretest	30	56,48	12,44	37,50	93,75
Posttest	30	75,83	14,47	43,75	100,00

Table 4 shows that the average of the pretest and posttest increased. To prove that there was a significant difference after using the developed LKPD, a t-test was performed. Before the T-test, the pre-test and post-test data were subjected to normality and homogeneity tests. The results of the normality test of the pretest-posttest mean using the Shapiro-Wilk test and the homogeneity test using the Lavene test. The Shapiro Wilk normality test stated that the data were normally distributed with a significance value > 0.05. The results of the homogeneity test stated that the pretest and posttest values were homogeneous with a significance level > 0.05. This indicates that the value is normally distributed and homogeneous, allowing the t-test to continue.

The results of the paired sample t-test showed a significance level of <0.05 and $t_{count} > t_{table}$. This proves that H_0 is rejected and H_1 is accepted, this means that the use of STEM PBL-based worksheets shows that there is a significant difference in students' critical thinking skills before and after learning. It is proven that the problem-based learning model with STEM-integrated PBL-based LKPD can improve critical thinking skills. The descriptive results obtained also support this. The pretest scores have an average of 56.48 while the posttest scores have an average of 75.83.

Table 5. N-Gain Score Results

Number of samples (*N*)	N-Gain Score (%)		
	Mean	Minimum	Maximum
30	48,14	0,00	100

Table 5 shows the results of the N-gain score, which is used to determine the increase in pretest-posttest scores after learning. The average increase is 48.14% and the results are included in the sufficient criteria. Learning with PBL-based LKPD integrated STEM has been designed to have a positive impact on increasing critical thinking skills of students in grade VIII of SMPN 1 Kepanjen. Students' critical thinking skills are enhanced through the use of LKPD, which facilitates the learning process, explains the relationship of STEM to life, and can be used independently. This is consistent with previous research that the use of LKPD in science learning is effective in helping the learning process, mastering the material, and developing independent study habits for students (Gomba, 2019). It is also supported by other studies that PBL-based worksheets integrated with green chemistry and ethnoscience are useful for improving students' thinking skills in three thinking domains, namely cognitive, psychomotor, and affective (Sudarmin et al., 2019). In addition, in another study of the implementation of the PBL model combined with STEM-based worksheets on environmental pollution material, it was able to improve students' critical thinking skills (Hasanah et al., 2021).

Table 6. The results of the N-Gain Score on each critical thinking indicator

Critical thinking indicator	N-Gain Score (%)
Basic clarification	60
Bases for a decision	61,11
Inference	46,67
Advanced clarification	44,45
Suppotition and integration	50,56

The application of learning with STEM-based PBL worksheets, the teacher accompanies students in analyzing a problem and is connected to the results of the investigation through a simple experiment. Therefore, each student tries his best in the investigation to find links to problems and simple solutions that can be done. In the process, students find more information to analyze an event and result. This can be explained in the following 5 stages of STEM-integrated problem-based learning.

In the first stage of problem orientation, the teacher provides an overview of the learning objectives. In problem orientation, students are confronted with a problem in everyday life. This orientation can motivate students to engage in problem solving activities. One of the critical thinking skills according to Ennis (2011), basic clarification, is developed at this stage. In Table 6, the basic clarification indicator experienced an n-gain of 60% after learning with the PBL-STEM student worksheets. Basic clarification consists of activities that focus, analyze, and answer questions about a statement or explanation of the problem in problem orientation (Ennis, 2011). Problem-oriented questions encourage students to think more critically and to make connections between everyday problems and the material being studied. Questions are also used to stimulate interaction between students and teachers to encourage critical thinking.

In the second stage of organizing for learning, various relevant reading sources are presented to help students connect problem solving to the material. Students are guided in the bases for a decision. In Table 6, the indicator of bases for a decision experienced an n-gain of 61.11% after learning using the PBL-STEM worksheets. Bases for a decision consists of thinking about reliable or unreliable sources on the organization for learning (Ennis, 2011). Students determine and manage what will be done in relation to the problem orientation.

In the third stage of independent inquiry, students are trained to conduct simple experiments. Experiments help students explore concepts in the material. Critical thinking questions complement the experiments. Questions are an important part of learning (Duron et al., 2006). Students' reasoning skills are trained in this phase. In Table 7, the inference indicator experienced an n-gain of 46.67% after learning with PBL-STEM worksheets. Inference consists of considering deductive activities or the results of deductions, generating or considering induction results, generating and determining the value of reasoning in independent investigations (Ennis, 2011).

In the fourth stage, students present their work in the form of a simple report. In this stage, students' advanced clarification skills according to Ennis (2011) are developed. In Table 6, the advanced clarification indicator experienced an n-gain of 44.45% after learning using the PBL-STEM worksheets. Advanced clarification consists of identifying terms, establishing considerations, and reviewing assumptions when presenting work in the form of a report (Ennis, 2011). The purpose of this report is to train students in conveying what understanding has been obtained.

In the fifth stage of assessment, students reflect on their learning by working on assessment questions. The questions are provided with STEM aspects related to the material. The aim is for students to relate the material to everyday life and to analyze STEM aspects of life. Critical thinking indicators according to Ennis (2011) supposition and integration skills are developed at this stage. In Table 6, the supposition and integration indicator experienced an n-gain of 50.56% after learning using the PBL STEM worksheets. Supposition and integration consists of considering the reasons for an answer and integrating the disposition at the evaluation stage (Ennis, 2011).

Improved test scores in the experimental class prove that students respond well when teachers use STEM-integrated PBL-based worksheets on light and optical materials. Treatment with the worksheets developed and validated in the experimental classroom encourages students to think critically at each stage of the problem-based learning model associated with a simple life problem. In addition, the STEM aspect of the worksheets makes students integrate all aspects of STEM in the life of light and optical materials. PBL STEM worksheets can improve students' critical thinking skills. The results of this study are consistent with previous research that the PBL learning model combined with STEM-based LKPD can improve students' critical thinking skills (Hasanah et al., 2021).

CONCLUSIONS

The results of this study prove that STEM-based Problem Based Learning worksheets are very feasible to implement in learning based on expert validation questionnaires and readability questionnaires. The descriptive data from the pretest and posttest results after the implementation of STEM-based Problem Based Learning worksheets showed an increase in the average critical thinking from 56.48 to 75.85. Based on the results of the t-test, it shows that there are significant differences in students' critical thinking skills before and after learning with STEM-integrated PBL-based worksheets. This is supported by an N-gain of 48.14% including the sufficient category, so the developed worksheet is quite effective in improving students' critical thinking skills.

Based on the research results, suggestions that can be considered are (1) STEM-based PBL-based worksheet can be used as an effort to improve students' critical thinking skills, (2) worksheet development can be done better by paying attention to more detailed things in exploratory thinking critical, (3) the need for a control class on the effectiveness test of the LKPD, which was developed as a comparison for the experimental class, (4) the need for a questionnaire to explain the effect of the worksheet on students' critical thinking skills after learning.

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