Active learning using PBL and DELMAN method to enhance students' Higher Order Thinking Skills (HOTS) on Coulomb's Law material

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Abstract
This study aimed to investigate: (1) the enhancement of students' HOTS, and (2) the effectiveness of the Problem Based Learning (PBL) model combined with the DELMAN method in enhancing students' HOTS in the context of Coulomb's Law. This study employed a quasi-experimental design utilizing a non-equivalent control group. The participants consisted of two classes of Grade 12 students: one class of Science 2 students as the experimental group, while a class of Science 1 students as the control group. A HOTS test consisting of 12 multiple-choice questions was used as the research instrument. Data analysis was conducted using N-Gain scores and General Linear Model (GLM). The findings showed a notable difference in the improvement of HOTS between the experimental and control groups, with a significance level of <0.05. The experimental group, which utilized the PBL model combined with the DELMAN method, achieved a gain score classified as moderate, while the effect size was considered very large. These findings suggest that the PBL model combined with the DELMAN method is effective in enhancing the HOTS of high school students.

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1. Introduction

The learning process is an activity where teachers, students, and lesson materials interact within a supportive learning environment. The interaction between teachers and students is the key element of this process (Rustaman, 2007; Rohmah, 2017). As facilitators, teachers have a vital role in choosing suitable teaching methods to aid students in effectively grasping the material. By choosing the right methods, an active, meaningful, and enjoyable learning experience can be created.

Active learning methods encourage students to actively participate in their learning by thinking, discussing, investigating, and creating. According to Warsono & Hariyanto (2012), active learning involves students being actively engaged throughout the learning process. This method enables students to consistently acquire meaningful learning experiences and encourages them to think critically about their actions throughout the lesson. Silberman (2010) adds that active learning encourages students to actively engage in hands-on experiences, rather than simply learning concepts or theories. Active learning occurs when students enjoy seeking out new information, answering questions, solving problems, or exploring how to complete tasks.

According to Suyadi (2013), active learning has several distinct characteristics: 1) It focuses on the learning process, 2) Students are not passive, 3) Emphasis is placed on exploring values and attitudes related to the subject matter, 4) Students are encouraged to think critically, analyze, and evaluate, rather than just memorizing theories, and 5) Quick feedback is integrated into the learning process. Ubaduddin (2020) defines active learning as any approach where students take an active role in their learning. Zaini (2011) further explains that active learning enables students to solve problems on their own and apply their knowledge in practical tasks. In conclusion, active learning is student-centered, emphasizes discovery, is enjoyable, incorporates various methods and media, and

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builds on existing knowledge. Through active learning, teachers guide students to consistently engage in more meaningful learning experiences and reflect on their actions throughout the process.

One type of active and student-centered learning method is problem-based learning (Silberman, 2008; Ubaduddin, 2020). PBL is an instructional model that positions students at the center of the learning process, where they encounter real-world problems that require investigation and collaborative problem-solving (Meke et al., 2019; Putra & Iswantir, 2021; Nurhayati et al., 2021). Through PBL, students not only acquire academic knowledge but also cultivate critical, creative, and analytical thinking skills necessary for addressing complex issues (Hmelo-Silver, 2004; Meke et al., 2019). Students who engage in PBL demonstrated superior abilities in communication, analysis, and problem-solving compared to those who were taught using conventional methods (Yanti, 2017; Hasrawati et al., 2020; Rahmi et al., 2022; Hidayat & Taufiqurrahman, 2022).

Numerous studies have shown the success of PBL in physics education. Chamidah and Suhartono (2022) found that the implementation of PBL and STEM at Hang Tuah 4 Surabaya High School significantly enhanced students' HOTS. Another study by Putra & Iswantir (2021) highlighted that although there were challenges in implementing HOTS through PBL, it effectively enhanced students' critical thinking abilities. Nurhayati et al. (2021) demonstrated that PBL enhances students' analytical and creative skills in physics learning. Similarly, Amelia (2019) found that STEM-based PBL effectively enhanced problem-solving skills in mathematics. Arviani et al. (2023) also supported the impact of PBL on enhancing students' HOTS, showing that students who learned through PBL had better analytical skills compared to those taught through conventional methods. This aligns with Zou et al. (2020) assertion that conventional learning methods may not be effective enough in delivering this material adequately. Freeman et al. (2014) argue that traditional learning, which relies on passive lecture methods where the teacher presents material while students only take notes, can limit student engagement and make it more difficult for them to understand and apply concepts or skills. Moreover, when students merely observe without actively participating, they miss valuable opportunities for hands-on experience and skill practice (Onge & Eitel, 2017). Therefore, it is crucial for educators to adopt active, student-centered learning strategies that encourage students to construct their own knowledge.

In problem-based physics learning, supporting methods are needed to embed concepts effectively and help students construct their understanding. PBL in physics, especially when paired with experimental methods, fosters effective collaboration. (Liana et al., 2020; Sakliressy et al., 2021). Liana et al. (2020) demonstrated that PBL, integrated with experimental methods, enhances students' HOTS, especially in thermodynamics. Sakliressy et al. (2021) also showed that combining PBL with experimental methods can enhance students' scientific attitudes, achieving a score of 74.14, which is considered high. Suryaningsih (2017) described experimentation as a learning activity that enables students to test and apply theoretical knowledge using resources both within and outside the laboratory. According to Supriadi and Lismawati (2018), experimental activities are essential for enhancing students' comprehension of the material, providing two main advantages. Firstly, they allow students the autonomy to test and apply theories through hands-on experimentation. Second, experiments spark interest in concept development, providing students with direct experience to observe phenomena (Supriadi & Lismawati, 2018). Additionally, in 21st-century learning, experiments are one way to make students more active in discovering physics concepts, alongside processes such as observation, project assignments, simulations, exploration, and collaboration (Etkina et al., 2017; Wilcox & Lewandowski, 2017; Estuhono, 2022; Sakliressy et al., 2021). Experiments also help develop students' collaboration and communication skills (Wiwin & Kustijono, 2017; Malik & Ubaidillah, 2021; Estuhono, 2022).

Physics experiments are essential in physics education. The physics experiment course in high school plays a vital role in cultivating students' scientific thinking and inquiry skills, and it helps them understand the laws of physics more effectively (Ma et al., 2021). The use of experimental learning methods helps students grasp concepts in a more concrete and visible way (Qiao et al., 2019; Azzahra et al., 2024). High school students, in particular, benefit from hands-on experiences, as these allow them to observe physics principles firsthand, which helps them understand the concepts better than through explanations alone (Chun et al., 2020). The experimental method can help students enhance higher-order thinking skills, including critical thinking (Agustin et al., 2023). This is because the experimental method offers students the flexibility to manipulate and solve the given problem independently.

Several previous studies have shown the positive impact of using experiments in the learning process. According to Azzahra et al. (2024), experiment-based learning methods tend to be more engaging for students because they actively involve them in the learning process, increasing their motivation to understand physics concepts. Additionally, experimental methods can enhance motivation (Wati et al., 2021), student interest (Nugroho & Waslam, 2020), student activity (ETP et al., 2014; Telaumbanua, 2017), and learning outcomes (ETP et al., 2014; Zakiyah et al., 2019; Wati et al., 2021). When students are engaged in experiments, the information taught becomes more meaningful and sparks more interest (Djudin, 2018; Fardela et al., 2024). According to Liana et al. (2020), PBL supported by experiment-based media can enhance students' HOTS in thermodynamics. Hanifah et al. (2023) added that contextual physics learning through experiments can enhance learning outcomes in thermodynamics. The development of physics learning devices based on guided inquiry with experiments can enhance students' creativity (Wahyuni et al., 2019).

In addition to the experimental method, the use of the demonstration method in teaching can also help students build knowledge and promote active learning. According to Muhajir (2020), this method involves the teacher demonstrating tasks to students instead of merely explaining them. The demonstration method involves the teacher actively demonstrating a process, concept, or activity while explaining it to the students (Suaedy, 2011). This approach is particularly useful in subjects like physics, where abstract concepts can be difficult for students to understand through lectures alone (Rosmaya et al., 2018). By observing a demonstration, students are provided with a concrete example, helping them to better visualize and comprehend the material. Demonstrations typically include the use of equipment, models, or simulations to illustrate concepts in real-time. According to Bhoki (2023), the demonstration method enhances active learning in several ways: 1) It encourages student engagement, 2) It promotes critical thinking, 3) It helps build students' confidence, 4) It facilitates practical learning, and 5) It provides visual aids. This method enhances students' understanding and retention by engaging them directly, encouraging critical thinking, building confidence, supporting experiential learning, and providing visual aids (Hajar et al., 2021).

Several studies have highlighted the positive impact of the demonstration method in physics education. The method enhances students' learning outcomes (Rosmaya et al., 2018; Djatmiko et al. 2020; Siska et al., 2023), enhances students' achievement in physics (Soe & Nyunt, 2018), enhances student performance (Rakhshand & Dafiyah, 2024), boosts learning activities (Ozuho et al., 2021), and strengthens conceptual understanding (Ozuho et al., 2021; Rakhshand & Dafiyah, 2024). Additionally, Rakhshand & Dafiyah (2024) note that demonstration methods increase student engagement, interest, and inclusivity, receiving positive feedback from both students and teachers. This study highlights the transformative potential of demonstration methods in physics education and emphasizes the importance of innovative teaching practices in supporting student learning and engagement. This is in line with the research by Kruglak (1952), which proved that there is a significant difference between students taught with the demonstration method and those using conventional methods, particularly in terms of learning outcomes. Hardyaningtyas & Arty (2023) showed that the use of learning devices developed with the demonstration method had a positive impact on enhancing students' critical thinking skills and self-efficacy. They argued that learning tools based on the demonstration method help students achieve a deeper understanding of the material by exposing them to real-life problems and direct evidence related to the topic.

The demonstration and experimental methods are believed to enhance student engagement and students' thinking skills. Research by Jannah et al. (2014) supports this statement, showing that physics lessons at SMA Negeri 1 Pakusari using a cooperative learning model through lesson study combined with the demonstration method led to very high levels of student engagement. Likewise, Mariya (2023) found that the application of the experimental method in science education can enhance students' higher-order thinking skills, with an N-Gain score of 0.7, which falls into the high category. Amaliya & Anas (2024) showed the impact of using the experimental method to improve students' higher-order thinking skills, with hypothesis testing results using the paired sample t-test in IBM SPSS, which obtained a significance value (2-tailed) of $0.000 < 0.05$. Liana et al. (2020) applied PBL supported by IoT-based experimental media to enhance students' HOTS skills. The results showed that the significant impact of IoT-based experimental media on improving HOTS can be seen from the Multivariate Test analysis on GLM, which revealed a partial eta squared value of 85.9%. Susiyanti (2020) showed that the demonstration method can enhance students' higher-order thinking skills from the pre-cycle phase to the end of cycle II, with an improvement of 96%. A study by Santoso and Gunanto (2024) indicates that the application of the demonstration method successfully optimized students' critical thinking abilities. This success is reflected in students' ability to interpret, evaluate, and synthesize when applying the steps of the demonstration method. A study by Flamboyant et al. (2018) also indicated that PBL, which integrates both demonstration and experimental methods, can significantly enhance students' HOTS in physics topics such as Archimedes' Principle, with an effect size analysis of 0.53, which falls under the moderate category. Through demonstration and experimentation activities, students are trained to develop critical thinking, analytical skills, and problem-solving abilities (Kartikasari et al., 2018). A study by Sari et al. (2024) showed that the experimental method is quite effective in improving students' learning outcomes in science, with an N-gain of 41.35% or 0.4135. This research suggests that teachers should consider applying the experimental method in science instruction.

Based on the explanation above, this research will implement PBL using a combination of demonstration and experimentation methods. Additionally, the researcher will integrate science literacy into the learning process to help improve literacy levels at SMAN 1 Balai Riam. This combination is applied for several reasons: (1) Theoretically, it can help students link new phenomena and improve their learning outcomes, and (2) incorporating a variety of teaching strategies and methods in presenting material increases students' motivation to participate actively in learning, facilitating better understanding and retention (Ubaduddin, 2020). In addition, literacy, which encompasses reading, writing, and information processing skills, is strongly linked to the development of higher-order cognitive abilities such as critical thinking, problem-solving, and analytical skills (Mohseni et al., 2020; Barr et al., 2020; Zulyusri et al., 2022). Enhancing students' literacy levels can improve their capacity for higher-order thinking, which is essential for academic success and lifelong learning (Barr et al., 2020). Several studies have demonstrated a positive relationship between literacy and the development of higher-order thinking skills. For instance, research by Fatimah and Marnita (2023) found that literacy-based learning can enhance students' higher-order thinking skills, including critical thinking. Nasution (2023) showed a significant difference in physics learning outcomes between classes taught using literacy-based learning and those taught using conventional methods. However, other studies highlight that students' science literacy skills are still low (Stacey, 2011; Kusumastuti et al., 2019; Putranta et al., 2021). This is due to students' inability to develop their reasoning skills, as they lack the habit of reading while thinking and working to understand essential and strategic information in solving problems (Jurnaidi & Zulkardi, 2014). According to Ngertini et al. (2013), skills such as logical thinking, higher-order thinking, initiative, and adaptability to change and development are the skills that lead students to possess literacy competence. Based on this explanation, it can be assumed that higher-order thinking skills are connected to literacy abilities. Therefore, in addition to applying PBL using a combination of demonstration and experimentation methods, this study is also science literacy-based.

Science literacy is closely connected to activities that students regularly participate in, both in the classroom and in daily life, which require them to understand potential occurrences and apply physics concepts to find solutions (Jonāne, 2015; Putranta et al., 2021). Such activities, including observing natural events or engaging in simple activities like traditional games, highlight the need for students to choose the most effective strategies based on their existing knowledge of physics concepts (Yilmaz et al., 2012). Furthermore, studies have demonstrated that students' science literacy can be improved by integrating digital or Android-based learning tools (Liu et al., 2018; Putranta et al., 2021). Therefore, it can be concluded that high school students can enhance their science literacy by utilizing their understanding of physics concepts to analyze and address real-world physics issues, supported by digital learning resources. In this study, science literacy is assessed through questions designed to be completed by students during the learning process.

The three methods in this research are combined into an acronym called DELMAN, which stands for Demonstration, Literacy, and Experimentation. Although studies on the use of PBL, experimentation, and demonstration methods have been conducted separately to enhance student learning outcomes, very few studies have explored combining PBL with both methods for the same purpose (Mayanti et al., 2022). Additionally, no research has yet incorporated a literacy method into this combination. Therefore, this study will apply PBL using the DELMAN method. The aim is to evaluate the effectiveness of the PBL model combined with the DELMAN method in improving students' HOTS on the topic of Coulomb's Law.

2. Method

This study utilized a quantitative research approach, specifically a quasi-experimental design with a non-equivalent control group. The research population included all Grade 12 students at SMAN 1 Balai Riam for the 2024/2025 academic year. The sample was chosen through total sampling, with Grade 12 Science 2 students serving as the experimental group and Grade 12 Science 2 students as the control group. Data collection involved administering a HOTS test to evaluate students' skills in analysis, evaluation, and creation. The HOTS test instrument, which was validated by content experts, was analyzed using Aiken's V with the equation (Adlina, A., & Supahar, 2019):

$$V = \sum \frac{s}{[n(c-1)]} \quad (1)$$

Interpretation of the Aiken's V value using the product categories presented in Table 1 (Aiken, 1985).

Table 1. Product Criteria

Interval Aiken's V Value	Category
$0.8 < V \leq 1$	Excellent
$0.6 < V \leq 0.8$	Good
$0.4 < V \leq 0.6$	Fair
$0.2 < V \leq 0.4$	Poor

The enhancement in students' HOTS is assessed through gain score analysis. This test was conducted both before and after the learning process. The gain score is calculated using the following formula (Meltzer, 2002):

$$g = \frac{posttest\ score - pretest\ score}{maximum\ score - pretest\ score} \quad (2)$$

The gain score is used to interpret the enhancement in students' HOTS according to the gain score criteria outlined in Table 2.

Table 2. The Gain Score Criteria

Gain Score	Category
$g \geq 0.7$	High
$0.3 \leq g < 0.7$	Moderate
$g < 0.3$	Low

The effectiveness of the PBL model combined with the DELMAN method in enhancing students' HOTS was evaluated through statistical testing using the General Linear Model (GLM) analysis, facilitated by the SPSS application. The research stages are depicted in Figure 1.

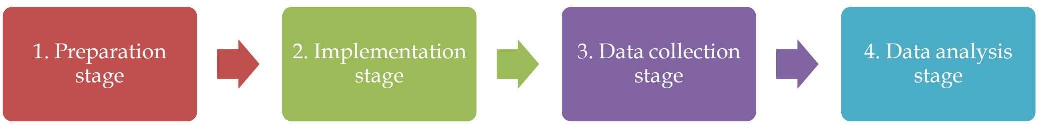

Figure 1. The Research Procedures

Based on Figure 1, before the actual learning began, the researchers planned their study, selected participants, obtained approval from the school principal, and developed teaching materials and tests to evaluate HOTS. These tests were reviewed by three experts to ensure their validity. The results of the test instrument validation by content experts are presented in Table 3. Result of Instrument Test Validity.

Table 3. Result of Instrument Test Validity

Item	V Value	Category
1	0.89	Excellent
2	0.89	Excellent
3	1.00	Excellent
4	1.00	Excellent
5	1.00	Excellent
6	0.89	Excellent
7	1.00	Excellent
8	1.00	Excellent
9	0.78	Good
10	0.89	Excellent
11	1.00	Excellent
12	0.78	Good

After the tests were confirmed as valid, they were used to evaluate the students' HOTS. During the learning process, the researchers implemented a PBL model combined with the DELMAN method. The students took the HOTS test both before and after these learning sessions. Once the learning was complete, the researchers collected data by administering the test again, followed by data analysis.

3. Results and Discussion

The research was conducted using a quasi-experimental model consisting of two groups: an experimental group and a control group. The experimental group was taught using the PBL model combined with the DELMAN method, while the control group followed conventional learning methods. The learning sessions were conducted twice, beginning with a pretest and ending with a posttest. In the experimental group, during the first meeting, the topic discussed was the basic concept of Coulomb's Law. In the second meeting, the topic focused on the application of Coulomb's Law in daily life. Each session began with a demonstration relevant to the topic being taught. The demonstrations presented problems that students were required to solve. Then, students were given specific time to engage in independent literacy using digital learning materials prepared by the teacher to analyze the problems at hand. Afterward, students were organized into small groups to conduct experiments and solve the problems. In the first meeting, the experiment utilized a virtual lab, namely PhET Colorado, while the second meeting involved simple tools from the surrounding environment to conduct experiments observing the interaction between charged objects. The science literacy activities in this study involve using practice questions designed with 6 indicators derived from OECD (2010), namely procedural knowledge, content knowledge, epistemic knowledge, interpreting data and evidence scientifically, explaining phenomena scientifically, and evaluating scientific inquiry processes. In contrast, the control group used conventional teaching methods with textbooks as learning media. The pretest and posttest results from both the experimental and control classes were analyzed to observe the improvements that occurred in both groups after the intervention. Table 4 presents the gain score analysis results, showing the enhancement in students' HOTS in both the experimental and control groups.

Table 4. Result of HOTS Test

Class	Average HOTS		Gain Score	Category
	Pretest	Posttest		
Experimental	60.20	84.24	0.60	Moderate
Control	58.80	73.32	0.35	Moderate

The analysis of students' HOTS revealed a gain score of 0.60 for the experimental group, classified as moderate, and 0.35 for the control group, also moderate. These findings align with those of Arviani et al. (2023) and Sutika et al. (2022), which indicated that implementing PBL in instruction can improve students' HOTS on Coulomb's Law Material. As shown in Table 4, both groups experienced enhancement in HOTS test results, with the experimental group demonstrating a greater increase than the control group. According to Liana et al. (2020), PBL is highly effective in boosting students' HOTS. This is further supported by Rinesti et al. (2019), who argued that PBL not only enhances students' HOTS but also fosters greater classroom engagement. Other studies, such as those by Zikriana et al. (2021) and Mayanti et al. (2022), have shown that combining PBL with experimental and demonstration methods effectively enhances students' learning outcomes.

The General Linear Model (GLM) statistical test was performed using the SPSS software to analyze students' pretest and posttest scores. This analysis aimed to (1) assess the enhancement in HOTS for both the experimental and control groups, and (2) evaluate the effectiveness of the PBL model combined with the DELMAN method in enhancing students' HOTS on Coulomb's Law Material. Prior to conducting the GLM test, assumption tests were completed to verify the normality and homogeneity of the sample. The results confirmed that the sample was normally distributed and homogeneous, as shown in Table 5 and Table 6.

Table 5. Outcome of the Normality Test

Variable	Sig.	Category
Pretest_Experimental	0.153	Normal
Posttest_Experimental	0.162	Normal
Pretest_Control	0.399	Normal
Posttest_Control	0.324	Normal

Table 6. Outcome of Homogeneity Test

Variable	Box's M	F	Sig.	Category
HOTS	6.724	2.140	0.093	Normal

The analysis conducted with the GLM statistical test reveals students' HOTS on Coulomb's Law Material, which can be visualized in the Plot of Estimated Marginal Means, displayed in Figure 2.

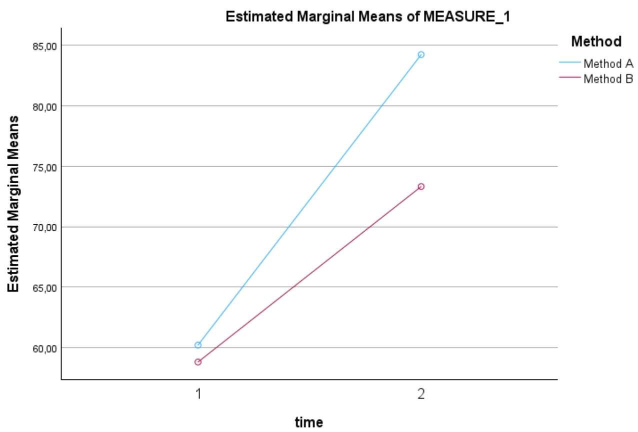

Figure 2. Graph of Estimated Marginal Means

Description: Method A (experimental group), Method B (control group)

Figure 2 illustrates the enhancement in students' HOTS on Coulomb's Law Material for both the experimental and control groups, with the experimental group exhibiting a more substantial increase than the control group. The graph further suggests that there is no interaction effect between the experimental and control groups. To validate the hypothesis, a multivariate test was performed, with the outcomes displayed in Table 7.

Table 7. Result of Hotteling's Trace Test

Effect	Sig.	Decision Criteia	Decision
Hotteling's Trace	<0.001	Sig. <0.05	H_0 rejected

The Hotelling's Trace test results indicate a significance value below 0.05, leading to the rejection of H0. This suggests a significant difference in the mean enhancement of students' HOTS on Coulomb's Law Material between the experimental group, which applied the PBL model with the DELMAN method, and the control group, which followed conventional teaching methods. Based on these findings, an additional effectiveness test was carried out to assess the impact of the PBL model combined with the DELMAN method on enhancing students' HOTS on Coulomb's Law Material. The results of the effect size analysis are shown in Table 8.

Table 8. Effect Size

Variable	ES	Interpretation
The PBL Model with the DELMAN Method	1.727	Very Large

The effect size analysis indicates that the PBL model with the DELMAN method has a very large impact on enhancing students' HOTS on Coulomb's Law Material. These findings are consistent with research by Arviani et al. (2023), which also highlighted the PBL model's significant role in boosting students' HOTS. Implementing the PBL model with the DELMAN method enables students to thoroughly grasp conceptual material, as this approach effectively cultivates their ability to build knowledge across various HOTS dimensions. It also enhances their communication, reasoning, problem-solving, and self-assessment skills (Akmalia et al., 2016; Meke et al., 2019; Hidayat & Taufiqurrahman, 2022).

A multivariate statistical test was conducted to assess the effective contribution of teaching variables, measured using Partial Eta Squared. The contributions of each variable to the teaching process are detailed in Table 9.

Table 9. Effective Contribution of HOTS Variable

Variable	Class	Sig.	Partial Eta Squared
The PBL Model with the DELMAN Method	Experimental	<0.001	0.749

Table 9 presents the effective contribution of the method applied to the variables examined in the Wilks' Lambda test. The experimental class shows an effective contribution of 74.9% to HOTS. These results suggest that the experimental class contributes more effectively than the control class, confirming that the PBL model combined with the DELMAN method is effective in enhancing students' HOTS on Coulomb's Law Material.

4. Conclusion

The research findings demonstrate that the PBL model, when paired with the DELMAN method, effectively enhances the HOTS of high school students studying Coulomb's Law. A significant difference in HOTS improvement was observed between the experimental and control groups, with a significance level below 0.05. The experimental group's gain score, using the PBL model with DELMAN, falls within the moderate range, with a very large effect size. This outcome suggests that the PBL model combined with the DELMAN method is indeed effective in enhancing the HOTS of high school students.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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