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Development of Physics Electronic Student Worksheets (E-LKPD) based on Problem Based Learning (PBL) to Improve Critical Thinking Skills of Grade X Students

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Abstract: Critical thinking skills are essential in 21st-century education. However, physics learning in schools still relies on conventional teaching materials and limited instructional approaches, resulting in students' low critical thinking skills. Therefore, this study aimed to develop a Problem-Based Learning (PBL)-based Physics Electronic Student Worksheet (E-LKPD) and examine its feasibility and effectiveness in improving students' critical thinking skills. This research employed a Research and Development (R&D) approach using the Four-D (4-D) development model. The effectiveness of the developed E-LKPD was evaluated using a pretest–posttest control group design. Data were collected through interviews, observations, questionnaires, tests, and documentation. The results showed that the developed E-LKPD was highly feasible based on expert validation, practical based on students' responses, and effective in improving students' critical thinking skills. The experimental class achieved a higher N-Gain score (0.364, medium category) than the control class (0.265, low category). These findings indicate that integrating PBL into interactive digital worksheets supports student-centered learning and promotes students' critical thinking skills. Therefore, the developed PBL-based Physics E-LKPD can be used as an effective digital teaching material for improving students' critical thinking skills.

Keywords: Critical thinking skills; E-LKPD; Physics learning; Problem-based learning

Introduction

21st-century education requires students to possess a variety of higher-order thinking skills, one of which is critical thinking. Critical thinking skills are essential for problem-solving, decision-making, and logically and rationally analyzing and evaluating information in daily life (Anggraeni et al., 2023; Ariadila et al., 2023; O'Reilly et al., 2022). Additionally, this skill is reflected in the ability to regulate oneself, draw inferences, and evaluate information logically to understand concepts (Khasanah et al., 2019). Students who possess critical thinking skills can understand complex information and make better judgments and decisions (Dwyer, 2023). These skills can be developed through the learning process (Viennot, 2020). Therefore, the development of critical thinking skills needs to be integrated into the learning process, including in physics education.

Physics learning in schools still faces many challenges. Based on observations and interviews at SMA Negeri 1 Sewon, Yogyakarta, it was found that teachers tend to use conventional textbooks and worksheets that contain material and questions. In addition, the learning model is not varied and is not optimal in training students to think critically. This results in students being less actively involved in the learning process and has an impact on their low critical thinking skills. Meanwhile, this school has implemented the Merdeka Curriculum. Learning in the Merdeka Curriculum is student-centered and allows students to

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learn effectively according to their style and interests (Artisari et al., 2024; Kurdi et al., 2024). This student-centered learning model can encourage critical thinking skills (Darwati & Purana, 2021). Therefore, innovative physics learning is needed to encourage active involvement and train students' critical thinking skills.

One student-centered learning model is Problem-Based Learning (PBL). This model can be used to develop various skills, including critical thinking skills (Nirmayani & Suastra, 2023). Various studies have shown that the application of the PBL model in learning can improve students' critical thinking skills (Anggraeni et al., 2023; Habibah et al., 2022; Huda & Abduh, 2021; Indriani et al., 2022; Liu & Pásztor, 2022). The PBL model focuses on presenting real-world problems as stimuli to spark interest and encourage students to think critically in understanding the essence of the material, collaborate, and seek solutions to the problems (Aprina et al., 2024; Rahmadani & Anugraheni, 2017). From a constructivist perspective, meaningful learning occurs when students actively construct their understanding through authentic learning experiences (Jonassen, 1999; Savery & Duffy, 1995). Accordingly, PBL provides opportunities for students to develop critical thinking skills through active engagement in solving contextual problems (Hmelo-Silver, 2004). Therefore, the PBL model is a relevant and effective approach to apply in learning to develop students who are able to think critically in facing various contextual problems in real life.

With the development of technology, the use of digital teaching materials has become an innovative solution that can support learning. Digital technology can serve as a tool to support the development of various skills among students, as well as enhance an engaging and innovative learning environment, thereby fostering students' interest in learning (Haleem et al., 2022; Permana et al., 2024). One innovation in utilizing this technology is the creation of educational materials such as Electronic-LKPD (E-LKPD). E-LKPD has advantages over conventional worksheets because it can be accessed flexibly, presented with an attractive interface, supports self-directed learning, and trains students to engage in higher-order thinking (Martatiyana et al., 2024; Masruroh, 2024; Rahayu et al., 2021; Saraswati & Suhartini, 2024; Sariani & Suarjana, 2022; Suradi et al., 2024; Yulanda et al., 2023). Thus, the use of technology such as E-LKPD not only supports the development of students' skills but also provides a more interactive, engaging, and effective learning experience. The integration of digital learning media with appropriate instructional models can create meaningful learning experiences that actively engage students in the learning process (Jonassen, 1999; Mishra & Koehler, 2006). Therefore, integrating the PBL model into E-LKPD can support student-centered learning while facilitating the development of students' critical thinking skills (Sakdiyah et al., 2026).

Given the importance of technology integration in learning and the low level of critical thinking skills among students, there is a need for innovative teaching materials that can facilitate students in developing critical thinking skills. PBL-based e-LKPD is one of the right solutions because it can provide a contextual learning situation and encourage students to be directly involved in the problem-solving process. Through the PBL approach, students are encouraged to identify problems, develop problem-solving steps, gather relevant information, make decisions or arguments based on logical reasoning, and analyze and evaluate problem-solving (Arends, 2012; Pakpahan et al., 2025). This process aligns with critical thinking indicators such as inference, recognizing assumptions, deduction, interpretation, and evaluating arguments (Watson & Glaser, 2002). Thus, PBL-based E-LKPD has great potential to enhance students' critical thinking skills.

However, based on the observations and interviews conducted at SMA Negeri 1 Sewon, the worksheets currently used still mainly emphasize procedural exercises rather than contextual problem-solving activities that foster students' critical thinking skills. This condition indicates the need for learning resources that integrate problem-based learning into physics instruction. Therefore, developing a PBL-based Physics E-LKPD is important to provide an interactive digital worksheet that supports student-centered learning and enhances students' critical thinking skills (Heldalia et al., 2025; Sakdiyah et al., 2026).

This study aims to develop PBL-based E-LKPD for physics on vector material, as well as to test its validity and effectiveness in improving the critical thinking skills of 10th grade students at SMA Negeri 1 Sewon. The developed E-LKPD is expected to provide an interactive learning resource that supports student-centered learning and improves students' critical thinking skills.

Method

Time and Place of the Research

This study employed a Research and Development (R&D) approach and was conducted at SMA Negeri 1 Sewon, Yogyakarta, Indonesia, during the second semester of the 2024/2025 academic year, from March to May 2025.

Research Design

This study employed a Research and Development (R&D) method using the Four-D (4-D) development model, which consists of four stages: define, design, develop, and disseminate (Sugiyono, 2013). The effectiveness of the developed product was evaluated

using a True Experimental Design with a Pretest–Posttest Control Group Design, as illustrated in Figure 1. Two classes were randomly selected (R), with the experimental class receiving the treatment (X) in the form of the developed PBL-based E-LKPD, while the control class received conventional instruction. O1 and O3 represent the pretest scores, whereas O2 and O4 represent the posttest scores for the experimental and control classes, respectively. The population of this study consisted of all Grade X students at SMA Negeri 1 Sewon, Yogyakarta, during the 2024/2025 academic year. The research sample comprised 32 students, consisting of 18 students from Class X-7 as the experimental class and 14 students from Class X-2 as the control class. The sample was selected using the cluster random sampling technique (Sugiyono, 2013). The independent variable in this study was the Problem Based Learning (PBL)-based Physics Electronic Student Worksheet (E-LKPD), while the dependent variable was students' critical thinking skills. Data were collected through interviews, observations, questionnaires, tests, and documentation. The research instruments included interview guidelines, observation sheets, expert validation sheets, student response questionnaires, and critical thinking test instruments. The materials used in this study included the developed PBL-based Physics E-LKPD on vector material and the supporting learning modules used during the implementation.

R	O_1	X	O_2
R	O_3		O_4

Figure 1. Pretest-posttest control group design

Research Procedure

The research procedure followed the Four-D (4-D) development model proposed (Sugiyono, 2013), which consists of four stages: define, design, develop, and disseminate. During the define stage, classroom observations and interviews with physics teachers were conducted to identify learning problems, students' needs, and the characteristics of the curriculum. The design stage involved preparing the PBL-based Physics E-LKPD, developing learning activities, research instruments, and assessment tools, as well as designing the E-LKPD using Canva before converting it into an interactive flipbook using Heyzine. In the develop stage, the product was validated by experts, revised based on the validators' suggestions, and tested for practicality and effectiveness through student response questionnaires and classroom implementation. Finally, the disseminate stage involved implementing and distributing the final version of the developed E-LKPD after it had met the feasibility and effectiveness criteria.

Research Data Analysis

The data analysis in this study consisted of feasibility analysis, student response analysis, and effectiveness analysis of the developed PBL-based Physics E-LKPD. The feasibility of the developed E-LKPD was evaluated by four expert validators, consisting of two material experts and two media experts. The feasibility score was calculated using Equation (1) (Ernawati, 2017), and the results were interpreted according to the feasibility criteria presented in Table 1 (Arikunto & Jabar, 2009).

$$\text{Feasibility Percentage} = \frac{\sum \text{Total score}}{\sum \text{Maximum score}} \text{ x } 100\% \quad (1)$$

Table 1. Feasibility Category

Score (%)	Category
< 21 %	Not Feasible
21 – 40 %	Less Feasible
41 – 60 %	Fairly Feasible
61 – 80 %	Feasible
81 – 100 %	Highly Feasible

Student responses to the developed E-LKPD were analyzed using Equation (2). The obtained scores were interpreted based on the response criteria presented in Table 2 (Hermawan, 2021).

$$\text{Response Percentage} = \frac{\sum \text{Total score}}{\sum \text{Maximum score}} \text{ x } 100\% \quad (2)$$

Table 2. Categories of Student Responses to E-LKPD

Score (%)	Category
0 – 20 %	Very Poor
21 – 40 %	Poor
41 – 60 %	Fair
61 – 80 %	Good
81 – 100 %	Very Good

The effectiveness of the developed PBL-based Physics E-LKPD was evaluated using the pretest and posttest scores obtained from the experimental and control classes. The normality of the data was examined using the Kolmogorov–Smirnov and Shapiro–Wilk tests (Nuryadi et al., 2017). Since the data were not normally distributed, the Wilcoxon Signed-Rank Test was used to analyze the differences between the pretest and posttest scores within each group, whereas the Independent-Samples Mann–Whitney U Test was employed to compare the posttest scores between the experimental and control classes (Muhid, 2019). Furthermore, the improvement in students' critical thinking skills was measured using the normalized gain (N-Gain) score (Hake, 1998). The N-Gain categories are presented in

Table 3. Higher N-Gain scores indicate greater improvement in students' critical thinking skills, with a higher N-Gain score in the experimental class indicating greater improvement than in the control class.

Table 3. N-Gain Categories

Percentage Range (%)	Category
$g \geq 0.7$	High
$0,3 \leq g < 0.7$	Medium
$g < 0.3$	Low

Result and Discussion

This study was conducted at SMA Negeri 1 Sewon, Yogyakarta, with students in grades X-2 and X-7 in the 2024/2025 academic year. The research activities were carried out between March 2025 and May 2025 using a Research and Development (R&D) model focused on the development of PBL-based physics E-LKPD. The development model used was the 4-D model, which consists of four steps: define, design, develop, and disseminate.

Needs Analysis Results

Based on the results of the observations and interviews, it was found that teachers only used conventional worksheets. Additionally, the lack of variety in the learning model and its ineffectiveness in training critical thinking skills were identified as the main issues contributing to the low level of critical thinking skills among students. The curriculum used at SMA Negeri 1 Sewon is the Merdeka Curriculum. In physics lessons, textbooks and printed student worksheets containing materials and questions are also used.

E-LKPD Design Results

The following step is the design stage, which involves creating an E-LKPD based on PBL to enhance learning based on the analysis that was done. The final product is an E-LKPD that was made in PDF format with Canva and turned into a flipbook with Heyzine. As a result, this E-LKPD is accessible online through a variety of devices, including laptops, personal computers (PCs), and cellphones. Figure 2 depicts the developed product's appearance.

The E-LKPD developed contains a title page, instructions for use, learning objectives, material descriptions, learning activities based on PBL syntax, and evaluations. The learning stages based on PBL syntax are also intended to improve critical thinking skills. The indicators of critical thinking are inference, recognizing assumptions, deduction, interpretation, and evaluation of arguments (Watson & Glaser, 2002).

Figure 2. E-LKPD design

Validation and Practicality Results

The development stage aimed to determine the feasibility and practicality of the developed E-LKPD before its implementation in learning activities. The validation test was conducted by four validators who provided assessments and recommendations for product improvement. The results of the E-LKPD feasibility analysis are presented in Table 4.

Table 4. E-LKPD Feasibility Scores

Validator	Percentage	Category
Validator 1	86,67%	Highly Feasible
Validator 2	86,67%	Highly Feasible
Validator 3	100%	Highly Feasible
Validator 4	80%	Feasible
Average	88.33%	Highly Feasible

Based on the results of the validation analysis, the PBL-based E-LKPD obtained an average feasibility percentage of 88.33%. Therefore, the developed E-LKPD was categorized as highly feasible and suitable for implementation in learning activities.

The practicality data of the E-LKPD were obtained from a student response questionnaire consisting of 13 statements. Based on the analysis results, a percentage of 72.84% was obtained, which was categorized as "good."

Thus, the developed E-LKPD was considered practical and suitable for implementation in learning activities.

The developed E-LKPD is aligned with students' needs in supporting the learning process to improve critical thinking skills. The integration of PBL syntax in interactive E-LKPD facilitates students' active involvement in analyzing problems, constructing knowledge, and developing critical thinking skills.

These findings are consistent with previous studies on the development of PBL-based electronic worksheets. Heldalia et al. (2025) reported that a PBL-based electronic student worksheet developed using the Liveworksheet platform was categorized as highly feasible and effectively supported the improvement of students' critical thinking skills in physics learning. Similarly, Saraswati et al. (2024) found that the developed PBL-integrated E-LKPD met the feasibility criteria and successfully promoted students' critical thinking skills. These findings indicate that integrating Problem-Based Learning into digital worksheets not only produces feasible learning media but also supports meaningful and student-centered learning.

Effectiveness Test Results

After the product had been revised based on the validators' suggestions and limited trials, the developed E-LKPD was implemented in the experimental class to evaluate its effectiveness in improving students' critical thinking skills. Learning activities were conducted using the developed E-LKPD and the corresponding teaching modules.

The effectiveness of the PBL-based E-LKPD was evaluated using pretest and posttest scores from the experimental and control classes. The obtained data were analyzed to determine the average pretest and posttest scores of each class. The critical thinking skill scores of both classes are presented in Table 5 and Figure 3.

Table 5. Average Critical Thinking Skill Scores

Variable	Pretest	Posttest Score Difference
Experimental Class	40.56	62.78 22.22
Control Class	52.14	65.71 13.57

Based on the data analysis, the experimental class had an average pretest score of 40.56. After the intervention, the average posttest score was 62.78. This means that the average posttest score was higher than the pretest score for critical thinking skills, with an average score difference of 22.22. Meanwhile, in the control class, the difference between the pretest and posttest average scores was 13.57. There was a difference in the average scores between the two classes. The experimental class obtained higher scores than the control class. This was due to the difference in treatment between the two classes.

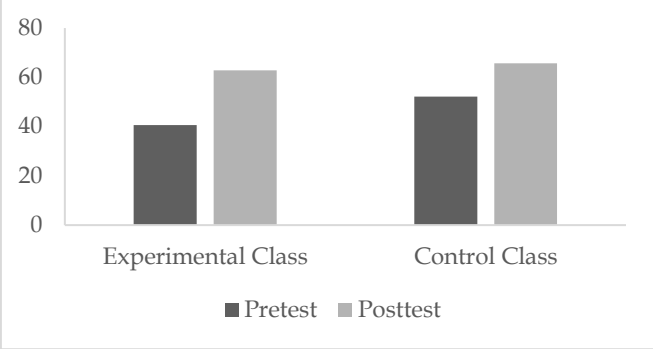

Figure 3. Diagram of critical thinking skills scores

The effectiveness test to determine whether the E-LKPD was effective in improving students' critical thinking skills was conducted using a normality test with the pretest and posttest data as the requirement for the paired sample paired T-test analysis. The results of the normality test can be seen in Table 6. The test was conducted using the SPSS statistical application with a significance level of 5% or 0.05. The basis for decision-making in the normality test is that the data is normally distributed if the Sig. value is > 0.05 and the data is not normally distributed if the Sig. value is < 0.05. Based on the normality test (Kolmogorov–Smirnov/Shapiro–Wilk), the data is not normally distributed, i.e., sig < 0.05. Therefore, the analysis cannot be continued with a paired-sample T-test and can be continued with a non-parametric statistical test, namely the Wilcoxon Rank Sum Test.

Table 6. Results of the Normality Test for Critical Thinking Skills

Normality Test	Class	Statistic	df	Sig.
Kolmogorov-Smirnov[a]	Experimental Class	0.230	18	0.013
	Control Class	0.320	14	0.000
Shapiro-Wilk	Experimental Class	0.826	18	0.004
	Control Class	0.794	14	0.004

The nonparametric statistical test, namely the Wilcoxon Rank Sum test, was conducted using the SPSS program. The significance level used was 5% or 0.05. The hypothesis in this study was H0 : there is no difference in the improvement of critical thinking skills among students between the experimental class and the control class, meaning that there is no effect of the application of PBL-based E-LKPD in improving students' critical thinking skills. Meanwhile, Ha : there is a difference in the improvement of critical thinking skills among students between the experimental class and the control class, meaning that there is an effect of the implementation of PBL-based E-LKPD in improving

students' critical thinking skills. The basis for decision making is that if the Sig. value is < 0.05, then H0 is rejected and Ha is accepted, but if the Sig. value is > 0.05, then H0 is accepted and Ha is rejected. The results of the Wilcoxon Rank Sum test for critical thinking skills are shown in Table 7.

Based on the results of the Wilcoxon Rank Sum test, the Sig. value for critical thinking skills was 0.049. This Sig. value indicates that Sig. < 0.05, meaning that there is a significant difference in the improvement of critical thinking skills between students in the experimental class and the control class, indicating that the implementation of PBL-based E-LKPD has an effect on improving students' critical thinking skills. Thus, the hypothesis test results indicate that the implementation of PBL-based E-LKPD on students in class X of SMA N 1 Sewon, Yogyakarta, has an effect on improving critical thinking skills. The data was then retested using the N-Gain test.

Table 7. Non-Parametric Statistical Test Results

H_0	Test	Sig.	Decision
The distribution of Experimental Class is the same across categories of Control Class	Independent-Samples Mann-Whitney U Test	0.049	Reject H0

The N-gain test was conducted to determine whether there was an improvement in critical thinking skills among students in the experimental class and the control class. The N-Gain calculation results for the experimental class and the control class can be seen in Table 8.

Based on the N-gain analysis results, it is known that the N-gain value in the experimental class is 0.364 with a medium criterion, while the N-gain value in the control class is 0.265 with a low criterion. The N-gain value of the experimental class is greater than the N-gain value of the control class. This indicates that learning using PBL-based E-LKPD on vector material in the experimental class is better at improving critical thinking skills than the conventional teaching materials used by teachers.

Table 8. N-Gain Results for Critical Thinking Skills in the Experimental Class and Control Class

Class	Average student score		N-Gain Score	Criteria
	Pretest	Posttest		
Experimental Class	40.56	62.78	0.364	Medium
Control Class	52.14	65.71	0.265	Low

The findings of this study are consistent with several previous studies on the implementation of PBL-based E-LKPD. Sari et al. (2025) reported that students who learned using Liveworksheet-assisted PBL-based E-LKPD achieved a post-test mean score of 77.86 and an N-Gain score of 0.6179 (medium-high category), indicating an improvement in students' critical thinking skills. Likewise, Yulanda et al. (2023) found that PBL-based E-LKPD improved students' critical thinking skills with an N-Gain score of 0.56 (medium category). Similar results were also reported by Sari et al. (2024), who obtained an N-Gain score of 0.69 in the experimental class compared to 0.37 in the control class, indicating that PBL-based E-LKPD was effective in improving students' critical thinking skills. In addition, Suradi et al. (2024) reported an average N-Gain score of 0.69 (moderate category), indicating that the developed PBL-based E-LKPD effectively improved students' critical thinking skills. Wardhani et al. (2025) also reported that PBL-based electronic worksheets for practical work were effective in improving students' critical thinking skills. These consistent findings provide further evidence that PBL-based E-LKPD is an effective instructional medium for enhancing students' critical thinking skills.

Based on the analysis results, the PBL-based E-LKPD developed in the physics learning process on vector material is effective in improving the critical thinking skills of grade X-7 students at SMA N 1 Sewon, Yogyakarta. Critical thinking skills are one of the important skills that students must have to face various complex and ever-changing global challenges. Critical thinking is a skill used in understanding, acquiring knowledge, and solving problems (Baker, 2020). An individual with critical thinking skills will be able to reason, solve problems, participate in discussions, and develop knowledge (Davies & Barnett, 2015). E-LKPD serves as an interactive learning medium that facilitates student-centered learning and supports the implementation of PBL activities, thereby promoting students' critical thinking skills. Additionally, E-LKPD allows students to learn material independently and flexibly, as it can be easily accessed anytime and anywhere.

The effectiveness of the developed E-LKPD can be explained by the characteristics of the implemented PBL syntax and the meaningful learning activities embedded

in the worksheet. Students developed critical thinking skills in aspects such as inference, recognizing assumptions, deduction, interpretation, and evaluating arguments, which are consistent with the indicators proposed by Watson et al. (2002). The integration of authentic problems, collaborative investigation, and reflective learning activities in the PBL-based E-LKPD encouraged students to analyze information, evaluate evidence, and formulate appropriate solutions, thereby facilitating the development of critical thinking skills. Therefore, the present study provides further evidence that PBL-based E-LKPD is an effective instructional medium for fostering students' critical thinking skills in physics learning.

The PBL model presents real-world problem situations that can train students to hone various skills to address real-world challenges. PBL is a problem-based learning method that can stimulate motivation and develop several skills, one of which is critical thinking (Tan, 2010). Through the PBL syntax stages such as problem orientation, organizing students, group investigation, developing and presenting results, and analyzing and evaluating results (Arends, 2012), students are guided to think systematically, logically, and analytically. This process encourages active and collaborative involvement of students in developing critical thinking skills optimally (Musthowiyah & Muhibbin, 2024). Thus, the implementation of PBL-based E-LKPD in physics not only enhances conceptual understanding but also improves students' critical thinking skills.

The application of PBL-based E-LKPD can help students understand a subject. E-LKPD that contains PBL syntax encourages active learning activities such as discussions and question and answer sessions (Maharani et al., 2024; Novia et al., 2023). Additionally, PBL can help develop students' critical thinking skills (Rinesti et al., 2019; Arifah et al., 2021; Liu & Pásztor, 2022; Setyawan & Koeswanti, 2021; Anggraeni et al., 2023). Therefore, the use of digital media combined with the appropriate learning approach can be an innovative strategy in improving the quality of learning. This supports the transformation of education towards more meaningful, contextual learning that is oriented towards the comprehensive development of students' competencies.

Conclusion

This study successfully developed a Problem-Based Learning (PBL)-based Physics E-LKPD on vector material using the 4-D development model. The developed Physics E-LKPD was categorized as highly feasible based on expert validation and practical based on students' responses, indicating that it is suitable for use in physics learning. Furthermore, the effectiveness test showed that the developed PBL-based E-LKPD was more effective than conventional teaching materials in improving students' critical thinking skills, as indicated by the higher N-Gain score achieved by the experimental class. The implementation of PBL learning activities through the developed E-LKPD supported meaningful and student-centered learning, enabling students to develop critical thinking skills in physics learning. Therefore, the developed PBL-based Physics E-LKPD can be used as an effective digital teaching material to enhance students' critical thinking skills.

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Author Contributions

Conceptualization, N.H.M and J.J.; methodology, N.H.M.; software, N.H.M.; validation, P.P and J.J; formal analysis, N.H.M and P.P.; investigation, N.H.M.; resources, N.H.M.; data curation, N.H.M.; writing—original draft preparation, N.H.M.; writing—review and editing, P.P and J.J.; visualization, N.H.M. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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