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Developing a Geogebra-Assisted PBL E-LKPD on Circle Equations to Foster Critical Thinking of Vocational School Students: Validity and Practicality

Faiqotul Munawwaroh [1a*], Triyanto [2b], Getut Pramesti [3c]
[1,2,3] Universitas Sebelas Maret, Indonesia

[a]faiqotulmna@student.uns.ac.id, [b]triyantio.math@staff.uns.ac.id, [c]getutpramesti@staff.uns.ac.id

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***Correspondence Address:**
faiqotulmna@student.uns.ac.id

Abstract:
"This study aimed to develop a Problem-Based Learning (PBL) electronic student worksheet (E-LKPD) assisted by GeoGebra on circle equations to foster vocational high school (SMK) students' critical thinking, describing its validity and practicality. Following the Analysis, Design, and Development phases of the ADDIE model at SMK Yapek Gombong, needs analysis confirmed low critical thinking attainment, particularly in evaluation (28.1%) and inference (21.9%). The core innovation lies in explicitly mapping each PBL phase and dynamic GeoGebra applet to four critical thinking indicators tailored to vocational contexts. Validation by material, media, and language experts yielded valid scores (3.61, 3.47, and 3.45, respectively). Practicality evaluations from a practitioner (3.65) and student trials (small-group: 3.53, medium-group: 3.51, field trial: 3.48) confirmed high user acceptance. This paper focuses strictly on product development, validity, and practicality; product effectiveness is reported separately."

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Introduction (مقدمة)

Education aims not only to equip students with knowledge but also to develop the thinking skills needed to face real-life problems. Mathematics plays a vital role in this regard by training students to reason logically, build arguments, and make evidence-based decisions. These capabilities are directly tied to critical thinking, operationalized in this study through four core indicators: interpretation, analysis, evaluation, and inference. Consequently, mathematics instruction must deliberately foster critical thinking rather than leaving it as an indirect by-product of procedural drills.

This imperative is strongly reflected in national educational policy. Regulation of the

Minister of Primary and Secondary Education Number 13 of 2025 emphasizes critical reasoning as a key graduate profile dimension and promotes the Deep Learning approach focused on mindful, meaningful, and joyful learning (Kementerian Pendidikan Dasar dan Menengah [Kemendikdasmen], 2025a, 2025b). However, national and international assessments show that this objective remains unfulfilled. In PISA 2025, Indonesian 15-year-old students achieved an average mathematics score of 364 (Kemendikdasmen, 2026), with only 17% reaching basic proficiency (Level 2 or above) compared to the 65% OECD average (OECD, 2026b). This persistent gap indicates that most students struggle to interpret, analyze, and reason about mathematical situations.

Low critical thinking is closely linked to prevalent classroom practices dominated by routine, procedural exercises and teacher-centered instruction (Windya et al., 2025). This challenge is particularly evident in the topic of circle equations. Circle equations present a distinct cognitive hurdle for vocational high school (SMK) students because they require seamlessly connecting abstract algebraic equations with dynamic geometric visualizations (such as center positions, radii, and tangent lines) on the coordinate plane. A preliminary study conducted on 14 February 2026 at SMK YAPEK Gombong, Kebumen, revealed this critical gap. Diagnostic test results among 32 eleventh-grade students demonstrated a sharp decline across critical thinking indicators: 62.5% achieved interpretation, 43.8% analysis, 28.1% evaluation, and only 21.9% inference. Observations and teacher interviews confirmed that lessons relied on conventional textbooks and static blackboard drawings. Although most students possessed mobile devices, GeoGebra had never been utilized, and learning time was severely constrained by vocational practical training.

Technology, particularly GeoGebra, offers strong dynamic modeling and visualization capabilities to bridge geometric and algebraic representations (Gokce & Guner, 2022; Juandi et al., 2021; Ziatdinov & Valles, 2022). However, dynamic software alone does not guarantee higher-order thinking unless integrated into a structured, problem-centered pedagogical framework. Problem-Based Learning (PBL) complements GeoGebra by providing authentic contextual problems, active exploration, and reflective processing aligned with Deep Learning principles (Kemendikdasmen, 2025a; Kurniawan et al., 2026). To ensure that PBL effectively cultivates critical thinking, each phase of the PBL cycle must be explicitly mapped to a corresponding critical thinking indicator: problem orientation drives interpretation, investigation fosters analysis, solution synthesis enables evaluation, and reflective generalization guides inference (Loyens et al., 2023; Yu & Zin, 2023).

Delivering this integrated strategy effectively requires an electronic student worksheet (E-LKPD) accessible via mobile devices. While previous studies have developed E-LKPDs or PBL-GeoGebra materials for junior high or general senior high school topics (e.g., polyhedrons, linear equations, ratios) (Hermawati et al., 2025; Santika et al., 2026; Windya et al., 2025), none have integrated an E-LKPD, PBL, and GeoGebra specifically for circle equations to foster the critical thinking of SMK students within the Deep Learning framework.

Accordingly, this study develops a GeoGebra-assisted PBL E-LKPD on circle equations for eleventh-grade SMK students in Kebumen. The novelty of this work lies in the explicit mapping of PBL phases, dynamic GeoGebra exploration, and critical thinking indicators tailored to vocational contexts. This article focuses on product development and evaluates its validity and practicality based on three research questions: (1) How was the E-LKPD developed, and what are its key characteristics? (2) Is the E-LKPD valid according to material, media, and language experts? (3) Is the E-LKPD practical from the perspectives of the teacher and students? The product's effectiveness in improving critical thinking is evaluated and reported separately.

Method (منهج)

This study is a research and development (R&D) study that produces a PBL-based E-LKPD assisted by GeoGebra on circle equations for SMK students and evaluates its quality as valid and practical. The development followed the ADDIE model, which consists of analysis, design, development, implementation, and evaluation, with formative evaluation carried out at each stage; ADDIE has also been used to develop GeoGebra-based PBL media for critical thinking (Kurniawan et al., 2026). This article reports the Analysis, Design, and Development stages, in which the product was validated by experts and tested for practicality. The Implementation and Evaluation stages, in which a quasi-experiment tests effectiveness, are beyond the scope of this article and are reported separately.

The study was conducted at SMK Yapek Gombong, Kebumen, Central Java, Indonesia, with eleventh-grade students. The school was chosen because the researchers had carried out the preliminary study there, the school was willing to permit the research, and the required data were available. Participants differed at each stage and did not overlap (Table 1). Classes for the small-group, medium-group, and field trials were selected from grade XI classes outside those reserved for the later effectiveness study.

Table 1. Participants at Each Stage of the Study

Stage	Participants	Number	Selection
Need analysis	Mathematics teacher and grade XI students	1 teacher and 32 students	Preliminary study
Expert validation	Material, media, and language experts	2 per field (6 experts)	Expertise criteria
Practitioner trial	Grade XI mathematics teacher	1 teacher	Appointment
Small-group trial	High-, medium-, and low-achieving students	3 students	By learning achievement
Medium-group trial	Grade XI students	12 students	Random
Field trial	One grade XI class	30 students (1 class)	Random cluster

The analysis stage identified the root of the learning problem through a semi-structured interview with the mathematics teacher, a critical thinking test, and classroom observation. The test consisted of one essay item built on four indicators and eleven sub-indicators of critical

thinking (interpretation, analysis, evaluation, and inference), and the same indicators were used in the preliminary study reported in the Introduction. Interview, test, and observation data were analyzed through data collection, data reduction, data display, and conclusion drawing, and their credibility was checked by technique triangulation, that is, comparing the teacher's statements with the observation results and the students' test results.

The design stage prepared the concept and structure of the E-LKPD. The material and the learning scenario were determined through discussion with the mathematics teacher, and the learning objectives were formulated according to the national learning outcomes. The scenario followed the five PBL phases. The researchers then produced a storyboard covering the template, theme, colors, layout, worksheet components, material, and access route, together with a usage flowchart. The presentation considered the multimedia learning principles of coherence, signaling, and segmentation. The design was discussed with the teacher and the supervisor and revised before production.

The development stage produced the prototype in Canva Premium according to the storyboard, accessible through a barcode or link and through the PDF Flip application. The prototype was validated by three experts: a material expert (mathematics and mathematics education), a media expert (instructional material development and educational technology), and a language expert (Indonesian language). Expert suggestions were used to revise the product before it was tried out. After the product was declared valid, its practicality was assessed from the users' perspective through four consecutive trials: a practitioner trial with the mathematics teacher, a small-group trial with three students of high, medium, and low achievement, a medium-group trial with 12 randomly selected students from classes different from the small group, and a field trial with one grade XI class. Each trial was a formative evaluation whose results were used to revise the product.

The instruments were validation sheets and response questionnaires, all using a four-point scale (1 = poor, 2 = fair, 3 = good, 4 = very good). The material validation sheet (21 items) covered content, presentation, suitability of the GeoGebra applets, completeness of materials, and integration of PBL and critical thinking. The media validation sheet (25 items) covered content, presentation, illustration, and technical aspects. The language validation sheet (11 items) covered language and clarity of instructions. The teacher response questionnaire (20 indicators) and the student response questionnaire (11 indicators) covered material, language, learning, and graphics, with the student questionnaire additionally addressing the ease of accessing the applets through barcode and link and of operating GeoGebra.

Validation data were analyzed by recapitulating each validator's score for every criterion, averaging each criterion across validators, averaging each aspect across its criteria, and averaging all aspects to obtain the total mean validation (RTV). Practicality data were averaged with the same procedure. The categories are presented in Table 2. The product was declared valid and feasible for trial if the RTV was at least 3.00 in all three fields; a fairly valid product was revised according to the validators' suggestions and validated again, and a product that was not valid was redesigned. The product was declared practical if the teacher and student responses were both in the practical category (mean ≥ 3.00).

Table 2. Criteria for Validity and Practicality

Mean score interval	Validity category	Practicality category
3.00 ≤ mean ≤ 4.00	Valid	Practical

2.00 ≤ mean < 3.00	Fairly valid	Fairly practical
1.00 ≤ mean < 2.00	Not valid	Not practical

Permission for the study was obtained from the school before data collection, participants were informed about the research objectives and procedures, and the confidentiality of their data was maintained.

Result (نتائج)

Results of the Needs Analysis

The preliminary study conducted at SMK YAPEK Gombong on 14 February 2026 involved one mathematics teacher and 32 grade XI students. Table 3 presents the attainment of the critical thinking indicators on the circle test. Attainment declined consistently from interpretation to inference, indicating that students could relatively understand the information in a problem but were weak in evaluating results and drawing conclusions.

Table 3. Attainment of Critical Thinking Indicators in the Preliminary Study (n = 32)

Critical thinking indicator	Students achieving the indicator (%)
Interpretation	62.5
Analysis	43.8
Evaluation	28.1
Inference	21.9

The interview and observation results explain this pattern. The teaching materials were textbooks and worksheets of routine problems with procedural solutions, which offered little space for students to interpret information, test statements, and draw conclusions. Students had difficulty imagining the position of the center, the radius, and tangent lines on the coordinate plane, and lessons were dominated by lectures and individual exercises with circles drawn manually on the board. This condition is consistent with the view that inappropriate use of media and learning models contributes to low critical thinking (Windya et al., 2025). At the same time, GeoGebra had never been used although most students carried mobile devices. These findings led to the decision to develop an E-LKPD that trains critical thinking and supports visualization of circle equations, delivered through devices that students already have.

Design and Characteristics of the E-LKPD

The product is a PBL-based E-LKPD assisted by GeoGebra for grade XI SMK students on circle equations. Its structure adapts the standard worksheet structure to the five PBL phases and consists of (a) identity, objectives, and instructions for use; (b) brief supporting information containing prerequisite concepts; (c) a contextual vocational problem (phase 1); (d) work steps and GeoGebra-assisted exploration (phases 2 and 3); (e) a space for solutions and conclusions (phase 4); and (f) reflection and reinforcement problems (phase 5). The sub-materials are circle equations with center $O(0, 0)$ and $P(a, b)$, the general form, the position of a point relative to a circle, the position of a line relative to a circle, and tangent lines. Each sub-material is given a vocational problem, for example determining the coverage of a signal transmitter or a surveillance camera on a floor plan.

GeoGebra is used in its two-dimensional version (Graphing and Geometry) because circle equations lie on the coordinate plane. For each sub-material the researchers prepared an applet with sliders for the center and radius, draggable points and lines, and the Intersect and Tangent commands. The applets are embedded in the E-LKPD through links and barcodes in phases 3 and 5, and every exploration is accompanied by guiding questions that direct observation, conjecture, and verification so that GeoGebra is not used merely as a drawing tool. The E-LKPD is also equipped with an online quiz and short video materials. Table 4 summarizes how the PBL phases were translated into E-LKPD activities and the critical thinking indicators each phase trains.

Table 4. Integration of PBL Phases, E-LKPD Activities, and Critical Thinking Indicators

PBL phase	**Activities in the GeoGebra-assisted E-LKPD**	**Indicators trained**
1. Orientation to the problem	Reading a contextual vocational problem, writing what is known and asked, and separating relevant from irrelevant information	Interpretation
2.Organizing students to learn	Forming groups, planning the solution, and recalling prerequisite concepts (distance between two points, Pythagorean theorem) through supporting information	Interpretation; analysis
3.Guiding investigation	Exploring GeoGebra applets (center and radius sliders, dragging points and lines, Intersect and Tangent commands) and modeling the problem as a circle equation	Analysis; evaluation
4. Developing and presenting results	Writing the complete solution, composing a conclusion in the problem context, and presenting it	Evaluation; inference
5. Analyzing and evaluating the process	Verifying results with GeoGebra, reflecting on errors, and working on reinforcement problems	Evaluation; inference

The mapping in Table 4 makes each component of the product traceable to a critical thinking indicator. Supporting information and the contextual problem support interpretation, the work steps and exploration support analysis, and the solution space, conclusion, and reflection support evaluation and inference. The design is intended to address the weakest indicators found in the preliminary study, evaluation and inference, by giving phases 4 and 5 their own place in the worksheet. This design choice responds to the concern that GeoGebra effects can depend on the surrounding instructional design (Juandi et al., 2021): here GeoGebra is embedded within a PBL sequence rather than used alone.

zzExpert Validation Results

The prototype was validated by six experts (two material experts, two media experts, and two language experts). Tables 5 to 7 present the validation results.

Table 5. Material Expert Validation Results

Aspect	Mean score	Category
Content	3.63	Valid
Presentation	3.50	Valid
Suitability of GeoGebra applets	3.67	Valid
Completeness of materials	3.50	Valid
Integration of PBL and critical thinking	3.75	Valid
Total mean validation (RTV)	3.61	Valid

Table 6. Media Expert Validation Results

Aspect	Mean score	Category
Content	3.50	Valid
Presentation	3.40	Valid
Illustration	3.43	Valid
Technical aspects	3.56	Valid
Total mean validation (RTV)	3.47	Valid

Table 7. Language Expert Validation Results

Aspect	Mean score	Category
Language	3.40	Valid
Clarity of instructions	3.50	Valid
Total mean validation (RTV)	3.45	Valid

Table 5 shows that the material experts gave a total mean of 3.61, categorized as valid. The highest-scoring aspect was the integration of PBL and critical thinking (3.75), followed by the suitability of the GeoGebra applets (3.67), while presentation and completeness of materials scored lowest (3.50 each). Table 6 shows a media total mean of 3.47, with the highest score on technical aspects (3.56) and the lowest on presentation (3.40). Table 7 shows a language total mean of 3.45, with clarity of instructions (3.50) slightly above language use (3.40). Because the RTV in all three fields reached at least 3.00, the E-LKPD was declared valid and feasible for trial according to the criteria in Table 2.

The high score on the integration of PBL and critical thinking is important because this aspect carries the central claim of the product, namely that every phase is deliberately tied to an indicator (Table 4). The experts judged that the five phases were reflected in the activities and that the guiding questions directed students from observation to conjecture and verification. The

high score on the applets suggests that GeoGebra was embedded in structured activities rather than used only as a drawing tool, which matters because the benefit of GeoGebra depends on the surrounding instructional design (Juandi et al., 2021). The lower scores on presentation and language point to readability: some instructions were long, and some terms needed simplification for vocational students. Based on expert feedback, concrete revisions were executed prior to field trials, as detailed in Table 8.

Table 8. Product Revisions Based on Validators' Suggestions

Validators' Suggestions (Expert Feedback)	Specific Revisions Conducted on the E-LKPD Prototype
Instructions in several discovery phases were too long and text-heavy.	Shortened descriptive paragraphs in Phases 2 and 3 and reformatted them into clear, numbered sequential steps.
Mathematical notation for circle equations and center coordinates showed minor inconsistencies across pages.	Standardized all mathematical symbols and notations for centers $P(a,b)$, radii r, and standard circle equations in line with formal curriculum standards.
Guidance on operating GeoGebra dynamic sliders was insufficient for independent student use.	Added a dedicated, concise visual mini-guide on how to operate applet sliders and zoom tools directly preceding Phase 3.
Font sizes, line spacing, and layout margins lacked uniformity on interactive pages.	Unified typographic hierarchy (font sizes and weights) and aligned graphic elements across all layout screens to ensure optimal readability on mobile viewports.

Practicality Results

Practicality was assessed from the users' perspective through the practitioner trial and the three student trials, using questionnaires on material, language, learning, and graphics. Table 9 presents the teacher's response and Table 10 the students' responses across the small-group, medium-group, and field trials.

Table 9. Teacher Response toward the Practicality of the E-LKPD

Aspect	Mean score	Category
Material	3.60	Practical
Language	3.60	Practical
Learning	3.80	Practical
Graphics	3.60	Practical
Overall mean	3.65	Practical

Table 10. Students' Responses toward the Practicality of the E-LKPD

Aspect	Small group (n=3)	Medium group (n=12)	Field trial (n=30)
Material	3.58	3.52	3.49
Language	3.50	3.46	3.43
Learning	3.56	3.50	3.47
Graphics	3.50	3.54	3.52
Overall mean	3.53	3.51	3.48
Category	**Practical**	**Practical**	**Practical**

The teacher's overall mean was 3.65, with the highest score on learning (3.80), indicating that the teacher found the phase structure and guiding questions easy to follow in class. The students' overall means were 3.53, 3.51, and 3.48 in the small-group, medium-group, and field trials, respectively. Because the teacher and student responses were all in the practical category ($\text{mean} \ge 3.00$), the E-LKPD was declared practical according to the criteria in Table 2.

Two empirical points warrant deeper interpretation. First, the mean scores exhibited a slight, consistent decrease as the trial scaled from the small group to the full class field trial, with language scoring lowest in the field trial (3.43). This downward trend is a standard methodological phenomenon in educational R&D, reflecting the greater diversity of student reading proficiencies and learning paces in an entire classroom compared to a highly selected small group. This justifies the necessity of staged formative evaluations rather than relying solely on small-sample pilots, particularly given that technology-integrated tools often show inflated usability ratings in small cohorts (Juandi et al., 2021).

Second, practical implementation heavily relies on device accessibility and network connectivity. During the small-group trial, a few students experienced initial friction scanning QR barcodes or establishing connection, which prompted the addition of direct short URLs adjacent to every barcode. Furthermore, students occasionally required brief scaffolding to manipulate GeoGebra parameters effectively. Aligning with meta-analytic evidence indicating that GeoGebra yields optimal cognitive gains when every student operates their own device (Juandi et al., 2021), instructors must verify hardware and internet readiness prior to classroom deployment. Nonetheless, the teacher's exceptionally positive evaluation of classroom learning practicality (3.80) confirms that the E-LKPD successfully supports structured inquiry despite time constraints imposed by vocational practical training schedules.

Discussion (مناقشة)

The findings are consistent with previous work that combined GeoGebra with PBL in geometry. A GeoGebra-based PBL medium for three-dimensional geometry was reported to be highly valid and practical (Kurniawan et al., 2026), a PBL- and GeoGebra-based worksheet was declared valid, practical, and effective for concept understanding in grade VII (Nesta et al., 2024), and a PBL-based E-LKPD assisted by GeoGebra was developed for polyhedron material (Santika et al., 2026). Unlike these studies, the present product targets circle equations in an SMK, states explicitly how each PBL phase trains a critical thinking indicator, and is aligned with the principles of mindful, meaningful, and joyful learning (Kemendikdasmen, 2025a).

Crucially, moving beyond a mere comparison of validity and practicality scores, the design of this E-LKPD directly addresses the specific cognitive vulnerabilities identified in the preliminary study—namely, the sharp drop in higher-order critical thinking indicators such as evaluation (28.1%) and inference (21.9%). By embedding structured inquiry within Phases 4 (developing and presenting results) and 5 (analyzing and evaluating the process), the E-LKPD shifts students away from passive calculation toward active hypothesis testing and error reflection. When students manipulate GeoGebra dynamic applets and sliders to observe how altering the radius or center coordinates affects a circle's relative position to lines or points, they receive immediate visual feedback that bridges abstract algebraic formulas with concrete geometric intuition (Gokce & Guner, 2022; Ziatdinov & Valles, 2022).

The results also echo E-LKPD studies in biology that reported PBL-based worksheets to be valid and practical (Milatti & Fitrihidajati, 2024; Nisa & Fitrihidajati, 2024; Nurjanah & Trimulyono, 2022), and studies that improved critical thinking through PBL assisted by GeoGebra at other levels and topics (Hermawati et al., 2025; Rahman et al., 2021). Compared with E-LKPD developed for critical thinking on other topics and levels (Fitriyah & Ghofur, 2021; Puspita & Dewi, 2021; Windya et al., 2025) and with PBL-based worksheets in SMK directed at numeracy literacy (Sari et al., 2023), this study adds GeoGebra as a dynamic exploration tool for a topic that links algebraic and geometric representations.

This study has limitations. It reports only validity and practicality, so it cannot show that the E-LKPD improves students' critical thinking; that claim requires the effectiveness test planned as the next stage. The trials were conducted in a single school, which limits generalization to other subjects and school levels, and the availability of devices and connectivity must be ensured whenever the product is used (Juandi et al., 2021). Practical classroom implementation also revealed that students occasionally require introductory scaffolding for digital tools and applet navigation, highlighting that technical readiness and digital literacy are vital prerequisites for successful inquiry-based learning. Because GeoGebra effects reported in the literature may partly reflect novelty and publication bias (Juandi et al., 2021), and because PBL results depend on design quality and on the subject and teaching method (Loyens et al., 2023; Lu et al., 2025; Yu & Zin, 2023), the effectiveness study should be designed cautiously, with a comparison group and adequate treatment duration. For teachers, the product offers a ready-to-use example of how PBL phases can be turned into guided GeoGebra activities; for researchers, the mapping in Table 4 can be adapted to other topics and levels.

This study successfully developed a Problem-Based Learning (PBL) electronic student worksheet (E-LKPD) assisted by GeoGebra on circle equations for eleventh-grade vocational high school (SMK) students using the Analysis, Design, and Development stages of the ADDIE model. Responding to preliminary findings showing a sharp decline in critical thinking attainment from interpretation (62.5%) to inference (21.9%), the E-LKPD was deliberately structured to train these higher-order cognitive indicators through the integration of the five PBL phases and guided GeoGebra exploration. Expert evaluations confirmed that the product is highly valid, achieving total mean validation scores (RTV) of 3.61 for material, 3.47 for media, and 3.45 for language. Furthermore, practicality assessments across practitioner and student trials—ranging from small-group to full-class field trials—yielded high practical ratings (a teacher mean of 3.65 and student means between 3.48 and 3.53), demonstrating strong user acceptance and usability in authentic classroom environments. Consequently, the developed E-LKPD provides a valid and practical alternative learning medium for vocational mathematics; its empirical effectiveness in significantly improving students' critical thinking skills will be thoroughly evaluated in the subsequent quasi-experimental research stage.

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