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Development of E-LKPD Based on Technology Pedagogical and Content Knowledge (TPACK) in High School Mathematics Subjects

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Abstract: Mathematics learning in Class X SMAN 1 Pelangiran remains suboptimal due to the dominance of lecture-based methods and conventional teaching materials, resulting in passive student engagement and low learning outcomes (only 41.38% completeness). This study aimed to develop a TPACK-based Electronic Student Worksheet (E-LKPD) for geometry materials to enhance learning effectiveness. TPACK integrates technological, pedagogical, and content knowledge, while E-LKPD promotes interactive, technology-assisted learning. Using a Research and Development (R&D) approach with the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), the E-LKPD was designed with multimedia elements such as videos, quizzes, and digital navigation. Expert validation results indicated high feasibility: material (95.4%), media (80%), and language (90.55%). Practicality tests showed the E-LKPD was very practical for teachers (90.95%) and students (85.25%). Effectiveness was demonstrated through an increase in students' average scores from 17.31 in pre-test to 61.21 in post-test, with and N-Gain of 57%. The findings conclude that the TPACK-based E-LKPD is valid, practical, and effective in supporting more interactive and adaptive mathematics learning.

Keywords: ADDIE model; E-LKPD; Geometry; Mathematics Learning; TPACK; Technology Integration

Introduction

The development of information and communication technology has had a significant impact on various aspects of life, including education (Harris & Hofer, 2018). The learning process that was previously dominated by conventional methods is now shifting toward more modern, technology-based approaches, enabling learning to be more interactive, flexible, and responsive to students' needs. (Lestari & Muchlis, 2021; Supriatna et al., 2022) In this context, mathematics learning as a subject characterized by a high level of abstraction demands innovative strategies to help students grasp complex concepts effectively (Siregar et al., 2023). Conventional approaches often fall short in facilitating deep understanding, particularly for students requiring visualization or more concrete, contextual learning experiences (Findayani, 2022; Salsabilla et al., 2024)

Technology plays a vital role in supporting the transformation of learning, including in mathematics education. One promising solution is the use of technology-supported teaching materials such as Electronic Student Worksheets (E-LKPD). E-LKPDs present mathematical content in an engaging, interactive format by integrating various digital media, including videos, simulations, and graphic visualizations, which help clarify abstract concepts (Lesilolo, 2018; Choiroh, S. S., Prastowo, S. H. B., & Nuraini, 2023).

E-LKPD is defined as a digital learning medium containing exercises, instructional videos, evaluations, and learning resources accessible anytime via internet-

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enabled devices. It supports more flexible and interactive learning and fosters students' creative thinking abilities (Ananda et al., 2021; Prastowo, 2015). Its development involves detailing learning outcomes, materials, and illustrations designed to facilitate independent student understanding and task completion (Noperman, 2022; Sofia, Hendracipta, & Syachruroji, 2023). The primary goals of E-LKPD include enhancing collaboration, critical thinking, and active participation among students (Octaviana et al., 2022; Indradewi et al., 2022; Julian, 2019). Additionally, E-LKPDs are environmentally friendly, practical, and efficient learning tools that can be customized by educators to suit student needs and encourage creativity (Puspita & Dewi, 2021; Stoilescu, 2015). Their feasibility is evaluated based on alignment with core competencies, learning objectives, curriculum demands, and visual design aspects that support learning effectiveness (Lestari & Muchlis, 2021; Hayani & Sutama, 2022).

TPACK is consist of several aspects, first is technological knowledge (TK), pedagogical knowledge (PK), and second is content knowledge (CK) that enables educators to optimize technology use in instruction (Rahmadi, 2019; Hayani & Sutama, 2022). This framework includes intersections such as Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK) (Koehler, 2022) TPACK supports teachers in designing contextual, interactive, and effective learning environments by selecting appropriate technologies and pedagogical strategies (Nusa, Sumarno, & Aziz, 2021; Angeli et al., 2015; Prastica, 2023). Its implementation involves stages from recognizing student and content needs, adapting and exploring technology, to enhancing integration effectiveness in learning. (Angeli & Valanides, 2015; Hayani & Sutama, 2022 ; Supriatna et al., 2022).

The advantages of TPACK include consistent technology integration, support for innovative teaching, and expansion of student knowledge (Stoilescu, 2015; Dayanti & Hamid, 2021). However, challenges such as limited technology access and varying user proficiency remain (Dayanti & Hamid, 2021). Applying TPACK positively influences lesson planning, delivery, and evaluation, especially in utilizing interactive digital media like E-LKPDs embedded with videos and online quizzes — which are particularly beneficial for subjects requiring high conceptual understanding like mathematics (Ngalim, 2007; Wulandari & Huda, 2020; Angeli, C., & Valanides., 2015; Jayusman, Gurdjita, & Shavab, 2017).

Mathematics learning in senior high school aims to develop students' critical, logical, and systematic thinking skills through relevant and applicable materials (Arsyad, 2015; Ngalim, 2007; Uzer, 2016), Effective instructional materials should be engaging, motivating, and aligned with student characteristics, comprising guides, competencies, evaluations, and worksheets (Nuryasana & Desiningrum, 2020). The learning objectives in accordance with the 2013 Curriculum and experts include concept mastery, logical reasoning, real-life application, and internalization of positive values (Permendikbud No. 59 Tahun 2014; Chambers, 2008) Challenges faced in high school mathematics learning include low student motivation, monotonous teaching methods, lack of varied instructional media, and heterogeneous student abilities unaccompanied by contextual learning approaches. (Haruman, 2018; Khumaidi, 2011; Rosnawati, 2020). Hence, technology-based and active pedagogical innovations like TPACK-developed E-LKPD can enhance the quality and effectiveness of high school mathematics instruction (Rahmadi, 2019; Farikah & Al Firdaus, 2020).

Preliminary observations among 21 teachers revealed that although most understood E-LKPD and TPACK well, 20% felt less competent, and 30% lacked confidence in integrating technology. While 80% were familiar with the flipped classroom model, only 70% had implemented it. All agreed on E-LKPD's role in boosting student interest, and 95% expressed willingness to use TPACK-based E-LKPDs, but 25% had not received relevant training, indicating the need for further professional development.

Data on student mathematics achievement showed only 41.38% reached minimum competency, especially in understanding exponents. This reflects a gap between teaching methods and student learning needs, partly due to limited interactive, technology-integrated learning media leading to low engagement and conceptual difficulties.

Addressing this, the current study focuses on developing a TPACK-based E-LKPD specifically for high school mathematics on exponent topics. This innovation integrates technological, pedagogical, and content knowledge to enhance interactivity, engagement, and comprehension of a concept area often challenging for students. Research by Koehler (2022), highlights TPACK's role in enabling differentiated instruction through technology-mediated learning, while (Zhang et al., 2016) found that TPACK-based media improve engagement and understanding, particularly for students requiring additional support (Angeli, C., & Valanides., 2015). Emphasize that TPACK centers on integrating TK, PK, and CK effectively in teaching.

Gusnidar et al. (2018), describe TPACK as a dynamic synthesis enabling meaningful, technology-integrated instruction design and implementation, reinforced by Triwahyudi (2021), who underscores its importance in creating learner-centered environments responsive to technological and pedagogical demands. This study contributes a practical solution to low mathematics achievement by bridging content mastery, effective pedagogy, and technology use, fostering teacher digital competence and supporting flexible, accessible, student-centered learning aligned with current educational needs.

Therefore, this study, titled "Development of E-LKPD Based on Technological Pedagogical and Content Knowledge (TPACK) in High School Mathematics Subjects," aims to develop instructional tools aligned with the independent curriculum to enhance student engagement and learning outcomes through relevant technology integration.

Method

This study employs a Research and Development (R&D) approach with the specific aim of designing, developing, and evaluating the practicality of a Technological Pedagogical and Content Knowledge (TPACK)-based Electronic Student Worksheet (E-LKPD) for Geometry: Geometric Elements in high school mathematics. The ADDIE development model consisting of Analysis, Design, Development, Implementation, and Evaluation, was selected as the framework for this process.

The ADDIE model was chosen due to its structured yet iterative nature, which allows for continuous refinement at each stage based on feedback and validation results. This flexibility is particularly important in the context of educational technology development, where alignment with pedagogical goals, technological capacity, and content suitability must be ensured. By following this model, the resulting E-LKPD is expected to be pedagogically sound, technologically appropriate, and responsive to students' learning needs in high school mathematics instruction.

The subjects in this study included three expert lecturers as validators, namely media, material, and language experts; two mathematics teachers at SMAN 1 Pelangiran; and grade X students who have good academic abilities. The research was conducted in the even semester of the 2024/2025 academic year, focusing on the development of E-LKPD as the main object of research.

The instruments used included two types, namely validation instruments and practicality test instruments. The validation instrument is a questionnaire given to experts to assess the quality of the product from the aspects of content, media, and language. Meanwhile, the practicality test instrument was given to teachers and students to determine the ease of use of E-LKPD in the actual learning context. Data from both instruments were used as the basis for improving the product before it was widely applied.

The validity analysis uses a Likert scale based on the validation sheet. The validity score was given using the Equation 1.

$$P = \frac{Total\ Score\ Obtained}{Maximum\ Possible\ Score}\ x\ 100 \quad (1)$$

Description :
P : Validator percentage gain

The criteria for the level of achievement of the validity test by experts in the development of E-LKPD listed in Table 1.

Tabel 1. Achievement Level of E-LKPD Validity

Achievement Level (%)	Qualifcation
81 – 100	Very feasible
61 – 80	Feasible
41 – 60	Feasible enough
21 – 40	Less feasible
20	Not feasible

Practicality analysis uses a Likert scale based on the practicality sheet. Practicality scores were given using the Equation 2.

$$P = \frac{Total\ Score\ Obtained}{Maximum\ Possible\ Score}\ x\ 100 \quad (2)$$

Description :
P : User percentage gain

The criteria for the level of achievement of the validity test by experts in the development of E-LKPD listed in table 2.

Tabel 2. Achievement Level of E-LKPD Practicality

Achievement Level (%)	Qualifcation
80 – 100	Very practical
65 – 79	Practical
55 – 64	Less practical
0 – 54	Not practical

Table shown that pre test and post test after being given treatment using the Equation 3.

$$g = \frac{(\text{Post test - Pre Test})}{(\text{Maxium test- Pre test})} \quad (3)$$

Description :
g : gain of the core

The results obtained are categorized according to Table 3.

Table 3. Normalized Gain Category

Value (g)	Classification
g < 0.3	Low
0.7 > g ≥ 0.3	Medium
g > 0.7	High

Result and Discussion

This study produces products in the form of TPACK-based E-LKPD developed through the five stages of the ADDIE model. At the analysis stage, it was found that learning at SMAN 1 Pelangiran uses the Merdeka Curriculum, with trigonometry material scheduled for 8 JP. Curriculum analysis shows the need for teaching materials that relate concepts to real life so that students do not just memorize formulas.

Analysis of the characteristics of students in class X E2 shows that the majority of students have a visual learning style (55.17%), followed by kinesthetic (27.59%) and auditory (17.24%). In addition, the aptitude assessment revealed that most students were interested in sports (48.28%) and arts (34.48%). These findings became the basis for designing interactive, visual, and contextual E-LKPDs to match students' preferences and potentials.

The needs analysis showed that the conventional E-LKPDs used by teachers were static, only in the form of text and images in PDF format, and not optimal in assisting the understanding of abstract mathematical concepts. Therefore, a TPACK-based E-LKPD was developed that is able to integrate content, pedagogy, and technology effectively. This product is designed to encourage students' active involvement, facilitate diverse learning styles, and present material in a contextual and applicable manner.

In the design stage, researchers developed E-LKPD using supporting tools and applications such as Canva, GeoGebra, Microsoft Office, and Flip PDF Professional. The E-LKPD design was made systematically to support an attractive, interactive, and visual display in accordance with the TPACK principles.

The E-LKPD product is designed to include several important components: an informative cover page, learning outcomes and instructions for use, "Let's Think and Read" activities that build curiosity, presentation of material through digital media (video, PowerPoint, teaching materials), and collaborative learning activities. At the end of each meeting, students are directed to draw conclusions, do exercises, quizzes, and independent reflections to measure their understanding.

This design shows that the developed E-LKPD not only displays information, but also activates students' role in building understanding through exploration, interaction, and self-evaluation. The integration of visual, audio and interactive elements strategically strengthens student engagement and supports the achievement of learning objectives more effectively and meaningfully.

The E-LKPD development stage includes product manufacturing, instrument development, and product assessment. The E-LKPD was developed based on the previously designed storyboard, then converted into an interactive format using the Flip PDF Professional application. Interactive features such as video integration, teaching material links, quizzes, and navigation buttons were added to improve interactivity and accessibility.

In addition, media, material, language, and practicality validation instruments were also developed. The instruments were validated by experts using the Aiken's V approach, with the results of all instruments declared highly valid, namely media (0.88), material (0.92), language (0.88), and practicality (0.96).

Product assessment was carried out through validation by experts: Material Expert (Dr. Sriyunita Ningsih, M.Pd): The E-LKPD obtained an average score of 95.40% (very feasible). The material is considered complete, relevant to the curriculum, up-to-date, interesting, and supported by a good visual display. Media Expert (Dr. Ulfia Rahmi, M.Pd): Validation of technical and visual aspects obtained an average of 80% (feasible), indicating that the software, visual communication, and learning media have been designed to be functional and attractive. Language Expert (Prof. Dr. Syahrul R., M.Pd): The average score was 90.55% (very feasible). The language is considered clear, communicative, dialogical, and in accordance with the level of development of students. Overall, the E-LKPD developed based on TPACK proved to be valid and feasible to use in the process of learning mathematics in class X. These results show that combining technological, pedagogical, and content elements can produce digital learning media that are effective, interesting, and support the achievement of learning objectives. The results of the E-LKPD validation is as follows:

Table 4. Validation of E-LKPD

Validation Type	Persentage (%)	Category
Media Expert	80	Feasible
Material Expert	95.40	Very feasible
Language Ekspert	90.55	Very feasible
Average	88.65	Very feasible

Referring to the validity criteria category, the results of the E-LKPD validity are included in the very feasible category. The results of the material, language and media validity analysis of the E-LKPD can be seen in Figure 1.

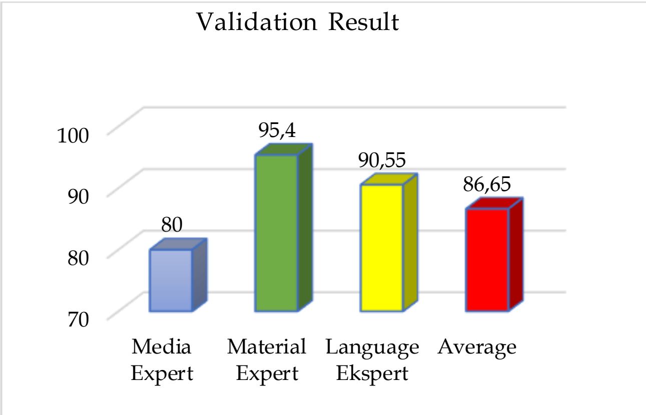

Figure 1. Validation Result Diagram

During the implementation phase of the TPACK-based E-LKPD, a practicality test was carried out to evaluate how practical the product is for use in learning activities. The results indicated that teachers found the product to be highly practical, with an average score of 90.95%. Specifically, the learning design aspect scored 92.86%, the operational aspect 95%, and the visual communication aspect 85%.

Table 5. Practicality of E LKPD by Teachers

Aspect	Persentage (%)	Category
Learning design	92.86	Very Practical
Operational	95	Very Practical
Visual Communication	85	Very Practical
Average	90.95	Very Practical

Figure 2 presents the results of the teacher practicality assessments.

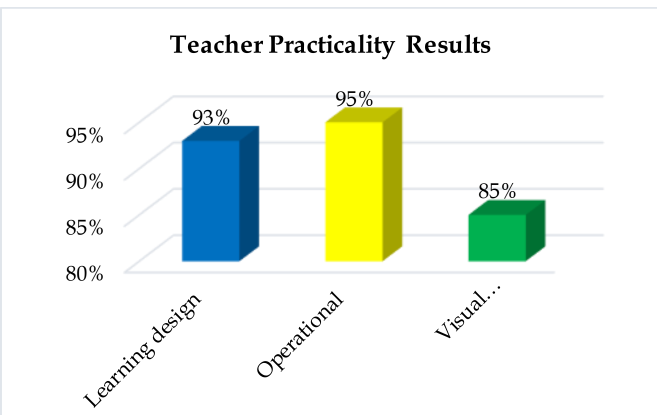

Figure 2. Diagram of teacher Practicality Result

The student practicality test resulted in an average of 85.25%, with cognitive aspects reaching 88.75%, affective 87%, and conative 80%. These results indicate that the product is very practical and supports student involvement in the learning process. In contrast, the results of the student practicality assessment are displayed in the following table 6.

Table 6. Practicality of E-LKPD by Students

Aspect	Persentage (%)	Category
Cognitive	88.75	Very Practical
Afektive	87	Very Practical
Conative	80	Very Practical
Average	85.25	Very Practical

The results of the student practicality tests can be seen in Figure 3.

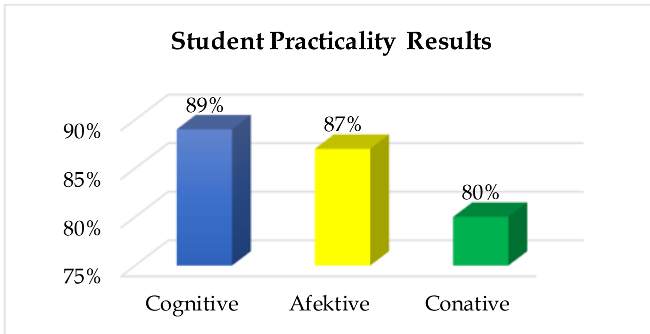

Figure 3. Diagram of Student Practicality Result

The results of the student practicality test indicate that the product is highly practical for use in the learning process. The cognitive aspect received 88.75%, indicating the product is effective in helping students' understanding. The affective aspect gets 87%, indicating the product is interesting and motivates students. The conative aspect gets 80%, indicating students are motivated enough to learn independently. With an average of 85.25%, this product is considered very practical and feasible to use, although it can still be improved to further increase student learning motivation. The effectiveness of E-LKPD is measured through pre-test and post-test. Pre-test data distribution is as follows:

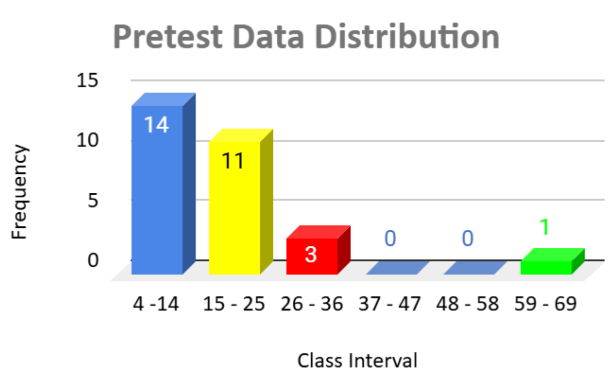

Figure 4. Distribution of Student Pretest Data

The frequency distribution table and historicalgram above present the results of grouping the Pre Test score data into five interval classes. The 4-14 interval has the highest frequency, which is 14 students or 48.28% of the total data. While the description of the distribution of post test data is as follows:

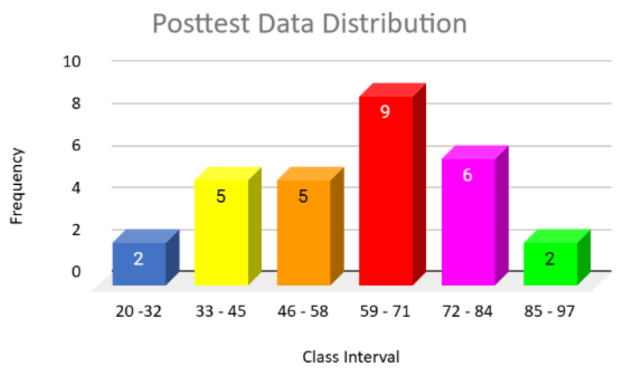

Figure 5. Distribution of Student Posttest Data

The frequency distribution table and histogram show the distribution of students' Post Test scores after participating treatment of LKPD. Most students are in the interval class 59-71 with a total of 9 students or 31.03%, which indicates an increase in understanding in the moderate to high category.

The pre-test results revealed a low average student score of 17.31. However, the post-test scores showed a substantial improvement, with an average of 61.21. The Mann-Whitney test demonstrated a significant difference between the pre- and post-test scores (p-value < 0.05), suggesting that the use of the E-LKPD had a positive effect. Additionally, the N-gain analysis produced an average score of 0.57, reflecting an approximate 57% improvement in student learning outcomes. This can be seen in the following table 7.

Tabel 7. N Gain

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Pretest	29	4.00	65.00	17.3103	11.70196
Posttest	29	20.00	94.00	61.2069	18.35830
NGain	29	.05	1.00	.5676	.24434
NGain_Persen	29	5.13	100.00	56.7637	24.43376
Valid N (listwise)	29				

Overall, the implementation of the TPACK-based E-LKPD successfully improved students' understanding, although there were variations in improvement between participants. The product proved effective in supporting learning, but there is still room for further improvement to optimize student motivation and engagement.

In the evaluation stage of the TPACK-based E-LKPD, the evaluation results showed positive findings. Students' perceptions of the E-LKPD were generally positive, with students feeling that the appearance and content of the materials were attractive and easy to understand. Some suggestions from students included color variations to enrich the display, while teachers provided feedback on fonts and quiz links that were not working. Evaluation of learning outcomes showed significant improvement between the pre-test (17.31) and post-test (61.21), with an average N-gain value of 0.52 indicating an improvement of approximately 52%. The material expert suggested extending the E-LKPD processing time from 40 minutes to 50 minutes and fixing the inaccessible quiz link. Media experts recommended adjusting the time for quizzes and changing the term “Let's Remember” to “Flashback” to better support learning objectives in Flip PDF format. The linguist provided input to include the source of the illustrations and to tidy up the text to make it easier to read.

The results of this study are reinforced by research (Khairinal, 2021) which developed a Flip PDF-based e-book and found that digital media can increase students' independence and interest in learning. In the context of this study, the increase in posttest scores reflects an increase in student motivation and attention during E-LKPD-based learning. (Febrianti, 2021) research also supports the effectiveness of Flip PDF-based digital media, which is proven to significantly improve students' science literacy. Although the focus of the research is different, the increase in posttest scores in this study illustrates similar results in terms of cognitive improvement (Ananda et al., 2021; Triwahyudi, 2021).

In addition, this finding is also related to (Dayanti, F. & Hamid, 2021) which integrates TPACK with ICT in learning. She concluded that the integration of technology, pedagogy, and content can improve learning effectiveness, as seen in the use of E-LKPDs designed with a similar approach in this study. Meanwhile, (Sulaiman, S., Didi, S., & Wahyudin, 2022; Hayani & Sutama, 2022), also proved that structured inquiry-based geometry modules can improve students' concept understanding and problem-solving skills.

Conclusion

This study successfully developed and validated a TPACK-based E-LKP for high school geometry using the ADDIE model. The product showed strong validity and practicality, supported by expert assessments and favorable feedback from both teachers and students. The combination of technological, pedagogical, and content knowledge created an engaging learning tool that successfully addresses various learning preferences. The test results showed a significant improvement in students' conceptual understanding of geometric elements, with an average N-gain of 0.57, indicating moderate to high effectiveness. These findings suggest that TPACK-informed digital learning materials can effectively enhance student engagement and learning outcomes in mathematics. More broadly, this research contributes to the growing body of evidence supporting the application of TPACK frameworks in developing instructional technologies that bridge pedagogy and content with digital innovation. The E-LKPD provides a practical resource for educators aiming to implement technology-enhanced, student-centered learning aligned with current curricular standards. Practically, this study highlights the importance of teacher training and continuous refinement of digital tools to optimize technology integration in classrooms. Future research should explore long-term impacts on learning motivation and the scalability of such interventions across different mathematical topics and educational contexts.

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Author Contributions
S. and R. identified problems related to the availability of teaching materials. S. drafted the research instruments and developed the TPACK-based E-LKPD. Both authors contributed to writing the initial drafts, providing ideas, reviewing and editing the manuscript. They also monitored research progress and provided feedback throughout the study. All authors contributed equally to the content of this article. We have read and approved the published version of the manuscript.

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The authors declare that there is no conflict of interest regarding the publication of this paper

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