

Review Article

## The Effectiveness of the Problem-Based Learning Model Assisted by Web-Based Interactive Learning Media is reviewed from Mathematical Communication Skills and Self Awareness in Class X Students of SMK Negeri 1 Tarakan

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**Abstract.** This study aims to describe: (1) the effectiveness of the problem-based learning model assisted by web-based interactive learning media reviewed from students' mathematical communication skills and self-awareness; (2) the effectiveness of the direct learning model is reviewed from students' mathematical communication skills and self-awareness; (3) a more effective learning model among the problem-based learning model assisted by web-based interactive learning media and direct learning is reviewed from the mathematical communication ability and self-awareness students. The study involved two classes: an experimental class and a control class. Class X MPLB 2 served as the experimental class, and Class X AKL 1 served as the control class, each consisting of 36 students. The data were obtained from the test results (pre-test and post-test) of mathematical communication skills, well as from non-test questionnaires measuring students' self-awareness. The research was considered effective if the average score mathematical communication skills exceeded the criteria for achieving learning objectives (KKTP) at SMK Negeri 1 Tarakan, which was 75, and if the average self-awareness score students exceeded 84, which falls in the very high category. The data were analyzed using Hotelling's  $T^2$ , one-sample t-test, and independent sample t-test. The results showed that (1) problem-based learning assisted by web-based interactive learning media was effective when viewed from students' mathematical communication skills and self-awareness; (2) ineffective direct learning reviewed from students' mathematical communication skills and self-awareness; (3) Problem-based learning assisted by web-based interactive learning media is more effective than direct learning reviewed from mathematical communication skills and self-awareness in students.

**Keywords:** Learning Media; Mathematical Communication Skills; Problem-Based Learning; Self-Awareness; Web-Based Interactive.

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### 1. Introduction

The rapid development of technology has brought changes to various areas of life, including education. The use of technology in learning is one of the efforts to create a learning process that is more flexible, independent, interesting, and in accordance with the needs of students (Timotheou et al., 2023). The use of technology-based learning media has also been proven to increase student engagement and support the achievement of learning outcomes through more interactive learning experiences (Jamshidifarsani et al., 2019). In line with that, the Merdeka Learning policy encourages the use of various learning applications so that students can learn according to their characteristics and needs (Melindawati & Silfi, 2021).

However, the use of innovative learning media in schools is still not optimal. This condition causes learning to tend to be monotonous, so that students' interest and motivation to learn decreases (Kristanti & Dantes, 2024). The lack of media variety makes it easy for

students to lose focus and be less active in following the learning process, which ultimately has an impact on low learning outcomes (Honggowidagdo et al., 2026; Purnamasari, 2025).

In mathematics learning, mathematical communication skills play an important role because they help students convey ideas, explain thought processes, and build a systematic understanding of concepts (Chasanah & Usodo, 2020). However, this ability is still one of the weaknesses of Indonesian students. The results of the *Programme for International Student Assessment (PISA)* in 2022 show that Indonesia is ranked 68th out of 80 countries with an average math score of 366, far below the OECD average of 472. The low achievement shows that students still have difficulty in representing problems, choosing solution strategies, and communicating mathematical ideas appropriately. In addition, the percentage of Indonesian students who achieve a high level of mathematical competence is still very low compared to the average OECD country (OECD, 2023).

Various curriculum changes have been made to improve the quality of mathematics education, starting from the 2004 Curriculum to the Independent Curriculum. However, students' mathematical communication skills are still not optimally developed. One of the reasons is learning that is still oriented towards providing formulas and practice questions so that students are not used to developing and communicating mathematical ideas independently (Gardenia et al., 2021). This condition is reinforced by the findings of Deswita et al. (2018) who show that students' answers are often not systematically structured and the mathematical arguments given are not based on the right concepts (Reyhan et al., 2025).

In addition to mathematical communication skills, *self-awareness* is also an important aspect of mathematics learning. *Self-awareness* reflects students' ability to recognize their strengths and weaknesses, understand the thought process, and determine effective learning strategies (Lio et al., 2023). However, this ability is still low because learning focuses more on cognitive aspects than on reflective and metacognitive aspects. The opportunity for students to conduct self-evaluation and reflect on the learning process is also limited. In addition, teacher-dominated learning causes students to play more of a role as recipients of information than as active learners (Mirna et al., 2023).

Mathematical communication skills and *self-awareness* have a mutually supportive relationship in mathematics learning. The ability to communicate mathematical ideas and arguments will develop when students are able to understand their own thought processes. On the other hand, *self-awareness* can be increased through communication, reflection, and evaluation of the strategies used in solving problems. Therefore, both abilities need to be developed simultaneously through proper learning (Mahaputra et al., 2025).

One of the learning models that is considered to be able to support the development of these two abilities is *Problem Based Learning (PBL)*. This model places contextual problems as the basis for learning so that students are encouraged to think critically, discuss, collaborate, and find solutions independently (Dwikoranto et al., 2023). Through this process, students have a wider opportunity to develop mathematical communication skills and reflect on the learning process experienced. Research by Kurniati and Suwanti (2019) shows that PBL is more effective than conventional learning in improving students' mathematical communication skills.

The effectiveness of PBL implementation can be supported by the use of web-based learning media. Digital media allows students to obtain better visualization of concepts, receive direct feedback, and monitor learning progress independently (Wong & Hughes, 2023). One of the relevant media is *Wordwall*, which is a web-based application that provides a variety of interactive educational activities and games to increase student engagement in learning. The use of *Wordwall* can also increase learning motivation and interaction between students through a more interesting learning atmosphere (Ishak et al., 2017).

The results of interviews with mathematics teachers at SMK Negeri 1 Tarakan show that learning is still dominated by lecture methods with limited media use of PowerPoint. As a result, students tend to be passive, lack focus, and have low motivation to learn. In addition, only a small percentage of students dare to express their opinions or answer questions during the lesson. This condition shows that student involvement in the learning process is not optimal, so more interactive learning model and media innovations are needed.

Based on the theoretical study and empirical conditions, the application of *Problem Based Learning (PBL)* assisted by web-based interactive learning media *Wordwall* is seen as having the potential to improve students' mathematical communication skills and *self-awareness*. However, research that specifically examined the effectiveness of the combination of PBL and *Wordwall* in SMK students in class X is still limited. Therefore, this study was conducted to analyze the effectiveness of *Problem Based Learning (PBL)* assisted by web-based interactive learning media from the mathematical communication skills and *self-awareness* of SMK Negeri 1 Tarakan students.

Based on this background, it can be identified that the use of technology and innovative learning media in mathematics learning is still not optimal so that the learning process tends to be less interesting and has not been able to encourage active student involvement. Students' mathematical communication skills are also still relatively low, which can be seen from the difficulties in putting forward ideas, explaining thought processes, and systematically arranging mathematical arguments. In addition, students' *self-awareness* has not developed optimally because self-reflection and self-evaluation activities are still rarely applied in learning. Learning practices that are still teacher-centered also cause low student learning participation and independence. Meanwhile, the implementation of *Problem Based Learning (PBL)* assisted by web-based interactive learning media such as *Wordwall* is still rarely done and its effectiveness on mathematical communication skills and *self-awareness* of SMK students in class X still requires stronger empirical proof.

This study aims to describe the effectiveness of the *Problem Based Learning (PBL) model* assisted by web-based interactive learning media from the perspective of students' mathematical communication skills and *self-awareness*. In addition, this study also aims to describe the effectiveness of the direct learning model on these two abilities and determine a more effective learning model between *Problem Based Learning (PBL)* assisted by web-based interactive learning media and direct learning.

Theoretically, this research is expected to be a scientific reference regarding the application of *Problem Based Learning (PBL)* assisted by web-based interactive learning media at the vocational school level. The results of the research are also expected to enrich the study of the use of interesting mathematics learning media and contribute to efforts to improve students' mathematical communication skills and *self-awareness*. Practically, this research is expected to provide a more interesting and enjoyable mathematics learning experience for students through the use of *Wordwall* in problem-based learning. For teachers, the results of the research can be a reference in choosing more innovative learning models and media so that they can increase student involvement in mathematics learning. Meanwhile, for researchers, this research can be a means of developing competencies in the field of research and learning and provide an overview of the effect of the application of *Wordwall-assisted Problem Based Learning (PBL)* on the mathematical communication skills and *self-awareness* of vocational school students.

## 2. Literature Review

Learning is a process of interaction between students, educators, and learning resources that takes place in a learning environment as regulated in the National Education System Law Number 20 of 2003. Learning is not only oriented to the transfer of knowledge, but also plays a role in shaping the attitude and character of students. Hamalik (2003) explained that learning involves various elements, both human and learning resources, that interact with each other to achieve educational goals. The effectiveness of the process is greatly influenced by the learning design and learning environment conditions that are able to encourage active involvement of students (Anderson & Shattuck, 2012).

In the context of mathematics, learning is directed at mastering mathematical concepts, principles, and skills through interactions that support the development of logical, critical, and systematic thinking skills. Therefore, it is necessary to use diverse methods so that students can learn more effectively (Gazali & Atsnan, 2022). A student-centered approach has been proven to improve understanding of mathematical concepts because it provides opportunities for students to be actively involved in the learning process (Mawela & Mahlambi, 2021).

Based on Permendikbud Number 22 of 2016, the purpose of mathematics learning includes the ability to understand concepts and relationships between concepts, use mathematical reasoning, solve problems, and communicate mathematical ideas through various representations such as symbols, tables, graphs, and other forms. Thus, mathematics learning focuses not only on mastering procedures, but also on developing mathematical thinking and communication skills.

Learning effectiveness refers to the level of success of the learning process in achieving the set goals. Slavin (2006) stated that the effectiveness of learning is influenced by the quality of learning, the suitability of learning levels, the provision of incentives, and the allocation of available time. Meanwhile, Kyriacou (2009) explained that effective learning occurs when teachers have clear learning goals and are able to provide learning experiences that support the achievement of these goals.

Effective learning involves cognitive, affective, and social aspects in a balanced manner. Therefore, the success of learning can be seen from the ability of students to achieve the targeted competencies and the learning achievements obtained (Elkalmi et al., 2015). In this study, the effectiveness of mathematics learning is interpreted as the level of success in the

application of the *Problem-Based Learning (PBL)* model assisted by web-based interactive learning media in improving students' mathematical communication skills and *self-awareness*.

PBL uses authentic problems as a means to develop conceptual understanding and higher-level thinking skills. In the process, students can work individually or in groups to identify learning needs and find the right solutions (Tanjung et al., 2022). This model not only helps students understand academic concepts, but also develops the communication, collaboration, decision-making, and problem-solving skills needed in real life (Duch et al., 2001).

Based on these various views, *Problem-Based Learning (PBL)* can be understood as a learning model that places students at the center of learning activities through collaborative contextual problem solving to build knowledge, critical thinking skills, and communication skills.

In this study, the syntax of PBL refers to the stages proposed by Putri et al. (2021), namely problem-orientation, organizing students to learn, guiding individual and group investigations, developing and presenting the results of their work, and analyzing and evaluating the problem-solving process. These stages were chosen because they are in accordance with the characteristics of mathematics learning that emphasize problem solving, mathematical communication, and learning reflection.

Considering its advantages and limitations, PBL remains one of the relevant models to be applied in mathematics learning because it is able to develop critical thinking skills, mathematical communication, collaboration, and student learning independence (Pransiska et al., 2024).

A broader classification is put forward by Heinich et al. (2002), which distinguishes learning media into text, audio, visual, projection media, models, and humans as learning resources. In addition, the combination of various media has been proven to be able to improve student understanding because it provides multimodal learning support (Song et al., 2023). Rahadian and Budiningsih (2018) also emphasized that the use of media such as images, videos, animations, simulations, digital presentations, and online learning can support the learning needs of secondary school students. Therefore, the selection of learning media needs to consider the learning objectives, student characteristics, and the context of use so that the learning process takes place optimally.

Web-based learning is the use of internet technology to support the delivery of materials, interactions, and learning evaluations flexibly without being limited by space or time. Through various digital media, such as videos, simulations, online quizzes, and educational games, learning becomes more interesting and able to increase students' motivation to learn (Nababan et al., 2023).

One of the widely used web-based learning media is Wordwall. The app is designed to help teachers create an interactive learning experience through a variety of educational activities and games. Wordwall applies the concept of *game-based learning* by providing a variety of quiz and game features that can be used as learning and evaluation media. Its use aims to improve material understanding, learning interaction, and students' memory of the concepts learned (Setyorini et al., 2023).

According to Sahanata et al. (2022), Wordwall has a number of advantages, including being able to improve students' understanding of the material, being easily accessible through various devices including mobile phones, and providing a more interesting learning experience through game elements. However, this application also has some limitations, such as the potential for cheating when used for evaluation, the relatively long time in the media creation process, and the reliance on stable internet connection quality.

Web-based learning media is a means of learning that uses the internet to deliver materials, carry out learning activities, and conduct online evaluations. This media allows for more flexible interactions between students, teachers, and learning resources to support continuous learning and in accordance with the needs of students (Ahyan et al., 2022).

The success of its implementation is greatly influenced by the ability of teachers to integrate technology with appropriate learning strategies (Syarifuddin et al., 2024). Various studies have shown that web-based media is able to improve concept understanding, learning outcomes, motivation, and student involvement in the learning process (Setyadi & Qohar, 2017).

Research shows that the use of interactive platforms such as Quizizz, Genially, and Nearpod is able to improve problem-solving skills, learning experience, and students' understanding of learning materials (Ayuningtyas et al., 2024). The findings are reinforced by Oktavia et al. (2024) who state that web-based media can significantly increase students' interest in learning and engagement.

In addition, active involvement in PBL can increase students' *self-efficacy* so that they are more confident in facing various learning problems, especially mathematics (Peranginangin et al., 2019). Therefore, PBL contributes not only to academic achievement but also to the development of students' self-awareness.

Mathematical communication skills are closely related to *self-awareness*. Students who are able to recognize their thought processes tend to explain ideas, strategies, and mathematical concepts more clearly. Communication and reflection activities are known to play an important role in the development of conceptual and procedural understanding of mathematics (Rittle-Johnson et al., 2001).

Based on the Independent Curriculum, SPLTV is one of the mathematics materials for class X of SMK in Phase E which is in the elements of Algebra and Functions. SPLTV learning aims to enable students to understand concepts, solve problems using substitution, elimination, or combination methods, and model contextual problems into mathematical form (Ministry of Education and Culture, 2014).

The settlement of SPLTV can be done through substitution, elimination, and mixed methods (*elimination-substitution*). The substitution method is carried out by replacing one of the variables using another form of equation until the value of each variable is obtained. The elimination method is carried out by eliminating one of the variables to obtain a simpler system. Meanwhile, the mixed method combines the process of elimination and substitution so that it is often considered more practical in solving SPLTV problems.

In addition to these three methods, SPLTV can also be solved using matrix methods, such as Cramer's rule and matrix inverses. However, this method requires an understanding of the determinants and functions of the matrix which are relatively more complex so that they are generally studied at higher levels of education. In secondary school learning, elimination methods and blended methods are more often used because they are more suited to the characteristics of the students and learning objectives.

### 3. Materials and Method

This study uses a *quasi experiment method*, because the researcher cannot randomize the subjects completely. The research group used classes that had been formed at the school without creating new classes. The study compared the application of the Problem-Based Learning (PBL) model assisted by web-based interactive learning media with the direct learning model. The bound variables studied included students' mathematical communication skills and *self-awareness*.

The research design used was a pretest-posttest control group design, where the experimental class received treatment in the form of a PBL model assisted by web-based interactive media, while the control class received direct learning. Measurements are carried out through a *pretest* to determine the initial condition of students and a *posttest* to measure changes in mathematical communication skills and *self-awareness* after treatment is given.

The research was carried out at SMK Negeri 1 Tarakan, North Kalimantan, in the odd semester of the 2025/2026 school year. The research activities will take place during August 2025 with learning materials on the Three-Variable Linear Equation System (SPLTV). The implementation of the research included *pretest* activities, three learning meetings, and *posttests* in the experimental class and the control class.

The research population is all students of class X of SMK Negeri 1 Tarakan who have not studied SPLTV material. Samples were selected using the purposive sampling technique, which is the determination of the sample based on certain considerations that are in accordance with the research objectives (Creswell & Clark, 2011). Two classes that have relatively equivalent initial abilities were selected as samples, namely class X MPLB 2 and X AKL 1. The determination of experimental and control classes is carried out through lotteries. As a result, class X MPLB 2 was designated as an experimental class that obtained PBL learning assisted by web-based interactive media, while class X AKL 1 became a control class with direct learning.

The research data was collected using both test and non-test techniques. The test technique is used to measure mathematical communication skills, while the non-test technique in the form of a questionnaire is used to measure *students' self-awareness*. The stages of data collection include the preparation of learning tools, the development of Wordwall-based media, the preparation and validation of instruments, the implementation of instrument trials, the provision of *pretests* and initial questionnaires, the application of learning according to treatment, and the provision of *posttests* and final questionnaires.

Descriptive analysis was used to describe the condition of students' mathematical communication skills and *self-awareness* before and after treatment. The statistics used include average scores, standard deviations, minimum scores, and maximum scores.

The *self-awareness* score was then categorized into very high, high, medium, low, and very low based on criteria developed by Widoyoko (2009). The results of the categorization showed that the experimental class increased from the medium to very high category, while the control class increased from the medium category to the high category (Stevens, 2009).

## 4. Results and Discussion

### Research Results

Descriptive analysis was carried out to describe the initial and final conditions of students based on pretest and posttest data. Pretest data was used to determine the initial ability of mathematical communication and self-awareness before treatment, while posttest data was used to see changes after learning and assess the effectiveness of the Problem-Based Learning (PBL) model assisted by web-based interactive learning media compared to the direct learning model.

The results of the analysis showed that both groups experienced an increase in mathematical communication skills after the learning process. In the experimental class, the average score increased from 33.78 to 80.22. The increase is also seen in the maximum score which changes from 52 to 96 and the minimum score from 20 to 60. These findings show that the increase occurs in almost all students, both those with low and high initial ability.

Meanwhile, the control class also increased, with the average score increasing from 33.67 to 67.22. The maximum score increases from 48 to 80 and the minimum score from 20 to 32. However, the improvement achieved by the control class was still lower than that of the experimental class.

Based on these results, it can be concluded that both learning models contribute to the improvement of mathematical communication skills, but the Problem-Based Learning (PBL) model assisted by web-based interactive learning media shows more optimal results in developing these skills.

Judging from each indicator, the improvement in mathematical communication ability in the experimental class was seen to be higher than that of the control class. In the indicator of the use of symbols or mathematical notation in problem modeling, the value increased from 40.6% to 95.0%, while the control class increased from 35.6% to 81.7%. The ability to communicate mathematical ideas logically also increased from 39.4% to 74.4%, while the control class increased from 31.7% to 67.8%.

In the indicator of drawing conclusions based on the reasoning results, the experimental class increased from 43.3% to 87.8%, while the control class increased from 37.2% to 68.3%. Overall, the posttest achievement of the experimental class was in the high to very high category, thus showing that the application of Problem-Based Learning (PBL) was more effective in improving students' mathematical communication skills compared to direct learning.

The results of the descriptive analysis showed that students' self-awareness increased in both groups after the learning process. In the experimental class, the average score increased from 55.72 to 88.67. The maximum score goes up from 70 to 95, while the minimum score increases from 30 to 79. This improvement shows that the Problem-Based Learning (PBL) model assisted by web-based interactive learning media is able to encourage the development of students' self-awareness evenly.

In the control class, the average score increased from 55.83 to 79.78. The maximum score increases from 75 to 93, while the minimum score increases from 30 to 60. Despite the improvement, the results obtained are still below the achievement of the experimental class.

In general, both learning models have a positive influence on the development of students' self-awareness. However, a greater improvement in the experimental class showed that the Problem-Based Learning (PBL) model assisted by web-based interactive learning media was more effective in fostering self-awareness than the direct learning model.

Based on the measured aspects, the increase in self-awareness in the experimental class appeared to be more consistent. In the aspect of recognizing emotions, the ability to understand the meaning and influence of emotions increased from 56.0% to 87.9%, while the control class increased from 55.2% to 76.5%. The ability to use emotions as a guideline to act on values and goals increased from 57.2% to 91.9%, higher than the control class which increased from 58.0% to 83.7%.

In the aspect of self-recognition, an increase occurred in indicators of awareness of self-strengths and weaknesses, self-reflection, ability to learn from experience, and openness to feedback. A fairly pronounced difference was seen in the indicators of learning from past experiences, where the experimental class increased from 60.3% to 90.0%, while the control class only increased from 40.2% to 61.1%.

In terms of confidence, both groups have increased. However, the experimental class showed better development in the indicator of courage to express an opinion, from 55.3% to 83.3%, while the control class increased from 36.9% to 64.1%. Overall, the results show that learning in the experimental class provides a more equitable increase in self-awareness, especially in the aspects of self-reflection and emotion management which are the main focus of learning.

Inferential analysis was used to compare the average mathematical communication skills and self-awareness of students before and after treatment in the experimental class and the control class. The comparison of pre-treatment data aimed to determine the equivalence of the initial abilities of the two groups, while the comparison of post-treatment data was used to test the research hypothesis regarding the effectiveness of the Problem-Based Learning (PBL) model assisted by web-based interactive learning media compared to the direct learning model in improving students' mathematical communication skills and self-awareness.

Multivariate normality tests are performed to ensure that the research data comes from a normally distributed population before hypothesis testing is carried out. The test was carried out by analyzing the Pearson correlation coefficient between the Mahalanobis distances using the help of *IBM SPSS Statistics 26*. The data is declared to be normally distributed when the value of the Pearson correlation coefficient is greater than the critical value of the correlation of 0.9652 (Johnson & Wichern, 2019).

The results of the analysis showed that all research data met the assumption of multivariate normality. In the experimental class, the value of the Pearson correlation coefficient for *the pretest* data was 0.971 and *the posttest* was 0.975. Meanwhile, in the control class, a correlation coefficient value of 0.986 was obtained for *the pretest* and 0.980 for *the posttest*. All of these values are above the correlation critical value of 0.9652, so it can be concluded that *the pretest* and *posttest* data in both groups come from a normally distributed population. Thus, the multivariate normality assumption has been fulfilled and the data are feasible for use in follow-up analysis. The full test results are presented in Appendix 20 (Johnson & Wichern, 2019).

The homogeneity test aims to determine the similarity of the variance-covariance matrix between the experimental group and the control group. The test was conducted using *the Box's M* test with the help of *IBM SPSS Statistics 26*. The decision-making criterion used is that the data is declared homogeneous if the significance value is greater than the significance level of 0.05.

Based on the test results, *the pretest* data obtained a Box's M value of 6.598 with a significance of 0.699. The *posttest* data produced a Box's M value of 15.123 with a significance of 0.176. The two significance values are greater than 0.05, indicating that the variance-covariance matrix in the experimental class and the control class is homogeneous.

The fulfillment of the homogeneity assumption in the *pretest* and *posttest* data shows that the two groups have equal data characteristics in terms of variance and covariance. Therefore, the data meet the requirements to proceed to the hypothesis testing stage using inferential analysis. The results of the homogeneity test in detail can be seen in Appendix 20.

An average similarity test was performed to find out whether the experimental class and the control class had equivalent initial capabilities before the treatment was given. Analysis using MANOVA Hotelling's  $T^2$  on *data to pretest* mathematical communication skills and *self-awareness* with the help of *IBM SPSS Statistics 26*. The test results showed a significance value of 0.998 which was greater than 0.05. Thus,  $H_0$  is accepted, so that there is no difference in the initial ability of mathematical communication or *self-awareness* between the two groups before learning is carried out. This condition shows that both classes have equivalent initial characteristics so it is feasible to use to compare the effectiveness of the treatment given (Johnson & Wichern, 2019).

The effectiveness analysis was conducted to assess whether the Problem-Based Learning (PBL) model assisted by web-based interactive learning media and the direct learning model met the effectiveness criteria based on *posttest* data. Learning is declared effective if the average mathematical communication ability exceeds the KKTP of 75 and the average *self-awareness* reaches a very high category with a minimum score of 84.

The test was carried out using Hotelling's  $T^2$  to determine the effectiveness of each learning model simultaneously on mathematical communication skills and *self-awareness*. The results of the analysis showed that both the experimental class and the control class had a significance value of 0.000 ( $< 0.05$ ). These results show that the mean vectors of the two variables differ from the reference values that have been set, so further analysis using a one-sample t-test is needed to determine which variable meets the effectiveness criteria.

The results of the one-sample t-test in the experimental class showed a t-value of calculating mathematical communication skills of 4.164 with a significance of 0.000. Because the significance value is less than 0.05 and t calculates a positive value, the average mathematical communication ability is proven to be higher than that of KKTP 75. Thus, the

Problem-Based Learning (PBL) model assisted by web-based interactive learning media is effectively reviewed from the students' mathematical communication skills.

In the *self-awareness variable*, a calculated t-value of 5.892 with a significance of 0.000 was obtained. These results show that the average *self-awareness* of students exceeds the reference score of 84, so that the Problem-Based Learning (PBL) model assisted by web-based interactive learning media is also effective in increasing *self-awareness*.

On the other hand, in the control class, the t-value of mathematical communication ability was -3.571 with a significance of 0.001. This value shows that the average score has not reached the set KKTP. Similar results were found in the *self-awareness variable* with a t-value of -3.659 and a significance of 0.001, indicating that the average score has not reached the very high category. Therefore, the direct learning model was declared not to be effective in reviewing the two research variables (Field, 2018).

This analysis was conducted to find out whether there is a difference in effectiveness between the Problem-Based Learning (PBL) model assisted by web-based interactive learning media and the direct learning model on students' mathematical communication skills and *self-awareness*.

The difference in effectiveness of the two models was analyzed using MANOVA Hotelling's  $T^2$  on *posttest* data. The test results showed a significance value of 0.000 ( $< 0.05$ ), so  $H_0$  was rejected. These findings show a significant difference in effectiveness between the experimental class and the control class after the treatment was administered. In other words, there was an average difference in mathematical communication skills and *self-awareness* between the two groups (Johnson & Wichern, 2019).

In mathematical communication skills, a calculated t-value of 5.172 with a significance of 0.004 was obtained. Because the significance value is less than 0.05, it can be concluded that the Problem-Based Learning (PBL) model assisted by web-based interactive learning media is more effective than the direct learning model in improving students' mathematical communication skills. These findings are in line with research showing that web-based media and interactive activities are able to increase student participation, motivation, and the quality of mathematical communication (Sahudra et al., 2024).

In the *self-awareness variable*, a calculated t-value of 5.709 with a significance of 0.000 was obtained. These results show that the Problem-Based Learning (PBL) model assisted by web-based interactive learning media is also more effective than direct learning in increasing students' *self-awareness*. Active involvement in the problem-solving process and the use of interactive media provides opportunities for students to better understand themselves, reflect on the learning process, and increase awareness of their abilities (Simal et al., 2022).

## Discussion

The *Problem-Based Learning* (PBL) model supported by web-based interactive learning media provides a learner-centered learning experience through real problem solving. This approach encourages students to actively discuss, exchange ideas, and convey solutions orally and in writing so that mathematical communication skills develop more optimally (Chen et al., 2019). In addition, the use of web-based media allows students to learn more flexibly according to their respective learning needs and characteristics (Yusup et al., 2024).

PBL also contributes to increasing *self-awareness* because students are involved in the process of reflection, self-evaluation, and group cooperation. Through these activities, students can recognize their strengths and weaknesses and understand their contribution to the learning process (Carden et al., 2021). The use of digital technology also supports the development of metacognitive skills that are important in independent and continuous learning (Sevilla, 2021).

The results of the study showed that PBL learning assisted by web-based interactive media was effective in improving mathematical communication skills and *self-awareness*. These findings are supported by the results of statistical tests that show significant differences between the experimental group and the control group. Theoretically, these results are in line with the view of social constructivism that emphasizes the importance of interaction, collaboration, and reflection in building knowledge (Manu, 2023). During the learning process, students were seen actively discussing, completing LKPD, taking quizzes, and presenting the results of group work. This condition is in line with research that states that PBL is able to improve mathematical communication while developing students' self-awareness (Marlina et al., 2023).

Based on the results of *the One Sample T-Test*, the PBL model assisted by web-based interactive learning media has proven to be effective in improving students' mathematical communication skills. The average score increased from 33.78 in the *pretest* to 80.22 in the *posttest*, which shows that students are able to develop the skills of conveying mathematical ideas more clearly and systematically.

These findings support various studies that state that PBL can improve learning engagement, argumentative skills, and mathematical communication through collaborative activities and problem-solving (Ameliyah et al., 2024). PBL also helps students build a deeper conceptual understanding because they are directly involved in the process of finding and explaining solutions. In addition, this approach provides opportunities for students to participate according to their abilities thereby increasing confidence and social interaction during learning (Novitasari et al., 2024). Thus, the application of PBL assisted by web-based interactive media not only supports the mastery of mathematical material, but also strengthens students' mathematical communication skills through active, collaborative, and problem-solving-oriented learning (Muhayaroh & Pertiwi, 2023).

The results of the study showed that PBL assisted by web-based interactive media was effective in increasing *students' self-awareness*. The average score increased from 55.72 in the *pretest* to 88.67 in the *posttest*, which indicates the development of self-awareness after the application of learning.

The increase occurred because students were given the opportunity to evaluate the learning process, recognize their strengths and weaknesses, and develop learning strategies independently. These findings are in line with research that states that the use of web-based media is able to increase students' motivation, engagement, and self-awareness in the learning process (Simal et al., 2022). In addition, the interactive element in PBL has been proven to encourage active participation and improve students' self-reflection skills (Arfianti & Azmi, 2021).

These results are also in accordance with the theory of social constructivism which asserts that learning will be more meaningful when students actively build knowledge through continuous interaction and reflection (Vygotsky, 1978). Therefore, the PBL model assisted by web-based interactive learning media can be declared effective in developing *students' self-awareness*.

The hands-on learning model emphasizes the delivery of material by teachers through demonstrations, structured exercises, guided exercises, and self-paced exercises. Although this approach is able to help students understand basic concepts systematically, the results show that its effectiveness is still lower than the PBL model assisted by web-based interactive media.

The results of the analysis showed that the direct learning model did not meet the criteria for effectiveness in improving students' mathematical communication skills. Limited opportunities to discuss, argue, and communicate mathematical ideas cause the development of students' communication skills to be less optimal.

These findings are in line with several studies that state that conventional learning tends to be teacher-centered, so it does not provide space for students to actively build understanding and convey their mathematical ideas (Sakdiyah et al., 2024). In addition, the lack of social interaction during learning also reduces students' opportunities to develop thinking and communication skills as described in Vygotsky's theory (1978).

Thus, the direct learning model is considered not effective in improving students' mathematical communication skills.

*Self-awareness* is the ability of individuals to recognize emotions, understand their strengths and limitations, and be aware of their influence on behavior and decision-making (Lawrence, 2018). In this study, direct learning has not been able to achieve the set *self-awareness* category.

This condition can be caused by limited opportunities for students to reflect, receive feedback, and interact deeply with friends and teachers. As a result, students are less encouraged to evaluate themselves and develop awareness of the learning process undertaken. These results are in line with research showing that conventional learning tends to be less supportive of the development of self-reflection and active involvement of students (Hariyanto & Köhler, 2020). Therefore, the direct learning model is considered not effective in increasing student *self-awareness*.

Based on the results of *the independent sample t-test*, the *Problem-Based Learning* model assisted by web-based interactive learning media has been proven to be more effective than the direct learning model in improving students' mathematical communication skills and *self-awareness*.

The advantage of PBL can be seen from the higher average learning outcomes compared to the control class. Through problem-solving activities, group discussions, and the use of interactive media, students gain more opportunities to put forward ideas, formulate arguments, and explain the problem-solving process in a systematic manner. These findings support research that confirms that PBL is able to integrate cognitive, social, and metacognitive skills needed in 21st-century learning (Siregar, 2023).

The use of web-based media also strengthens student involvement because learning becomes more interesting, contextual, and relevant to daily life (Fitrianingsih et al., 2024).

PBL assisted by web-based interactive media also showed higher effectiveness in developing *self-awareness*. The process of group work, discussion, and giving feedback allows students to recognize their abilities, increase their sense of responsibility, and develop confidence in facing learning challenges.

These findings are in line with research showing that web-based learning and interactive activities are able to increase student motivation, participation, and self-awareness (Sahudra et al., 2024). In contrast, hands-on learning that is more teacher-centered tends to provide more limited space for students to reflect and build deep self-awareness (Arfianti & Azmi, 2021).

Overall, the results of the study confirm that *the Problem-Based Learning* model assisted by web-based interactive learning media is the most effective model in improving students' mathematical communication skills and *self-awareness* compared to the direct learning model.

#### 4. Conclusion

Based on the results of the research on the application of *the Problem-Based Learning* (PBL) model assisted by web-based interactive learning media in class X students of SMK Negeri 1 Tarakan, it can be concluded that the model is effective in improving students' mathematical communication skills and *self-awareness*. This effectiveness is shown by the average mathematical communication ability that has exceeded the school KKTP, which is 75, as well as the average *self-awareness* which is above the score of 84 and belongs to the very high category.

In contrast, the hands-on learning model has not met the established effectiveness criteria. The average mathematical communication ability of students is still below KKTP 75, while the average *self-awareness* has not reached a score of 84. However, the learning results showed an increase in mathematical communication skills and *self-awareness* after the learning process.

Overall, the results of the study prove that the *Problem-Based Learning* (PBL) model assisted by web-based interactive learning media has a higher level of effectiveness than the direct learning model in improving students' mathematical communication skills and *self-awareness*. These findings show that learning that emphasizes problem-solving, collaboration, and the use of web-based interactive media can provide more optimal learning outcomes than teacher-centered learning.

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