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Effectiveness of a Problem-Based Learning Model Integrated with Socio-Scientific Issues to Improve Science Process Skills of High School Students

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ABSTRACT

Problem-Based Learning (PBL) integrated with SSI (SSI-integrated PBL) is a learning model used to enhance science process skills based on the context of 21st-century skills. This study intends to investigate the difference in science process skills between students taught by using SSI-integrated Problem-Based Learning and those taught by using Problem-Based Learning on salt hydrolysis. Four classes (N = 136) at a high school in Mandau were the study participants. This study used two treatments: the experimental group using SSI-integrated Problem-Based Learning (PBL) and the control group using Discovery Learning (DL). Relevant data were collected using the science process skills instrument. The data were analyzed using ANOVA. The finding was confirmed for the PBL model with science process skills, with a significance value of < 0.05. Looking at the mean value, the average for students who take PBL differs from that of students who take DL. The PBL model in the experimental class can enhance science process skills better than in the control class. The study's findings were compiled via discussion of the literature review and recommendations process. The SSI-integrated PBL approach is significantly better than the DL model in enhancing science process skills. The percentage of the contribution of SSI-integrated PBL to science process skills is 8.9%, which shows a high influence.

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INTRODUCTION

Education aims to teach and train individuals to achieve their full potential in intellectual, emotional, and spiritual competencies [1], [2]. Education in the 21st century is not like that of previous centuries. The answer is in the great advances of modern technology and information that make science elope [3], [4]. However, the major problem in education today is the poor quality of education, particularly in science learning [5], [6]. The low quality of learning science can be seen from the 2022 PISA result (Program for International Student Assessment), where the science skills of students in Indonesia are still very low, ranking 63rd among 81 PISA participant countries [7].

Consistent with the 4.0 industrial revolution, education has also been based on the balance between theory and practice; students must have experience, knowledge, and skills [8]. Several strategies in developing 21st-century education include activity- or practice-based learning [9], [10]. This approach can enhance student learning. Students learn best when interacting with real situations and applying their knowledge and skills [11], [12] by engaging in inquiry activities. One of the 21st-century competencies in science studies is science process skills (KPS) [13], [14]. KPS are competencies that show how researchers do science, performing the whole procedure [15], [16], [17]. KPS are competencies required to perform the process of searching, finding, and concluding by their own experience, using the scientific approach or steps [18], [19].

Scientific personality is a fundamental skill that students must master when participating in science learning, especially in chemistry. In Indonesia, students' science process skills are still relatively low. Indonesia has incorporated science process skills into the science education assessment by the Trends in International Mathematics and Science Study (TIMSS) by the International Association for the Evaluation of Educational Achievement (IEA). TIMSS is an international study that researches trends in mathematics and science every four years. Jakarta (ANTARA) – Indonesia is in the 44th position of science test scores among 47 countries, according to 2015 TIMSS & PIRLS data. The science score is below the average TIMSS Scale Centerpoint 500 [20]. This is in line with [21], which states that students' science process skills are still at a low level, namely 30.67%. From this, it can be concluded that the KPS of Indonesian students is still weak.

The studies of [22] and [23] mentioned that real experience and practicum may improve students' science process skills. Theoretical understanding and practical work, correctly formulated experiments, precise measurements, and careful observations are paramount from the psychomotor side in learning [24], [25]. KPS is correlated to the degree of student competency in reaching study goals. Scientific competence development is related to students' skills that can be trained as students learn to develop scientific skills in problem solving. In the learning of content or materials, one thing that needs to be considered by the teacher is the model of learning that occurs in class.

Problem-Based Learning (PBL) is an active learning model where real-life problems are used to stimulate students to learn [26], [27]. PBL enables students to learn independently to construct information while the teacher guides students to solve the problem [28]. The PBL model consists of taking questions or problems as entry points; focusing on interdisciplinary connections, inquiries, and collaborative and project-based demonstrations, starting with presenting problems to stimulate student interest in small groups and creating products to solve problems [29]. An increase in science process skills based on PBL is one of the benefits of the PBL model itself, such as observing, classifying, communicating, measuring, predicting, and concluding [30], [31].

The PBL model can also be integrated with learning strategies, such as the Socio-Scientific Issues (SSI) approach. SSI supplied the learning setting of problem-based learning [32]. A related evidence-based approach is SSI, which builds on everyday social problems conceptually linked to learning about science

[33]. SSIs are widely used in science education. SSIs offer a critical context for examining scientifically solvable challenges and shaping views around controversial topics while, in doing so, promoting empathy and moral reasoning by way of a collective investigation [34]–[36]. Furthermore, students can solve the problems of social issues existing around them rationally, so that they can contribute to society by encompassing social significance. SSI promotes student involvement with socially linked scientific issues [37].

The distinction between PBL and SSI concerning science learning is a distinction in learning orientation. Students are not only being taught to analyse the social and ethical harms (SSI) but also to apply data to solve (PBL), a data-driven and scientific problem-based strategy to arrive at solutions that are real [38]. Integrating PBL's data-based critical thinking about SSI (which permits students not only to identify science-based solutions, but also to judge the social consequences of their decisions) with SSI, including social and ethical aspects, to help students develop as people who understand a science-in-society ethical toolkit, combines PBL and SSI to develop learning units that are more holistic, inquiry-based, and socially impactful. As a result, students learn science through the PBL conceptually and experimentally, and as part of a context-friendly situation in the larger society (using SSI) [39].

Science process skills in science learning in urban and rural areas are also good, based on previous studies carried out by [40]. Community charateristics This section describes the characteristics of the community in the form of location, facilities, population, and industrial environment. Science process skills and critical thinking skills 1) Science process skills affect critical thinking and science learning [41], revealing that science process skills can be used in any of the sciences and characteristics of how scientists carry out these sciences. However, the above-referred studies have not been put into practice. Research conducted by [42] showed that science process skills are significantly correlated with students' critical thinking, meaning that the better science process skills of the students, the higher the critical thinking. These skills promote learning Physical Science, assert the students' active participation, make them take responsibility for their learning, lengthen the duration of learning, and make them.

Science process skills and critical thinking learning require much effort [43]. The students' condition and facilities in school learning will affect learning achievement. A study by [44] indicated a positive influence of science process skills and critical thinking ability on student learning achievement.

This study contributes to the debate about how effective science process skills are in teaching chemistry using salt hydrolysis material. Science process skills are one set of skills that students have to have nowadays and in the 21st century [45], [46]. Science process skills are skills that relate to experimenting with the procedures of scientific inquiry and are usually performed through practical experiments [47], [48], [49]. The presence of science process skills enables the students to develop other research approaches and methods. No research on R&D problem-based learning models integrated with socio-scientific issues in science process skills is available.

Combining the problem-based learning model with socio-scientific issues is believed to make students more active in the learning process and form students' scientific characters. With this as an opening, the study aims to determine the effectiveness of the PBL model based on socio-scientific issues learning on students' science process skills at the high school level.

METHODS

1. Research Design

The research design of this study was a quasi-experiment. Two experimental (N = 60) and control groups comprised the design of this investigation. The experimental group used a problem-based learning model integrated with socio-scientific issues, while the control group used a discovery learning model.

Table 1. Syntax of Problem-Based Learning Model integrated with SSI.

Learning Steps.	Syntax	Description
Introduction		Teacher says greetings; teacher checks students' readiness for learning; teacher motivates students; teacher explains learning objectives.
Core Activity	The problem orientation phase (SSI)	The teacher divides the learners into groups of 4-5 members; the teacher gives LKPD 1 and directs the learners to look at the problem.
	Organising students for the learn phase	The teacher prepares students to follow the learning process; the Teacher directs them to access LKPD 1.
	Independent and group enquiry phase	The teacher guides learners to conduct group investigations by conducting experiments; learners write down the data obtained about buffer solutions.
	Phase Develop and present work	The teacher asks the learners to answer the questions on the LKPD by linking the discussion results and the experiment results.
	Analyse and evaluate the problem-solving process phase	The teacher asks the learners to conclude the results of the investigation; The teacher guides the learners if they have difficulties in concluding; The teacher asks each group to present the results of the discussion in front of the class; The teacher directs the learners to respond to each other's presentation activities; The teacher assists the learners in reflecting or evaluating the investigation.
Closing		The teacher asks the learners to collect the LKPD.

2. Research Samples

The research was conducted at a high school in Duri in class XI MIPA during the odd semester of the 2023/2024 school year. The population in this study was all students of class XI MIPA at a high school in Duri, Riau, selected by random sampling techniques. The sample size was 136 students, of which 68 were in the experimental group and 68 in the control group.

3. Instrument and Data Collection Research

The observation sheet was the tool utilized in the present research. The observation sheet was also applied to measure students' science process skills across six indicators: observing, hypothesizing, experimenting, classifying, communicating, and interpreting. The observation sheet had earlier been validated for content by two lecturers.

4. Data Analysis

The researchers collected science process skills data through learning with a scale of 1–4. Two observers observed the science process skills of students throughout three meetings. Results were subjected to a t-test. Normality and homogeneity tests were performed before applying the t-test. Data were processed using SPSS 27 software.

Table 2. Syntax of the Discovery Learning Model.

Learning Steps	Syntax	Description
Introduction		The teacher gave greetings, the teacher checked attendance, the teacher delivered apperception, the teacher delivered motivation, and the teacher delivered learning objectives.
Core Activity	Stimulation	The teacher displays the learning material, the Teacher divides learners into groups, and Learners understand the stimulus.
	Problem Statement	Learners formulate a problem on the learning material; learners write a problem hypothesis.
	Data Collection	Learners discuss the questions in the LKPD. Learners conduct experiments on adding small amounts of acids, bases, and pH dilution.
	Data Processing	Learners, together with their group mates, process and analyse the data.
	Verification	Learners present the results of group discussions and experimental results.
	Generalization	Learners discuss with their group mates and make conclusions.
Penutup		The teacher guides students to summarise the material that has been learnt.

Table 3. Aspects and Indicators of Science Process Skills.

No.	Aspects	Items	Indicators	Number of Items
1.	observation	1.	Collect information from various sources	2
		2.	Collect/use facts relevant to the given problem.	
2.	Formulating a hypothesis	3.	Formulate a hypothesis based on the formulation of the problem	1
3.	Conducting experiments	4.	Conduct experiments systematically	1
4.	Summarising	5.	Formulate conclusions relevant to the data collected	1
5.	Communicating	6.	Actively participate and provide ideas in group discussions	4
		7.	Asking rational and logical questions	
		8.	Present the results of the discussion briefly and clearly.	
		9.	Responding to others' opinions	
6.	Interpretation of Data	10.	Interpreting results on the observation sheet	1

RESULTS AND DISCUSSION

1. Analysis of Science Process Skills

As shown in Table 4, the experimental class's average science process skill score was higher (80.33) than that for the control class (75.07). The difference between them shows that the students taught with the PBL-SSI model resulted in a better development of science process skills compared to the students taught through the DL model. The greater mean in the experimental class may indicate that the students had more opportunities to comprehend the material more deeply when real-world contexts were infused via SSI, since these would promote more scientific reasoning and procedural skills.

Moreover, these findings indicate that the PBL-based SSI approach promotes the learning of content knowledge and maximizes the improvement in trainees' critical thinking skills for science process skills. The data further emphasize that active learning inquiry strategies are more efficient than discovery approaches, particularly when solving authentic SSI problems. Therefore, empirical evidence suggests that using the PBL model integrated with SSI can improve students' science process skills, especially in the salt hydrolysis material.

Table 4. Results of the analysis of science process skills.

Class	**Sample Quantity**	**Average Science Process Skill**
Experiment	68 student	80.33
Control	68 student	75.07

2. Prerequisite Test

2.1. Outlier Test

Before proceeding with statistical analyses, it is important to remove outlier points that might bias the results. This study identified univariate outliers for each group by examining the Box Plot of the dependent variables. Checking the Box Plot, no outlier values were present in the experimental or control groups. This result suggests that the distribution of the science process skills scores in both groups was nearly symmetric and had no outliers. Without outliers, we can acquire cleaner statistical tests that allow us to determine if the factors significantly influence the mean, standard deviation, and the shape of the overall distribution. The Box Plot results of science process skills in the experimental and control classes are shown in Figure 1, which shows no points being marked as extremes. Therefore, from the univariate Box Plot analysis, we can conclude that the two datasets are free from outliers and can be subjected to further normality tests and inferential analysis.

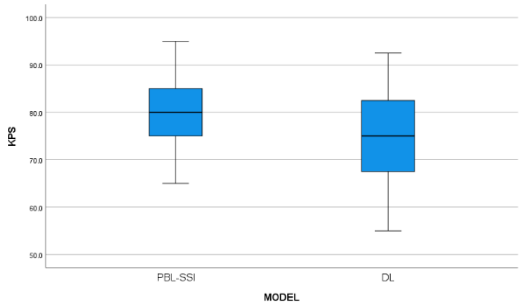

Figure 1. Box Plot of Science Process Skills in Experimental and Control Classes.

2.2. Test of Normality

Table 5. Shapiro-Wilk Test Results

Dependent Variable	**Class**	***Shapiro Wilks***
Critical Thinking Skills	Experiment	0.188
	Control	0.715

After establishing no outliers, the second condition for using parametric analyses was to check for the normality of the data distribution. The Shapiro-Wilk test was used to test for normality, which has been specifically recommended for small to moderate sample sizes. The Shapiro-Wilk test was performed separately in the SPSS 27 software for the experimental and control groups. If the p-value exceeds 0.05, the data can be considered "approximately normally distributed." Table 5 represents the normality test results for the science process skills scores. Results showed that both samples had p-values higher than the cut-off, according to the univariate assumption of normality. This aspect about establishing normality is very important because it allows for additional parametric analysis, such as multivariate analysis of variance (MANOVA) or t-tests. Furthermore, verifying that data is normally distributed guarantees that the inferential statistics generate valid and replicable results. According to the Shapiro-Wilk normality test, experimental and control group data are considered appropriate for further statistical analysis, without data transformation or non-parametric methods.

2.3. Anova One-Way Test

A one-way ANOVA test was conducted on collaboration skills to determine the differences between groups with different treatments. The one-way ANOVA test data for each treatment group are provided in Tables 6 and 7.

Table 6. Homogeneity of Variance Test

Instrument		Levene Statistic	df1	df2	Sig.
Science Process Skills	Based on the Mean	3.546	1	134	.062
	Based on the Median	3.641	1	134	.059
	Based on Median and with adjusted df	3.641	1	133.185	.059
	Based on the trimmed mean	3.568	1	134	.061

Table 7. One-Way ANOVA Test

Instrument		Sum of Squares	Df	Mean Square	F	Sig.
Science Process Skills	Between Groups	939.752	1	939.752	13.120	0.000
	Within Groups	9598.438	134	71.630		
	Total	10538.189	135			

The findings of this study indicate that the implementation of the PBL learning model had a very influential effect on students' science process skills. This is consistent with the multivariate testing results since Hotelling's Trace resulted in a value of 0.000, which rejected the null hypothesis (H_0) and validated the alternate hypothesis (H_a). This statistically proves a significant difference in science process skills between students learning by PBL and DL. Implementing the PBL model combined with the Socio-Scientific Issues (SSI) in the experimental class was more effective than in the control class. The students in the experimental class had higher participation, system analysis, and problem-solving ability. The results indicate that connecting real-world contexts to the SSI promotes students' cognitive engagement in learning activities. Accordingly, the approach developed in the present study, PBL integrated with SSI, is expected to improve students' science process skills in chemistry education.

This finding is supported by several studies [50], [51], which claimed that the PBL model was better than conventional learning models in enhancing science process skills. Science process skills are critical skills that students must possess to generate and apply scientific knowledge effectively [52]. These skills also prepare you for employing scientific methodology and problem-solving in the real world. Hence, science process skills are a key factor for students while they solve their problems. Concerning PBL, students practice and apply these abilities in a prescribed (though open-ended) environment. Incorporating SSI into the PBL structure also adds a contextualized dimension of learning, motivating students to focus much more on scientific concepts and their societal aspects. Therefore, one of the important educational goals is to improve science process skills using PBL integrated with SSI.

Science process skills are classified as a certain psychomotor domain that students should acquire [53]. These skills are grouped into basic and integrated skills, and they are geared towards higher scientific order cognition abilities. Fundamental skills, such as observing and measuring, are the foundation for more advanced skills such as hypothesizing, interpreting data, and experimenting. Students need authentic learning opportunities to promote such competencies as laboratory studies and inquiry-based experiments [54]. Title: The Casper College Physical Science/Oppi Project Abstract: By John F. Garrett. Simple investigations in science prompt students to use their hands to manipulate objects during the inquiry process; in this way, students can directly practice and experience their process abilities. The effective development of these capabilities greatly depends on the learning models instructors present [55]. Therefore, instructional methods must be consistent with curriculum standards that promote process-based pedagogy. Teachers also have a great role to play, since their experience and pedagogical knowledge are key to promoting a meaningful evolution of the science process skills [56].

To quote [57], education is a “conscious attempt to develop the knowledge, skills, and attitudes required to manage life.” In this approach, education is not only the passing down of information to the learner but also the learner's ability to make their understanding and participate in it. Science process skills are important to enable meaningful learning, which is when students learn from dealing directly with phenomena and derive scientific concepts by exploration and discovery. Such learning approaches enhance information retention and knowledge transfer to other contexts among students [56]. Well-prepared students in general science are better able to develop critical analysis skills. Scientific reasoning includes critical thinking and helps students to approach concepts logically and to remain open-minded in examining evidence [58]. Thus, developing science process skills also develops more general domains of cognition and intellect that underpin science.

The science process skills significantly improved the students’ observation skills in learning. When students observe, notice, and collect information, they do science. This process of active interrogation provides students with research training and fosters an attitude of inquiry. When students are trained to observe critically, they learn to ask scientific questions and to make testable hypotheses. Observation skills in the PBL model, based on [59], are notable when students carry out experiments, interpret data, make a hypothesis, and reach a logical conclusion. Students develop critical thinking, combining their intellect and senses, by honing observational skills. This skill is necessary not only for academic success but also for encouraging a scientifically literate populace.

Science process skills contribute to improving observational skills and fostering the development of the ability to formulate hypotheses. The PBL approach develops students' ability to pose significant questions, design investigations, and use evidence to solve problems [60]. Hypothesis formation promotes habits of thinking that include predicting, planning, and conducting inquiries to verify their predictions. The practice of hypothesizing, testing, and revising ideas represents a realist cycle in science itself. Engaging students in hypothesis design exercises enhances curiosity and resilience when facing difficult problems. In the PBL environment, students are motivated to integrate theoretical and empirical knowledge to promote conceptual comprehension. Therefore, developing the ability to pose hypotheses is an important part of educating scientifically literate and inquiry-capable individuals.

The context of the real world using Socio-Scientific Issues (SSI) for instruction adds significant value to the meaningful nature of learning. SSI issues, including but not limited to climate change, renewable energy, biotechnology, and environmental pollution, help to narrow the divide between abstract science knowledge and real-world societal issues [61]. Through addressing these issues, students see the importance of scientific knowledge in making everyday decisions and solving global problems. In addition, SSI learning allows students to judge the ethical, social, and scientific aspects of current issues. This multi-dimensional involvement encourages thoughtful citizenship and greater interest in applying scientific reasoning outside the classroom. Linking SSI into the PBL model not only serves to reinforce science process skills but also fosters students' abilities to make science-based, socially responsible decisions. In that sense, SSI is an important gateway that connects scientific knowledge with societal benefit.

Developing students' experimental skills is also key to enhancing science process skills. To balance this approach, students also engage in hands-on, experimental activities that apply scientific methods to test hypotheses and confirm discoveries through observation. According to the PBL process, students must actively look for information, plan experimental procedures, and cooperate with group work [62]. Experimentation breeds self-efficacy, resilience, and the ability to solve problems. It also emphasizes the connection of theory with application, enhancing students' understanding of basic concepts in science. The chance to be involved in experimental work also endorses advancing inquiry skills, creativity, and collaboration requirements for scientific work. Therefore, laboratory work is still a crucial and essential component of good science education.

A fundamental element of science process skills associated with experimentation is the capacity to make valid interpretations and inferences from data. Interpretation of data is the process of making sense of the results, looking for connections, and determining what they might mean.

Students must also critically evaluate the quality and validity of evidence found and explain aberrations and discrepancies [63]. Developing the ability to make inferences allows students to go beyond simply gathering data and into the realm of true scientific explanation and reasoning. In PBL, students learn to interpret data as they engage in cycles of testing and revising hypotheses. The iterative nature of this process contributes to their ability to build evidence-based arguments and promotes their conceptions of the nature of scientific investigation. Fostering inferential capabilities is crucial in promoting skilled, critical, and reflective science learners.

Combining PBL and SSI could be a very successful strategy for developing SPS. With the integrated approach, students are engaged in authentic problems that need to be solved, and they must use scientific methods and think about ethical, social, and ecological consequences [64]. In PBL-SSI settings, students perform problem recognition (PR), making hypotheses (MH), collecting evidence (EC), and interpreting evidence (IE)—motoric constituents of the SPS. SSI content also helps motivate and make content relevant to students, causing them to engage more in scientific practices. This combination of PBL and SSI would help enhance cognitive development and socio-ethical reasoning abilities. It means students are more ready to use their science learning to solve real-world problems.

The PBL model combined with SSI yielded good results in student process skills, as confirmed by previous findings [65], [66]. It has been observed that PBL focuses on real inquiry and real-world problem-solving, leading to notable gains in the students' prediction and data analysis skills [67]. The combined use of PBL and SSI enhances student learning. Students will have problem-solving competencies better than they would have had by an education indifferent to SSI beyond the classroom. The findings of this study provide empirical evidence that the integrated PBL-SSI model not only enables students to gain conceptual knowledge but also leads to a more advanced and extensive development of process abilities. The combination of PBL and SSI is more meaningful, situational, and powerful for studying the topic of salt hydrolysis in chemistry. Therefore, the PBL-SSI model provides an effective framework for developing students' scientific literacy and 21st-century skills.

CONCLUSION

The analysis and discussion revealed a significant difference in science process skills between students who participated in the Socio-Scientific Issues (SSI)-integrated Problem-Based Learning (PBL) class and those who received instruction through the Discovery Learning (DL) model on the topic of salt hydrolysis. The results confirmed that the SSI-integrated PBL approach enhanced students' science process skills more effectively than the DL model. Statistical analysis showed that the contribution of the SSI-integrated PBL model to the improvement of science process skills was 8.9%, indicating a moderate level of effectiveness. This suggests that integrating real-world socio-scientific issues into a problem-based learning framework creates richer and more meaningful learning experiences that support cognitive development. SSI provides authentic contexts that challenge students to apply scientific reasoning and procedural skills in problem-solving activities. Consequently, adopting SSI-integrated PBL in science classrooms can significantly contribute to fostering critical thinking, inquiry abilities, and scientific literacy. Based on these findings, educators are encouraged to incorporate SSI and PBL strategies more systematically to optimize the development of science process skills, particularly in complex chemistry topics such as salt hydrolysis.

Based on the research findings that highlight the effectiveness of integrating Problem-Based Learning (PBL) with Socio-Scientific Issues (SSI) in science learning, here are some practical recommendations for teachers: select relevant and contextualised socio-scientific issues, use the PBL approach to guide the problem-solving process, encourage scientific argumentation and decision-making skills, and provide opportunities for exploration and collaboration.

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