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Implementation of the problem-based learning model assisted by web-based practical media simulation on students' metacognitive abilities and activeness

Karlina [a,1], Etika Dyah Puspitasari [b,2*], Fika Enggar Prayogo [c,3]

[a,b] Universitas Ahmad Dahlan, Jl. Ringroad Selatan, Tamanan, Kec. Banguntapan, Kabupaten Bantul, Daerah Istimewa Yogyakarta, 55191, Indonesia
[c] Senior High School, 7155 5421 Al Zalaq, Al-Rehab, Jeddah 23343, Saudi Arabia
[1]karlina1900008083@webmail.uad.ac.id; [2]etika.puspitasari@pbio.uad.ac.id*; [3]fikaprayogo@gmail.com
*author correspondences

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ABSTRACT

Metacognition plays a crucial role in regulating and controlling students' cognitive processes in learning, thinking, and problem-solving. Teachers have not yet assessed students' metacognitive abilities. In biology learning at SMAN 1 Ngemplak, teachers focus more on theory, resulting in suboptimal student engagement. One factor is the less engaging learning activities, resulting in students being more interested in using their mobile phones than in the teacher. This study aimed to determine the effect of the PBL model supported by web-based simulation media on students' metacognition in the digestive system and student engagement. This study employed a quasi-experimental design with a pretest-posttest approach. The population consisted of 65 students from class XI MIPA at SMAN 1 Ngemplak (two classes), and the sample used was saturated. Data collection was conducted through observation and tests, utilizing research instruments that included student engagement observation sheets and test question sheets. The data analysis techniques used were descriptive and inferential. The hypothesis test used was the Mann-Whitney U test. The results of this study showed a significant value of $p < 0.05$, indicating that there is no influence of the PBL model assisted by web-based practical media simulation on students' metacognitive abilities. The findings imply that while PBL combined with web-based simulation enhances student engagement, it does not significantly improve metacognition. Therefore, educators should complement this approach with explicit metacognitive training to develop students' cognitive regulation skills. Integrating interactive media with strategies targeting metacognition can create more balanced and effective biology learning experiences.

INTRODUCTION

Twenty-first-century learning is student-centered and emphasizes the development of thinking skills, including metacognition, critical thinking, collaboration, problem-solving, communication, information literacy, as well as innovation and creativity (Mardhiyah et al., 2021). In this era, learning is not solely based on knowledge acquisition but also on essential skills, one of which is metacognitive ability. This ability plays a vital role in enabling students to regulate and manage their own learning processes, thereby enhancing learning effectiveness and adaptability across various contexts (Mishra et al., 2020; Müller & Mildenberger, 2021; Papagiannis & Pallaris, 2024).

Metacognition is the ability to construct complex thoughts (Soto *et al.*, 2019). In general, teachers have directed students to play an active role in biology learning in class, but have not empowered students' metacognitive and critical thinking skills (Sholihah *et al.*, 2016). Although teachers can provide metacognitive support through instruction, there are still difficulties in implementing strategies consistently and effectively (Zepeda et al., 2019). Metacognitive skills are still under-assessed by teachers, resulting in many students still not understanding or comprehending what they are learning. Students with good academic performance are often unable to provide solutions when asked about the material they have learned, and students with poor metacognitive skills are unable to monitor, assess, and solve their own problems (Amirul, 2021). In line with van Loon & Roebers van Loon & Roebers (2024), Students with low metacognitive skills tend to experience difficulties in understanding the subject matter's concepts because they are less able to monitor and regulate their own learning process.

Based on observations at SMAN 1 Ngemplak, teachers have not yet assessed students' metacognitive abilities, so the school supports research related to student metacognitive abilities. Metacognition plays a crucial role in regulating and controlling students' cognitive processes in learning, thinking, and problem-solving. Therefore, to make learning more effective and efficient, its implementation must be carried out through appropriate learning models. (Mardhiyah *et al.*, 2021). One application is the Problem-Based Learning model. The Problem-Based Learning model applied to science learning has been proven to improve students' metacognitive abilities effectively (Wirzal et al., 2022).

Problem-Based Learning (PBL) is an instructional model that presents students with real-world problems to encourage collaborative learning, critical thinking, analytical reasoning, and the ability to identify and utilize appropriate learning resources (Hotimah, 2020). Integrating PBL with suitable learning media, such as web-based platforms, can enhance learning effectiveness by supporting both the problem-solving process and learner autonomy. Website-based media offer flexible access to learning materials, allowing students to control the pace of their learning and choose resources that align with their individual preferences. This personalization supports the core principles of PBL, where students are expected to take ownership of their learning journey and explore solutions through self-directed inquiry (Rini et al., 2022). Moreover, website-based media are particularly effective in facilitating practical activities through virtual laboratories. According to Melennia (2021), web-based virtual labs are more cost-effective than traditional labs, as they eliminate the need for physical tools and materials. They also allow repeated practice, helping students reinforce their understanding and improve their experimental and analytical skills. In today's technology-driven era, teachers are encouraged to integrate these tools into science instruction—for example, using website-based virtual labs for digestive system topics, such as food testing—to create more engaging and efficient learning experiences.

Based on interviews with biology teachers, student engagement is still relatively low. Research conducted by Sukasih (2022) shows that teacher performance and the classroom environment have a significant impact on student attitudes and engagement in the classroom. Student engagement is a thought process for learning that determines the success of learning (Pangestu & Rohinah, 2019). During the learning process, if student activity is low, it will result in students being passive, bored, more focused on their mobile phones, experiencing poor learning outcomes, and having a reduced ability to express opinions, ask questions, or provide answers. This finding aligns with research by Freeman et al. (2014), which demonstrates that active learning significantly enhances student performance in science, engineering, and mathematics subjects, while also reducing failure rates.

Based on the problems above, innovation is needed in the learning process to achieve maximum learning outcomes, namely by varying strategies, media, and learning models. This study aims to determine the implementation of the PBL model, assisted by Web-based practical media simulations, on students' metacognitive abilities and activeness.

METHOD

This study uses a quantitative research method with a quasi-experimental research design. The research design is a pretest-posttest design (Rukminingsih et al., 2020). The population used in this study consisted of 65 students from class XI MIPA at SMAN 1 Ngemplak (2 classes). The sample used was saturated. The method of determining the control class and the experimental class was a random sampling technique, involving the drawing of lots. The instruments used observation sheets and closed questionnaires. Data analysis techniques included both descriptive and inferential methods. Data analysis used SPSS 25. Inferential techniques in the form of prerequisite tests (normality and homogeneity) and hypothesis testing.

This study uses eight metacognitive components, which include declarative, procedural, conditional, planning, information management, monitoring, improvement, and evaluation. Four components of student activity include visual activities, oral activities, listening activities, and writing activities. Hypothesis testing uses Mann-Whitney U at a significance level of 0.05. The control group utilizes the PBL learning model with 32 students, while the experimental class employs the PBL learning model supplemented by website-based practicum media simulation with 33 students. The website media used is https://chamberofbiology.com/?module=materi-ubm. Data collection was conducted over three meetings. The interval scale criteria related to student activity are presented in Table 1. As for the metacognitive criteria are presented in Table 2.

Table 1. Student Activity Interval Scale Criteria (Arikunto, 2017)

No	Scale	Criteria
1	75%-100%	High
2	51%-74%	Moderate
3	25%-50%	Low
4	0%-24%	Very low

Table 2. Metacognitive Interval Scale Criteria (Mastika et al., 2014)

No	Percentage Range	Criteria
1	85% < X ≤ 100%	Excellent
2	65% < X ≤ 85%	Good
3	45% < X ≤ 65%	Fair
4	25% < X ≤ 45%	Poor
5	0% < X ≤ 25%	Very insufficient

RESULTS AND DISCUSSION

The results of the study (Table 3) show that the percentage of metacognitive values in the control class and the experimental class had nearly the same average value, namely 71% (experimental) and 70% (control).

Table 3. Percentage of Average Metacognitive Values of the Experimental Class

No	Indicator	Experiment		Control	
		Percentage (%)	Category	Percentage (%)	Category
1	Declarative	71	Good	68	Good
2	Procedural	70	Good	72	Good
3	Conditional	71	Good	70	Good
4	Planning	71	Good	70	Good
5	Information Management Strategy	71	Good	71	Good
6	Monitoring	71	Good	69	Good
7	Improvement	75	Good	71	Good
8	Evaluation	70	Good	69	Good
Average		**71**	**Good**	70	**Good**

The metacognitive assessment results show that the experimental class scored 71% in the declarative, conditional, planning, information management strategy, and monitoring indicators—categorized as good. The procedural and improvement indicators scored 70% and 75%, respectively, and are also in the good category. In the control class, the declarative indicator scored 68%, procedural 72%, conditional and planning 70%, information management strategy and improvement 71%, and monitoring and evaluation 69%—all of which were categorized as good. Overall, the experimental class achieved a higher average metacognitive score of 71% compared to the control class, indicating better metacognitive development.

The syntax of PBL consists of student orientation to problems, organizing students to learn, guiding individual/group experiences, developing and presenting work results, and analyzing and evaluating (Arends, 2012). Based on research by Tahar (2022), the syntax of the PBL learning model is closely related to three components of metacognitive skills: planning, monitoring, and evaluation indicators.

In the planning indicator, there is an influencing syntax, namely the second syntax (organizing students to learn). In the experimental class, the percentage of 71% is categorized as good, and the control class has a percentage of 70%, also categorized as good; therefore, the experimental class has the higher percentage. This indicates that students use planning effectively in solving problems, such as explaining the concepts they have learned, solving a problem, reading instructions before working on an assignment, and managing their time to complete the goal. The high metacognitive ability in the planning indicator is due to the fact that, in PBL, students are required to be active in solving problems. This aligns with Celiker (2015), who stated that in the problem-solving process, students utilize their metacognitive awareness by engaging in active problem-solving, identifying concepts, and evaluating problems. This is also reinforced by Baumanns and Rott (2023), who stated that in the open problem-solving process, students exhibit strong metacognitive behavior, especially during the planning stage, as they need to reformulate the problem and organize appropriate solution strategies.

In the monitoring indicator, there is an influencing syntax, namely the third syntax (guiding individual/group experiences). In the experimental class, the percentage of 71% is categorized as good, and the control class has a percentage of 69%, also categorized as good. Therefore, the class with the higher percentage is the experimental class. The monitoring indicator requires students to monitor their understanding and learning process. The high metacognitive ability in the monitoring indicator is because in PBL, students are required to collect relevant information when solving problems, and this practice is encouraged. This finding aligns with the research of Delclos & Harrington in Schraw & Graham (2015), which demonstrates that monitoring abilities improve with training and practice. The importance of practice in the monitoring process is also shown by Santiago et al. (2024), who suggest that metacognitive interventions that direct students to monitor and reflect on their thinking processes during problem-solving can explicitly improve performance in problem-based tasks. In line with this, practice-based learning equipped with feedback can strengthen metacognitive monitoring skills (Del Olmo-Muñoz et al., 2024). Increasing awareness in the learning process requires students to be able to represent their thoughts by designing, monitoring, and assessing what they should learn, so that the learning and thinking carried out by students becomes more effective and efficient.

In the evaluation indicator, there is an influential syntax, namely the fifth syntax (analyzing and evaluating). In the experimental class, the percentage of 70% is categorized as good, and the control class has a percentage of 69%. Therefore, the class with the higher percentage is the experimental class. The evaluation indicator enables students to assess the extent of their understanding of the knowledge, their ability to complete tasks, summarize learned material, and be confident in their final answers. In the evaluation indicator in PBL, students are required to analyze and evaluate when solving problems. Highly metacognitive students can ask themselves whether they understand the learning process or not. This aligns with the research of Scrhraw and Graham (2015), which suggests that students engage in self-talk or introspection about the learning difficulties they encounter. In evaluating planning, students are asked to use a checklist to assess the strategies they employ and monitor their understanding of problem-solving. These findings are reinforced by a study conducted by Ilahi et al (2024), who conducted a meta-analysis and concluded that problem-based learning has a moderate effect on improving student metacognition in science learning, with an rRE effectiveness value of 0.67. This suggests that PBL encourages students to be more reflective and conscious in evaluating their learning strategies. Furthermore, Marthaliakirana et al. (2022) revealed that integrating metacognitive guidance into the PBL model significantly improved students' ability to construct arguments and think critically, which are closely related to self-evaluation in higher-order thinking processes.

Based on the research conducted, PBL syntax has a higher improvement indicator percentage than the other eight indicators. Syntactically, it can be seen that PBL should influence the planning, monitoring, and evaluation indicators. This research is inconsistent with Tahar's (2022) findings, which suggest that the syntax of the PBL learning model is closely related to three components of metacognitive skills: planning, monitoring, and evaluation indicators. However, in this study, PBL emphasizes learning syntax, which involves learning steps carried out by teachers, ensuring a well-structured learning process. Additionally, in the implementation of PBL, teachers can prepare students to learn effectively. Therefore, the implementation of PBL, assisted by website-based practicum media simulations that incorporate metacognition, aims to provide students with an understanding of how to think, thereby training them to develop metacognitive abilities.

PBL assisted by website-based simulation media for practical work has not yet had an impact on metacognitive abilities because this metacognitive research was only conducted for the first time at the school. Other influencing factors include students' inability to organize learning sequentially, their lack of awareness in summarizing what has been learned, and their lack of awareness in analyzing the effectiveness of learning strategies. The experimental class had a higher average percentage score than the control class. Research by Kamaliyah et al. (2022) revealed that factors such as learning readiness, motivation, and the ability to plan learning strategies play a crucial role in the development of students' metacognitive abilities. Students' lack of awareness in analyzing the benefits of the learning strategies used can hinder their metacognitive development.

During the learning process in the experimental class, over three meetings, the website-based simulation of practical media enabled students to hone their metacognitive skills in solving the presented problems. Furthermore, the website-based practical media included learning videos, thus providing an opportunity for students to develop metacognitive skills. This also aligns with the implementation of the Project-Based Learning model, which, assisted by interactive web-based media, can significantly improve metacognitive skills, allowing students to control their thinking processes and awareness in solving problems (Nurhaliza et al., 2024).

The implementation of the PBL model assisted by website-based practicum media has its own advantages or strengths where the website-based practicum media has a concise, easy-to-understand explanation of the material, there are practicum instructions, and learning material videos so that it makes it easier for students to carry out practicums directly in the laboratory because students before the practicum directly first do a website-based practicum simulation so that it provides convenience and increases student knowledge. This website-based learning media is also more student-oriented. This virtual laboratory enables students to engage with the subject matter in greater depth, enhance their conceptual understanding, and develop higher-order thinking skills (Noris, Muhammed et al., 2023). Students have an excellent opportunity to learn and understand the problems they repeatedly encounter, ultimately achieving a deeper understanding.

In this study, the PBL learning model, supported by website-based practical simulations, proved to be more effective than other learning models. This finding is consistent with Pujiati's (2015) research, which suggests that problem-based learning models can enhance students' metacognition. This is supported by Nurrita's (2018) research, which identified easy access as one of the criteria for effective learning media. Based on this, websites are considered an effective learning medium because they are easily accessible and accessible.

Table 4. Normality Test of Metacognitive Results

Kolmogorov-Smirnov[a]	Experiment	Control
	Sig. 0.142	Sig. 0.000
Description	Normally distributed	Not Normally Distributed

Table 4 shows that, based on the Kolmogorov-Smirnov normality test, the experimental class data showed a significant difference 0.142, indicating a normal distribution. In the control class, the normality test value was 0.000, indicating a non-normal distribution. Based on the non-normal distribution of the test data, a non-parametric test, the Mann-Whitney U-test, was used.

Table 5. Homogeneity Test of Metacognitive Results

Metacognitive	Levene Statistic		
	Sig.		**Description**
	0.912		Homogeneous

In Table 5, the homogeneity test results obtained were 0.912, indicating that the results are greater than 0.05. Therefore, the data in the two classes are considered homogeneous.

Table 6. Non-Parametric Hypothesis Test

Metacognitive			
	Mann-Whitney U	**Asymp. Sig. (2-tailed)**	**Description**
	393.500	0.072	H0 accepted

Several factors influence students' metacognitive abilities, including their conditions for solving problems. Students who experience difficulties or confusion in solving problems, cannot correct errors in working on questions, and lack accuracy in re-checking the answers they have obtained. Some students consciously solve the problems given, but some students answer carelessly, cheat with friends, fail to evaluate, and cannot explain what they know from the problem. This is in accordance with research by Kamaliyah et al. (2022), who stated that factors influencing students' metacognitive abilities include learning readiness, learning motivation, not planning effective strategies for problem-solving, not recognizing when a concept is inappropriate, and not evaluating well. Students' metacognitive abilities can be developed by working on critical analysis questions, allowing them to practice thinking logically, analytically, evaluatively, and creatively. This is supported by research from Schraw and Dennison (1994), which shows that students who are metacognitively aware are more strategic and perform better than those who are not. This awareness allows individuals to plan, sequence, and monitor their learning, directly improving performance.

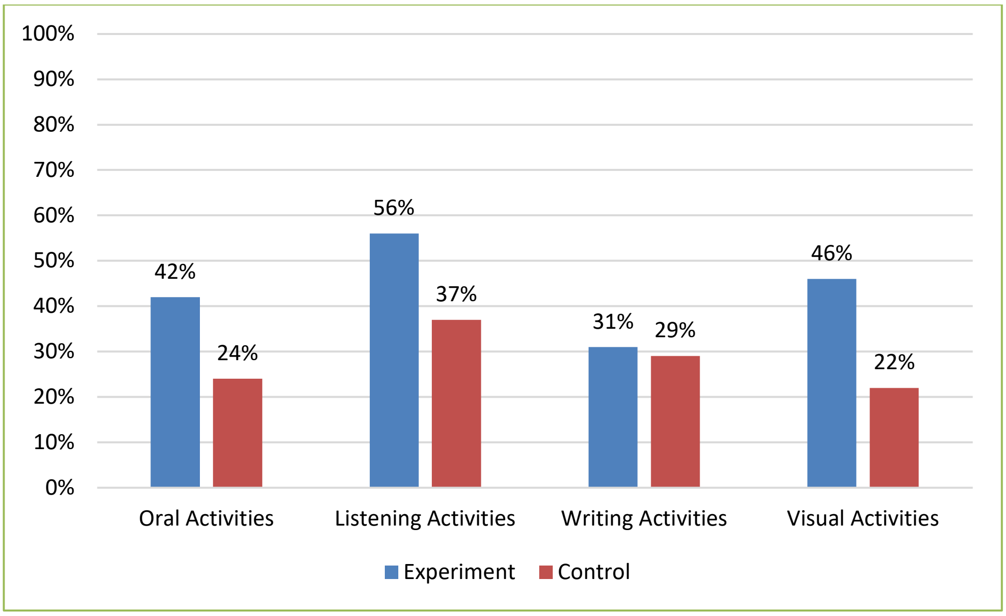

Figure 1. Percentage of Average Activeness Values of Experimental and Control Classes

Based on Figure 1, the percentage of student activity in the experimental class, with four indicators consisting of oral, listening, writing, and visual, shows that the oral activities indicator has a percentage of 42% and is categorized as low. The listening activities indicator has a percentage of 56% and is categorized as medium. The writing activities indicator has a percentage of 31% and is categorized as low. The visual activities indicator has a percentage of 46% and is categorized as low. In the control class, it can be seen that the oral activities indicator has a percentage of 24% and is categorized as low. The listening activities indicator has a percentage of 37% and is categorized as low. The writing activities indicator has a percentage of 29% and is categorized as low. The visual activities indicator has a percentage of 22% and is categorized as low. It can be said that the average value of student activity in the control class using the PBL model is lower than that of the experimental class using the PBL model assisted by website-based practicum media simulation.

Based on the data analysis, the average percentage of student activity shows that the experimental class has an average of 45% higher than the control class, with an average of 28%. This indicates that both classes fall into the low category. However, the PBL model, assisted by web-based practicum media, affects activating students, as indicated by statistical data. In terms of the average percentage value, the experimental class tends to have a low to moderate value, while the control class tends to have a lower value. This is because the implementation of learning is not optimal. Additionally, during the learning process, the student's active participation was not always evident during the three meetings. In the first meeting, the primary activities were oral and listening exercises. In the second meeting, the activities included visible components such as oral, listening, and visual elements. In the third meeting, the visible activities included oral, listening, writing, and visual components.

The low percentage of student engagement can be attributed to the group-based nature of the learning process, which limited opportunities for all students to express their opinions. Many students were still hesitant or lacked the confidence to participate. During presentations and discussions, participation was dominated by a small group of students, indicating uneven engagement. Although the PBL model supported by website-based simulations was implemented consistently, active involvement remained concentrated among a limited number of students. Additionally, writing activities were only assessed during the third meeting, when students submitted their lab reports, offering limited insight into students' ongoing written engagement. These findings suggest that the model has not yet succeeded in fostering equitable and meaningful student participation across the class.

This study is not in accordance with the research of Nurrohim et al. (2022), which states that the problem-based learning (PBL) model is perfect for increasing student learning activity. This shows that several factors influence student activity, namely visual activities: students ignore the teacher during demonstrations and do not read the material before learning begins, oral activities: students do not dare to express their opinions, students still have a sense of shame, when given discussion material only the same students speak, students who make presentations are the same, and do not engage in group discussions; listening activities: students do not listen to the teacher's explanation; and writing activities: students do not complete assignments on time. Additionally, low student activity is influenced by both internal and external factors. This is in accordance with the research of Prasetyo & Rabiman (2015), which suggests that the factors influencing student activity are external factors (influences received by students from the external environment) and internal factors (influences from within the student).

Based on the data analysis in Figure 1, it can be seen that the high percentage of listening activities indicators is influenced by the first syntax (student orientation to the problem), the second syntax (organizing students to learn), the fourth syntax (developing and presenting work results), and the fifth syntax (analyzing and evaluating the problem-solving process). This is in accordance with the research of Hidayah et al. (2018) that the syntax related to the listening activities indicator is the first syntax: student attention in following the learning process or listening to the teacher's explanation in solving problems, the second syntax: students listen to the teacher's explanation, the fourth syntax: students listen to the teacher's explanation, the fifth syntax: students pay attention to the teacher's explanation.

In this study, the indicator of listening activities was higher in the experimental class than in the control class. The experimental class utilized video materials and website-based practical simulations, which contributed to increased student attention and engagement during the learning process. Websites functioned not only as a source of content delivery but also as interactive learning tools that stimulated students' interest and focus. According to Maemunah and Alwie (2019), website-based learning media can enhance students' motivation and encourage greater involvement in classroom activities, including listening. This is particularly important in the context of modern learners, who are already familiar with digital platforms for entertainment; repurposing these platforms for educational use creates a more relatable and engaging learning environment (Yunus et al., 2013).

Furthermore, the integration of multimedia elements—such as audio-visual explanations, animations, and simulations—within website-based platforms supports diverse learning styles and sustains student attention during instruction. Mayer's Cognitive Theory of Multimedia Learning (2009) explains that multimedia learning materials can help learners process information more effectively by combining auditory and visual channels, which in turn supports better comprehension and retention. Thus, in the context of this study, the application of the PBL model combined with website-based practical media simulations positively influenced students' listening activities by providing engaging, interactive, and multimodal learning experiences.

Table 7. Normality Test of Activity Results

Kolmogorov-Smirnov[a]	Experiment	Control
	Sig. 0.097	Sig. 0.032
Description	Normally distributed	Not Normally Distributed

Table 7 shows that the experimental class, based on the Kolmogorov-Smirnov normality test, showed a significancy at 0.097, indicating that the data were normally distributed. In the control class, as the significancy at 0.032, indicated that the data were not normally distributed.

Table 8. Homogeneity Test of Activity Results

Activeness	Levene Statistic		
	Sig.		**Description**
	0.008		Not homogeneous

Table 8 shows the results of the Levene Statistic test, sig. 0.008, which indicates that the results are smaller than 0.05, so the data in the two classes are said to be non-homogeneous.

Table 9. Non-Parametric Hypothesis Test

Activeness			
	Mann-Whitney U	**Asymp. Sig. (2-tailed)**	**Description**
	31.000	0.000	H0 is rejected

Based on Table 9, it can be seen that the results of the non-parametric test show a significant result. Value of 0.000, which means the result is <0.05, so H0 is rejected and H1 is accepted with the interpretation that there is an influence of the PBL model assisted by website-based practicum media simulation on student activity, so that there is a significant difference between the experimental class and the control class. This finding aligns with the research of Wardani et al. (2021), which suggests a significant influence of the PBL approach on student activity. This is supported by the research of Fauzan et al. (2017), which explains that the application of the PBL model can increase student activity, thereby impacting their understanding of what they are learning, improving problem-solving skills, and enhancing students' cognitive learning outcomes.

In this study, the application of the PBL model, aided by website-based learning media, has an impact on student activity. This aligns with Irwandani's (2014) research, which suggests that web media is an effective learning medium, as it provides an alternative that is believed to capture students' attention in the learning process. This research is supported by Utami et al. (2020), who found that learning using website-based learning media is effective. In addition, research by Irwandani (2014) demonstrates that learning through website-based learning media is effective for students' independent and interactive learning, ultimately increasing their activity and involvement in the learning process.

CONCLUSION

Based on the findings, it can be concluded that the PBL model assisted by web-based practical media simulations did not significantly impact students' metacognitive abilities. However, it had a positive influence on student engagement in learning about the digestive system, particularly in food testing. Throughout the implementation, the learning process generally proceeded smoothly, with students demonstrating enthusiasm toward the use of interactive and visually engaging website-based simulations. Nevertheless, active participation was still limited to a select group of students, indicating a need for further refinement in promoting equitable engagement. Some students were hesitant to express their opinions during group discussions, and time constraints during practical sessions were identified as a challenge. Overall, the integration of web-based simulations within the PBL framework was well received and showed potential to enhance student engagement when properly managed and supported.

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