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Nearpod-assisted PBL enactment within the TPACK framework: Transforming mathematics learning to enhance problem solving skills and digital literacy

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ABSTRACT

Technology integration in mathematics learning requires a theoretically grounded design rather than simple digital adoption. Within the Technological Pedagogical and Content Knowledge (TPACK) framework, Problem-Based Learning (PBL) represents pedagogical knowledge, and Nearpod represents technological knowledge. This study does not propose a new model; instead, it operationalizes TPACK through a structured instructional enactment that aligns statistical content, PBL inquiry phases, and Nearpod affordances. A quasi-experimental pretest–posttest control group design was employed with twelfth-grade students. Baseline equivalence between the experimental and control groups was confirmed using an independent-samples t-test. Enhancement in mathematical problem-solving was analyzed using gain scores, independent-samples t-tests, and two-way ANOVA. Results revealed a significant difference in scores gained between groups. A significant main effect of the instructional approach and an interaction effect with initial ability were found. Digital literacy also differed significantly between groups. These findings demonstrate that TPACK becomes instructionally meaningful when statistical content is transformed through structured inquiry and technology-mediated representation, although students' initial mathematics ability moderates' effectiveness.

INTRODUCTION

The development of digital technology has significantly transformed educational practices, particularly in mathematics learning, which increasingly demands higher-order problem-solving and digital literacy skills (Crompton et al., 2021; van Laar et al., 2017; Voogt et al., 2013). The Indonesian government, through its National Digital Literacy Movement policy, has positioned digital literacy as a strategic competency encompassing four pillars: Digital Skills, Digital Ethics, Digital Culture, and Digital Safety. However, Indonesia's digital literacy index remains in the moderate category, increasing slightly from 3.49 (2021) to 3.54 (2022), with Digital Safety as the weakest component (BPSDM, Kominfo, 2024). This condition indicates that students' digital competencies remain inadequate to meet the challenges of technology-based learning.

Other studies in primary and higher education settings have also found that many students use ChatGPT primarily to complete assignments, write papers, and even during exams, raising concerns about the authenticity of their work and the decline in critical thinking skills (Labadze et al., 2023s). In classroom practice, teachers often encounter students who simply copy answers from AI without reading, checking for accuracy, or trying to understand the steps involved in solving the problem

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(Krupp et al., 2024). AI is positioned as an “instant answer machine” rather than a learning partner for checking understanding, discussing, or exploring various problem-solving strategies (Davar et al., 2025; Hwang & Chien, 2022). This pattern shows that the digital literacy of Indonesian students still tends to be technical and consumptive: they are proficient in accessing and copying, but weak in critical, creative, and ethical aspects (Zhai, 2022). Ideally, students should be able to use AI and digital media to deepen their understanding of concepts, test arguments, and produce original work, rather than simply speeding up task completion (Davar et al., 2025; Mirza & Rebello, 2025). Therefore, strengthening digital literacy requires not merely increasing technology access, but designing instructional models that transform subject-matter understanding through meaningful interaction among pedagogy, content, and technology (Mishra & Koehler, 2006). In this regard, the challenge lies not only in students’ digital habits, but in how instructional frameworks use technology to reshape mathematical content representation and reasoning processes.

Alongside digital literacy concerns, mathematical problem-solving remains a persistent challenge for Indonesian students. Problem-solving skills are a fundamental competency in mathematics learning because they enable students to understand concepts deeply and apply them in various contexts (Kilpatrick, Swafford, & Findell, 2002; Polya, 2014; Schoenfeld, 2016). In Indonesia, students' mathematical problem-solving skills remain a serious concern. The results of the 2022 Program for International Student Assessment (PISA) show that Indonesia's mathematics achievement is 359 points, far below the OECD average of 472 points, and that most students are still in the low-performer category in mathematical problem-solving (OECD, 2023). National data from the Minimum Competency Assessment (AKM) reinforces these findings. Based on the 2025 Indonesian Education Report Card, only 45.38% of junior high school students achieved minimum numeracy competency, while only 56.82% of elementary school students achieved this, illustrating the weakness in the ability to use mathematical concepts, procedures, and reasoning in everyday life.

Furthermore, various studies have indicated that in statistics, particularly when determining measures of central tendency such as the mode, students often experience difficulties when tasks require higher-order analytical thinking (National Council of Teachers of Mathematics, 2020; Ying et al., 2020). Under typical conditions, students can easily determine the mode of grouped data when all frequency information is provided. They simply need to identify the class with the highest frequency without performing complex calculations. However, difficulties arise when students are given problems that deviate slightly from routine formats. For example, consider a frequency distribution table in which the class interval $71 - 75$ has an unknown frequency m. Students are informed that the mode of the data is 73.5 and that the modal class is the interval $71 - 75$. In such situations, students must use the formula for the mode of grouped data to determine the unknown frequency m. Yet, many students become confused when required to identify the components of the formula (such as the frequencies preceding and following the modal class), construct the appropriate equation, and solve for m based on the given mode value. Students often struggle to transition from procedural calculations to conceptual statistical modeling (Garfield et al., 2008).

These conditions indicate that students’ mastery of the mode for grouped data remains largely procedural and has not developed into flexible conceptual understanding. From a Content Knowledge (CK) perspective within the TPACK framework, statistics—particularly grouped-data modeling—requires a conceptual reconstruction of frequency relationships and symbolic representation. Such content cannot be effectively taught through procedural explanation alone; it demands re-representation through pedagogical structuring and technological affordances that support modeling, visualization, and reasoning. Conceptual understanding enables learners to transfer knowledge to novel problem situations beyond routine procedures (Hiebert & Grouws, 2007). Therefore, teachers need to design instructional approaches that encourage students to develop problem-solving skills through conceptual exploration, rather than merely memorizing mechanistic solution steps. These observations highlight the urgency of conducting research to develop learning models that can effectively enhance students’ mathematical problem-solving skills.

Previous studies have shown that Problem-Based Learning (PBL) is effective in improving students’ mathematical problem-solving skills and conceptual engagement (Hmelo-Silver, 2004; Lazonder & Harmsen, 2016; Stylianides & Stylianides, 2014). Research indicates that students who learn through PBL are better able to analyze problems, select strategies, and construct solutions independently. However, the effectiveness of PBL depends heavily on the integration of appropriate learning technologies (Hoesny et al., 2024; Scherer et al., 2019). In this regard, the Technological Pedagogical and Content Knowledge (TPACK) framework emphasizes not merely the harmonization of content, pedagogy, and technology, but the transformation of subject matter through their intersection. Within TPACK, effective instruction emerges when technology reshapes how content is represented (TCK), pedagogy structures inquiry and reasoning processes (PK), and technological affordances mediate collaborative exploration and scaffolding (TPK), resulting in integrated content transformation (TPACK). Thus, TPACK is not simply technology integration, but content re-representation through deliberate pedagogical and technological design. The TPACK framework conceptualizes effective instruction as the intersection of content, pedagogy, and technology knowledge (Howard et al., 2021; Mishra & Koehler, 2006).

In this study, this transformation is enacted within statistics instruction focused on the grouped-data mode. The statistical content requires students to reconstruct frequency relationships and formulate symbolic equations to determine unknown values. This demand is addressed pedagogically through structured PBL stages that guide students from problem orientation to inquiry, modeling, presentation, and reflection. Technologically, specific Nearpod affordances, such as Collaborate Board and Draw-It, are embedded within these stages to facilitate visualization, collaborative reasoning, and real-time feedback. Through this deliberate alignment of statistical tasks, inquiry processes, and digital mediation, TPACK is operationalized as an explicit instructional enactment rather than remaining at a purely conceptual level. Several studies have reported that implementing PBL within the TPACK framework can significantly enhance learning activities, conceptual understanding, and overall learning outcomes across various educational contexts (Bond et al., 2020; Tanjung et al., 2022)

Nearpod is an interactive learning platform whose technological affordances, such as real-time visualization, collaborative boards, and structured response tools, enable statistical content to be dynamically represented and explored (Chiu, 2021; Kaliisa et al., 2019). When embedded within problem-based inquiry, these features function not merely as delivery tools but as mediators that support visualization, modeling, and collaborative reasoning. Emerging evidence shows that Nearpod-based interactive media is effective in improving students' numeracy and scientific literacy by presenting materials that foster digital mathematical reasoning and analysis (Ellianawati et al., 2025). However, an important research gap remains, as prior studies have largely examined PBL, TPACK, and Nearpod separately or in partial combinations.

Although previous studies have examined PBL to enhance problem-solving, TPACK as a general integration framework, and Nearpod as interactive media, most are implementation-based and do not explicitly operationalize TPACK within a structured instructional syntax. Compared with prior studies that primarily reported technology-assisted PBL implementations, this study offers clearer phase-to-technology alignment and examines interaction effects with initial mathematics ability within a specific statistical content domain. In particular, limited research has (1) aligned specific PBL stages with explicit technological affordances, (2) articulated how statistical content is transformed at the intersection of pedagogy and technology, and (3) empirically tested such a structured design while simultaneously measuring mathematical problem-solving and national digital literacy outcomes.

This study does not introduce a new theory or extend the TPACK framework. Rather, it operationalizes TPACK as an explicit instructional enactment by systematically aligning PBL pedagogy with Nearpod's technological affordances and statistical content and by empirically examining its impact on students' problem-solving skills and digital literacy. By providing a clearer operationalization of TPACK in statistics learning and by analyzing interaction effects with initial mathematics ability, this study extends prior implementation-based research toward a more structured and empirically validated instructional design. Therefore, this study aims to investigate how the Nearpod-assisted PBL-TPACK enactment can enhance students' mathematical problem-solving skills and digital literacy within statistics instruction.

Research question

Based on the above description, this study aims to enhance students' mathematical problem-solving skills and digital literacy through the Nearpod-assisted PBL enactment within the TPACK framework. Three central research questions were formulated:

1. Is there a difference in the improvement of mathematical problem-solving skills between students who learn through the Nearpod-assisted PBL enactment within the TPACK framework and those who learn through direct instruction?
2. Is there an interaction effect between the instructional approach (Nearpod-assisted PBL enactment within the TPACK framework and direct instruction) and students' initial mathematics ability on the improvement of mathematical problem-solving skills?
3. Is there a difference in digital literacy between students who learn through the Nearpod-assisted PBL enactment within the TPACK framework and those who learn through direct instruction?

In accordance with these research questions, three hypotheses were proposed:

1. There is a significant difference in the improvement of students' mathematical problem-solving skills between those who learn through the Nearpod-assisted PBL enactment within the TPACK framework and those who learn through direct instruction.
2. There is an interaction between the instructional approach (Nearpod-assisted PBL enactment within the TPACK framework and direct instruction) and students' initial mathematics ability on the improvement of mathematical problem-solving skills.
3. There is a significant difference in digital literacy between students who learn through the Nearpod-assisted PBL enactment within the TPACK framework and those who learn through direct instruction.

METHODS

This study used a quasi-experimental pretest–posttest control group design to examine the effectiveness of Nearpod-assisted PBL within the TPACK framework for improving students' mathematical problem-solving skills and digital literacy. Due to institutional constraints, random assignment at the individual level was not feasible; therefore, intact classrooms were assigned as experimental and control groups.

Study sample

The participants were twelfth-grade students from two senior high schools in Bekasi, Indonesia. The schools were selected based on comparable accreditation status, curriculum implementation, student academic performance records, and socio-economic background to minimize institutional differences. To control for potential school-level confounding effects, baseline equivalence between the experimental and control groups was examined using an independent samples t-test on Initial Mathematics Ability (IMA) pretest scores. However, although the baseline test demonstrated equivalence in students' initial mathematical ability, the use of intact classes from two different schools may still allow other contextual factors—such as school academic culture, teaching quality, facilities, or overall learning environment readiness—to influence the findings. Nevertheless, this study-maintained objectivity by ensuring comparable initial academic conditions across groups. Even though the groups were located in different schools, institutional variability was minimized because both institutions implemented the same national curriculum, used comparable assessment standards, and were supervised under the same regional education authority.

The sampling procedure followed established stratified sampling principles in quasi-experimental educational research (Creswell, 2017). Stratified sampling was based on students' Initial Mathematics Ability (IMA), categorized into high, medium, and low levels using the percentile distribution of pretest scores. A total of 72 students, aged 16 to 18 years old, were selected to participate in the study. The unit of assignment was the intact classroom rather than individual students. Two existing classes were selected purposively based on schedule availability and curriculum alignment. One class was assigned to the experimental group and the other to the control group. Individual random assignment was not feasible due to institutional constraints; therefore, this study followed a quasi-experimental design rather than a true randomized experiment. During the

Table 1

Pre-test, intervention, and post-test

The Experimental Group	O	X	O
The Control Group	O		O

Description:
O: Pretest-Posttest
X: Teaching with PBL-TPACK supported by Nearpod

intervention, the experimental group consisted of 36 students who received mathematics instruction through the Nearpod-assisted PBL enactment within the TPACK framework, while the comparison group consisted of 36 students who received conventional mathematics instruction without technological integration. To ensure objectivity in the teaching experiment, the two groups were taught at different schools while following the same curriculum. Indonesian was the first language of all participants, and to minimize teacher-related variability, both groups were instructed by teachers with comparable years of teaching experience and similar academic qualifications. Prior to the intervention, both teachers were briefed on instructional objectives and research procedures to ensure consistency in curriculum coverage.

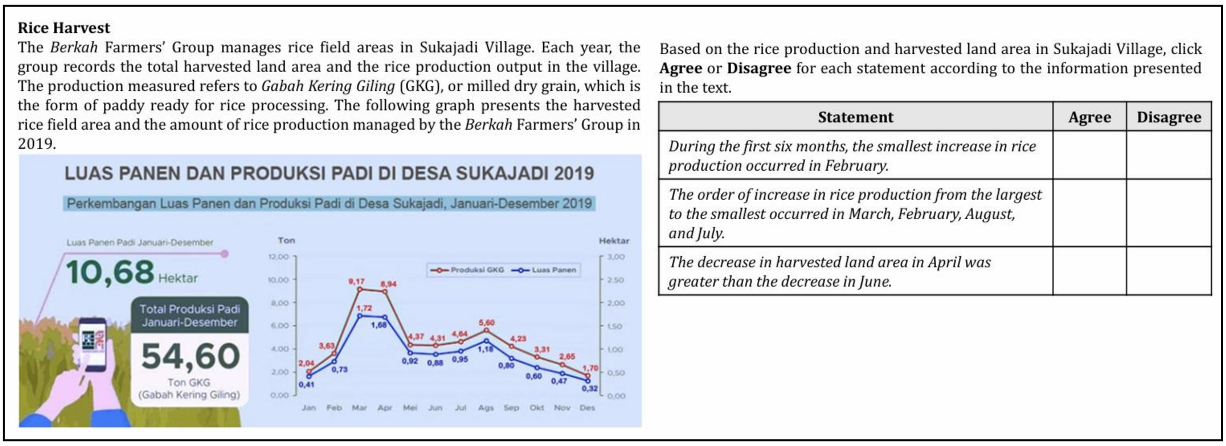
Intervention

The intervention in the experimental group followed the structure of the official lesson plan (RPP) on the mode for grouped and ungrouped data and was implemented by integrating Problem-Based Learning (PBL), the TPACK framework, and Nearpod. Instructional Framework Analysis using TPACK is as follows. Content Knowledge (CK): The instructional content focused on the statistical mode for grouped data, emphasizing conceptual reconstruction of frequency relationships and symbolic equation modeling. Pedagogical Knowledge (PK): The learning process followed structured Problem-Based Learning stages incorporating scaffolding strategies such as guided questioning, collaborative reasoning prompts, and reflective evaluation. Technological Knowledge (TK): Nearpod affordances (Collaborate Board, Draw-It, interactive quizzes) were used to facilitate dynamic visualization, real-time formative feedback, and collaborative representation of statistical reasoning.

The lesson began with preliminary activities, including an introduction, readiness checks, and a Nearpod-based pretest to assess students' prior knowledge. During the core learning phase, the five stages of PBL were implemented. The stages adopted in this study were adapted from the model proposed by Arends (2012) consisting of problem orientation, organizing students, guided investigation, presentation of solutions, and evaluation or reflection. Problem-Based Learning supports collaborative inquiry and conceptual knowledge construction (Hmelo-Silver, 2004). The instructional syntax implemented in the experimental group consisted of: (1) Problem Orientation (contextual statistical problem via Nearpod slide); (2) Problem Structuring (group identification of known and unknown variables); (3) Guided Inquiry (collaborative modeling using Draw-It and LKPD); (4) Presentation and Discussion (solution sharing via Collaborate Board); (5) Reflection and Conceptual Reinforcement (posttest and digital reflection).

First, students were oriented to a contextual problem presented through interactive slides. Next, they were organized into heterogeneous small groups and guided to identify problem-solving strategies using LKPD designed according to PBL-TPACK principles. Inquiry activities were supported by Nearpod tools such as Collaborate Board, Draw-It, and digital LKPD, enabling students to explore information, discuss solution ideas, and articulate reasoning collaboratively. Students then presented their group solutions, which were evaluated using the performance rubric. The lesson concluded with consolidation of key concepts, a Nearpod-based posttest, and a digital reflection using the Open-Ended Response feature and a digital literacy questionnaire. Formative assessment was conducted throughout the intervention using Nearpod's real-time response system, including interactive quizzes, open-ended responses, and collaborative board submissions. Immediate feedback was provided to guide conceptual refinement during inquiry stages.

This intervention aligned PBL stages, digital pedagogy, and the procedural steps outlined in the lesson plan, enabling students to engage in structured problem-solving supported by interactive technology. Meanwhile, the comparison group received instruction through direct teaching. Before the intervention, students in both groups completed a test assessing their initial problem-solving



Rice Harvest

The *Berkah* Farmers' Group manages rice field areas in Sukajadi Village. Each year, the group records the total harvested land area and the rice production output in the village. The production measured refers to *Gabah Kering Giling* (GKG), or milled dry grain, which is the form of paddy ready for rice processing. The following graph presents the harvested rice field area and the amount of rice production managed by the *Berkah* Farmers' Group in 2019.

Based on the rice production and harvested land area in Sukajadi Village, click **Agree** or **Disagree** for each statement according to the information presented in the text.

Statement	Agree	Disagree
During the first six months, the smallest increase in rice production occurred in February.		
The order of increase in rice production from the largest to the smallest occurred in March, February, August, and July.		
The decrease in harvested land area in April was greater than the decrease in June.		

Figure 1. Questions to examine Initial Mathematics Ability

skills. The intervention is depicted in Table 1. It was conducted over four sessions, beginning with an introduction to the research procedures, followed by PBL-based learning activities embedded in Nearpod, and ending with a post-test. Each session lasted 90 minutes and was held during regular course study hours.

Data collection

The research instruments developed included data-collection instruments and learning materials. These instruments comprised the students' Initial Mathematical Ability (IMA) test, a pretest–posttest measuring mathematical problem-solving skills, digital learning activity sheets, and a digital literacy questionnaire. All instruments were designed to assess improvements in students' mathematical problem-solving skills and digital literacy after participating in PBL-TPACK learning supported by Nearpod, across three initial ability levels: high, medium, and low. The data-collection procedure followed three stages: pre-intervention testing, implementation of the learning intervention, and post-intervention assessment.

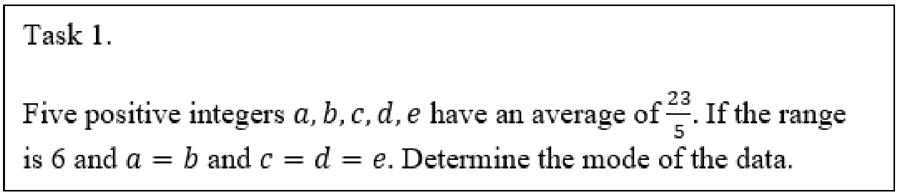
Mathematical problem-solving skills

Because the participants were 12th-grade senior high school students, all test items focused on statistical content. The IMA test was designed to assess students' initial understanding of data representation and consisted of four items. These items evaluated students' comprehension of graphical, bar-chart, and pie-chart representations, including skills such as decision-making, identifying true–false statements, and selecting statements consistent with the given data, as illustrated in Figure 1.

Based on Figure 1, the IMA test instrument not only measures basic mathematical skills but also assesses students' problem-solving abilities, particularly in identifying essential information from graphs on harvested land area and rice production, analyzing month-to-month changes—including increases, decreases, and production patterns—and evaluating data-based statements in which students must determine the validity of statements using logical reasoning rather than merely reading the graph accurately. Through Agree–Disagree-type items, the instrument requires students to employ multistep reasoning, such as calculating differences in data, comparing rates of change, and interpreting trends. Thus, the IMA test illustrates the extent to which students can apply fundamental mathematical concepts in real-world contexts and connect them to more complex problem-solving processes. The IMA test was administered to participants for approximately 40 minutes.

Furthermore, the mathematical problem-solving items were developed based on predetermined indicators, namely:

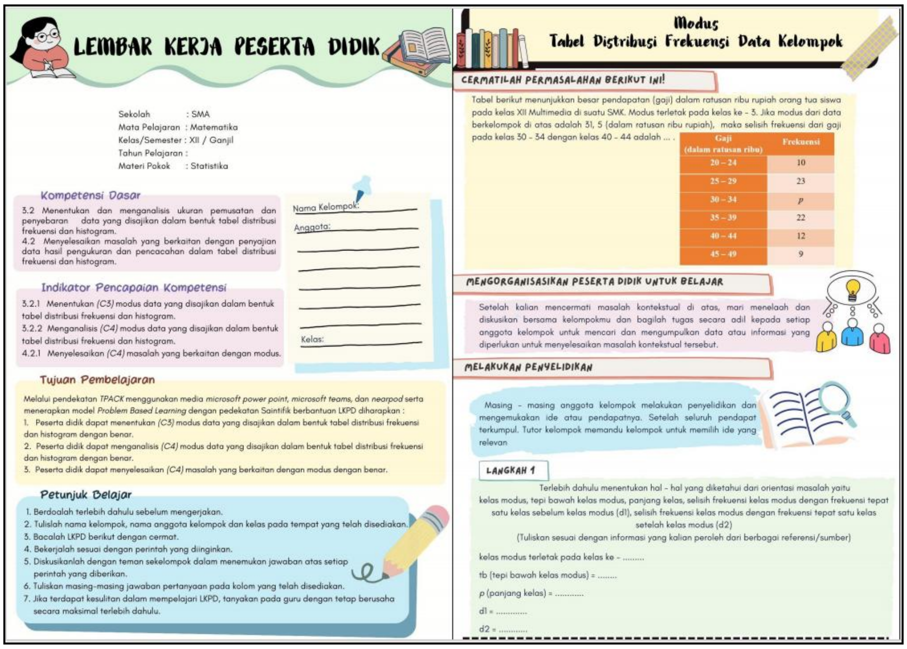
1. Gathering information – students are able to identify and record all relevant information presented in the problem.
2. Formulating a mathematical model – students are able to construct a mathematical model using appropriate symbols or variables.



Task 1.

Five positive integers a, b, c, d, e have an average of $\frac{23}{5}$. If the range is 6 and $a = b$ and $c = d = e$. Determine the mode of the data.

Figure 2. Example of a question for the pre-test and post-test.



LEMBAR KERJA PESERTA DIDIK

Sekolah : SMA
Mata Pelajaran : Matematika
Kelas/Semester : XII / Ganjil
Tahun Pelajaran :
Materi Pokok : Statistika

Kompetensi Dasar

3.2 Menentukan dan menganalisis ukuran pemusatan dan penyebaran data yang disajikan dalam bentuk tabel distribusi frekuensi dan histogram.
4.2 Menyelesaikan masalah yang berkaitan dengan penyajian data hasil pengukuran dan pencacahan dalam tabel distribusi frekuensi dan histogram.

Indikator Pencapaian Kompetensi

3.2.1 Menentukan *(C3)* modus data yang disajikan dalam bentuk tabel distribusi frekuensi dan histogram.
3.2.2 Menganalisis *(C4)* modus data yang disajikan dalam bentuk tabel distribusi frekuensi dan histogram.
4.2.1 Menyelesaikan *(C4)* masalah yang berkaitan dengan modus.

Nama Kelompok: ____
Anggota: ____
Kelas: ____

Tujuan Pembelajaran

Melalui pendekatan *TPACK* menggunakan media *microsoft power point, microsoft teams,* dan *nearpod* serta menerapkan model *Problem Based Learning* dengan pedekatan Saintifik berbantuan LKPD diharapkan :
1. Peserta didik dapat menentukan *(C3)* modus data yang disajikan dalam bentuk tabel distribusi frekuensi dan histogram dengan benar.
2. Peserta didik dapat menganalisis *(C4)* modus data yang disajikan dalam bentuk tabel distribusi frekuensi dan histogram dengan benar.
3. Peserta didik dapat menyelesaikan *(C4)* masalah yang berkaitan dengan modus dengan benar.

Petunjuk Belajar

1. Berdoalah terlebih dahulu sebelum mengerjakan.
2. Tulislah nama kelompok, nama anggota kelompok dan kelas pada tempat yang telah disediakan.
3. Bacalah LKPD berikut dengan cermat.
4. Bekerjalah sesuai dengan perintah yang diinginkan.
5. Diskusikanlah dengan teman sekelompok dalam menemukan jawaban atas setiap perintah yang diberikan.
6. Tuliskan masing-masing jawaban pertanyaan pada kolom yang telah disediakan.
7. Jika terdapat kesulitan dalam mempelajari LKPD, tanyakan pada guru dengan tetap berusaha secara maksimal terlebih dahulu.

Modus
Tabel Distribusi Frekuensi Data Kelompok

CERMATILAH PERMASALAHAN BERIKUT INI!

Tabel berikut menunjukkan besar pendapatan (gaji) dalam ratusan ribu rupiah orang tua siswa pada kelas XII Multimedia di suatu SMK. Modus terletak pada kelas ke - 3. Jika modus dari data berkelompok di atas adalah 31, 5 (dalam ratusan ribu rupiah), maka selisih frekuensi dari gaji pada kelas 30 - 34 dengan kelas 40 - 44 adalah ... .

Gaji (dalam ratusan ribu)	Frekuensi
20 – 24	10
25 – 29	23
30 – 34	p
35 – 39	22
40 – 44	12
45 – 49	9

MENGORGANISASIKAN PESERTA DIDIK UNTUK BELAJAR

Setelah kalian mencermati masalah kontekstual di atas, mari menelaah dan diskusikan bersama kelompokmu dan bagilah tugas secara adil kepada setiap anggota kelompok untuk mencari dan mengumpulkan data atau informasi yang diperlukan untuk menyelesaikan masalah kontekstual tersebut.

MELAKUKAN PENYELIDIKAN

Masing - masing anggota kelompok melakukan penyelidikan dan mengemukakan ide atau pendapatnya. Setelah seluruh pendapat terkumpul. Tutor kelompok memandu kelompok untuk memilih ide yang relevan

LANGKAH 1

Terlebih dahulu menentukan hal - hal yang diketahui dari orientasi masalah yaitu kelas modus, tepi bawah kelas modus, panjang kelas, selisih frekuensi kelas modus dengan frekuensi tepat satu kelas sebelum kelas modus (d1), selisih frekuensi kelas modus dengan frekuensi tepat satu kelas setelah kelas modus (d2)
(Tuliskan sesuai dengan informasi yang kalian peroleh dari berbagai referensi/sumber)

kelas modus terletak pada kelas ke - ....
tb (tepi bawah kelas modus) = ...
p (panjang kelas) = ...
d1 = ...
d2 = ...

Figure 3. An example of the student worksheet

3. Planning a solution – students are able to formulate a strategy to solve the problem.
4. Executing the solution plan – students are able to carry out the solution process in accordance with the plan that has been developed; and
5. Drawing conclusions – students are able to provide conclusions consistent with what is asked in the problem.

The example questions from the pre-test and post-test are specified in Figure 2.

This type of problem was used to assess students' logical reasoning, recognition of structural information (equalities among variables), and ability to identify numerical patterns. The use of integer constraints and range relationships was intentionally designed to stimulate reasoning beyond direct computation. The student worksheet (LKPD) used in this study was systematically designed to integrate the phases of Problem-Based Learning (PBL) with the TPACK framework and Nearpod's interactive features. Each component of the LKPD was designed to support the development of mathematical problem-solving and to enhance digital literacy through structured inquiry and technology-mediated collaboration. Figure 3 presents an example of the student worksheet (LKPD) used in the statistics lesson during the implementation of the Nearpod-assisted PBL enactment within the TPACK framework.

The LKPD begins with a non-routine contextual problem involving the mode of grouped data with an unknown frequency, intentionally creating cognitive conflict to prompt students to identify relevant information, construct mathematical models, and devise solution strategies. Presented digitally via Nearpod, the problem allows students to highlight key data, pose questions, and discuss ideas online, thereby strengthening their Digital Skills and Digital Ethics.

The inquiry section guides students in analyzing the frequency table, applying the mode formula, and articulating their reasoning in a structured way. This process is reinforced by Nearpod tools—such as *Draw-It*, *Collaborate Board*, and *Open-Ended Response*—that support data visualization, argument construction, and digital comparison of solutions across groups. These

Table 2
Digital literacy questionnaire statements

Digital Skills	Digital Ethics	Digital Culture	Digital Safety
I can use a laptop or smartphone independently for learning activities.	I always cite the source when using information or images from the internet.	I use digital technologies to support learning and increase productivity.	I use strong and unique passwords for different digital accounts.
I can search for academic information effectively on the internet.	I never share another person’s personal information without permission.	I can collaborate with peers on digital platforms (Google Docs, WhatsApp Groups, etc.).	I understand the risks of online fraud, such as phishing or scams.
I can use digital learning platforms such as Google Classroom, Nearpod, and Moodle.	I communicate respectfully on social media and respect different opinions.	I understand the importance of digital footprints and maintain my online reputation.	I check the security of a Wi-Fi network before connecting to it.
I can download, store, and properly organize digital files.	I understand that plagiarism is unethical behavior.	I can adapt to new technologies or digital tools quickly.	I keep my personal information (ID number, address, passwords) confidential.
I can evaluate the credibility of information sources before using them.	I can distinguish between appropriate and inappropriate content to share publicly.	I avoid negative online behaviors such as cyberbullying or spreading hoaxes.	I can recognize suspicious links or messages on social media or email.

activities sharpen problem-solving skills in representation, planning, and evaluation while fostering Digital Culture through collaborative digital interaction.

In the final stage, the LKPD requires students to develop group conclusions and complete a digital reflection in Nearpod. This reflection prompts students to evaluate the effectiveness of their strategies, identify errors, and reflect on their digital behaviors, thereby supporting metacognitive growth and Digital Safety awareness.

Overall, the LKPD serves as an integrated pedagogical instrument that promotes conceptual exploration, higher-order problem solving, and comprehensive digital literacy within a technology-enhanced PBL learning environment aligned with TPACK principles. Afterward, they completed a posttest parallel to the pretest and submitted a Nearpod-based reflection to document their learning experiences.

Digital literacy questionnaire

Students’ digital literacy was assessed using a Likert-scale questionnaire developed from Indonesia’s National Digital Literacy Framework, which comprises four pillars: Digital Skills, Digital Ethics, Digital Culture, and Digital Safety. Digital competence frameworks emphasize structured domains, including information literacy, communication, content creation, safety, and problem-solving (Carretero et al., 2017; Redecker, 2017). The instrument was adapted from established theoretical models of digital literacy (Eshet-Alkalai, 2004; Gilster & Watson, 1997; Jenkins, 2007; Martin, 2008; Ng, 2012; Ribble, 2011) and aligned with the competencies outlined by Kominfo and Kemdikbud (Carretero et al., 2017; van Laar et al., 2017). The questionnaire consisted of 20 items distributed across four dimensions, show in Table 2: (1) Digital Skills (5 items) (2) Digital Ethics (5 items): (3) Digital Culture (5 items): and (4) Digital Safety (5 items).

Digital literacy was measured using a Likert-scale questionnaire and digital tasks aligned with the four national literacy pillars (Digital Skills, Digital Ethics, Digital Culture, and Digital Safety), supplemented by observational data of students’ digital behaviors. The data provided a comprehensive overview of students’ development in problem-solving and digital literacy.

Data analysis

Data analysis was conducted to evaluate the proposed research hypotheses. Statistical conclusions were drawn using independent samples t-tests and two-way ANOVA at a significance level of $\alpha = .05$. Effect sizes (*Cohen's d* and *partial eta-squared*) were calculated to assess the magnitude of the observed effects. Students' improvement in mathematical problem-solving skills was measured using gain scores, calculated as the difference between posttest and pretest scores ($Gain = Posttest - Pretest$). The intervention was considered effective if:

1. The experimental group demonstrated significantly higher gain scores than the control group ($p < .05$).
2. A significant main effect of the learning model was found in the two-way ANOVA.
3. A significant interaction effect between learning model and IMA level was observed; and
4. Digital literacy scores differed significantly between groups.

To address the research hypotheses, a four-phase data analysis procedure was used as follows

Phase 1: Testing IMA score differences between the experimental and control groups

The first stage of the analysis assessed whether IMA scores differed between the experimental and control groups using either an independent-samples *t-test* or the *Mann–Whitney* test. Before conducting the difference test, both datasets were examined for normality and homogeneity. Normality was tested using the *Shapiro–Wilk* test, and homogeneity of variance was assessed using *Levene's* test, each at a significance level of $\alpha = .05$. When both datasets met the assumptions of normality and homogeneity ($p > .05$), the difference in IMA scores was evaluated using the *t-test*. Conversely, if either assumption was violated ($p < .05$), the $Mann - Whitney$ test was employed to analyze the difference between groups. The hypotheses tested were as follows:

H_0: *There is no significant difference in IMA scores between experimental and control groups.*
H_1: *There is a significant difference in IMA scores between the experimental and control groups.*

If the resulting significance value from either the *t-test* or *Mann–Whitney* test exceeded $\alpha = .05$, H_0 was retained; otherwise, H_0 was rejected in favor of H_1.

Phase 2: Testing differences in gain scores between experimental and control groups

The second stage of the analysis aimed to determine whether there was a significant difference in students' improvement in mathematical problem-solving skills between those taught through Nearpod-assisted PBL within the TPACK framework and those taught through direct instruction. Students' gain scores were calculated by subtracting pretest scores from posttest scores. Before conducting the difference test, gain scores in both groups were assessed for normality using the Shapiro–Wilk test and for homogeneity of variance using Levene's test at $\alpha = .05$. When assumptions were satisfied, an independent samples t-test was conducted to compare gain scores between the experimental and control groups. If assumptions were violated, the *Mann–Whitney* test was employed. The hypotheses tested were:

H_0: *There is no significant difference in gain scores between the experimental and control groups.*
H_1: *There is a significant difference in gain scores between the two groups.*

H_0 was rejected when $p < .05$. Effect size was calculated using *Cohen's d* to determine the magnitude of the improvement difference.

Phase 3: Testing the main and interaction effect of learning model and IMA level on gain scores

The third stage examined whether students' improvement in mathematical problem-solving skills differed by learning model (experimental and control), IMA level (low, medium, high), and the interaction between these two factors. Before conducting inferential analyses, gain scores were assessed for normality and homogeneity of variance. All datasets met the assumptions of normality and homogeneity ($p > .05$), indicating that the data were suitable for two-way ANOVA analysis. A two-way ANOVA was conducted with learning model (experimental and control) and IMA level (low, moderate, high) as independent variables. The hypotheses tested were:

Main Effect of Learning Model

H_0: *There is no significant difference in gain scores between learning models.*
H_1: *There is a significant difference in gain scores between learning models.*

Main Effect of IMA Level

> H_0: *There is no significant difference in gain scores among IMA levels.*
> H_1: *There is a significant difference in gain scores among IMA levels.*

Interaction Effect

> H_0: *There is no interaction effect between learning model and IMA level on gain scores.*
> H_1: *There is a significant interaction effect between learning model and IMA level on gain scores.*

H_0 was rejected when $p < .05$. When significant interaction effects were detected, post hoc comparisons *(Tukey HSD)* were conducted. Effect sizes were reported using *Partial Eta Squared* (η_p^2).

Phase 4: Testing differences in digital literacy scores between the experimental and control groups

The fourth phase of the analysis examined whether a significant difference in digital literacy emerged between students who received PBL-TPACK instruction supported by Nearpod and those taught through direct instruction. To address this objective, two sequential tests were conducted: (1) testing the normality and homogeneity of digital literacy scores in both the experimental and control groups, and (2) testing the difference in digital literacy scores between the two groups.

The first test followed the same procedures used in Phase 1, whereas the second analysis used either an independent-samples t-test or the *Mann–Whitney* test, depending on the results of the normality and homogeneity assessments. The hypotheses for assessing differences in digital literacy scores were as follows:

> H_0: *There is no significant difference in digital literacy scores between the experimental and control groups.*
> H_1: *There is a significant difference in digital literacy scores between the experimental and control groups.*

H_0 was accepted when the significance value exceeded $\alpha = .05$; conversely, H_0 was rejected when the significance value was below $\alpha = .05$, indicating that a significant difference in digital literacy scores exists between the experimental and control groups.

FINDINGS

As previously stated, this study aims to examine improvements in students' mathematical problem-solving skills and digital literacy through Nearpod-assisted PBL implementation within the TPACK framework. Four quantitative analyses were conducted as follows:

1. an analysis of students' initial mathematics ability (IMA) to ensure baseline equivalence between the experimental and control groups.
2. An analysis of differences in gain scores in mathematical problem-solving skills between students taught through Nearpod-assisted PBL within the TPACK framework and those taught through direct instruction.
3. a two-way ANOVA of gain scores to examine the main effects of the instructional approach and IMA level, as well as their interaction effect on students' improvement in mathematical problem-solving skills; and
4. an analysis of differences in digital literacy scores between students taught through Nearpod-assisted PBL within the TPACK framework and those taught through direct instruction.

Analysis of students' initial mathematics ability

Prior to hypothesis testing, assumption tests were conducted for all datasets. The Shapiro–Wilk test indicated that all variables, including Initial Mathematics Ability (IMA), gain scores, and digital literacy scores, were normally distributed ($p > .05$). Levene's test also confirmed homogeneity of variance across groups ($p > .05$). Therefore, parametric statistical analyses, including independent samples t-tests and two-way ANOVA, were considered appropriate.

Before the instructional experiment was conducted, an analysis of students' initial mathematics ability (IMA) in both the experimental and control groups was conducted to ensure that the two groups were equivalent at baseline. This step aimed to minimize the influence of external

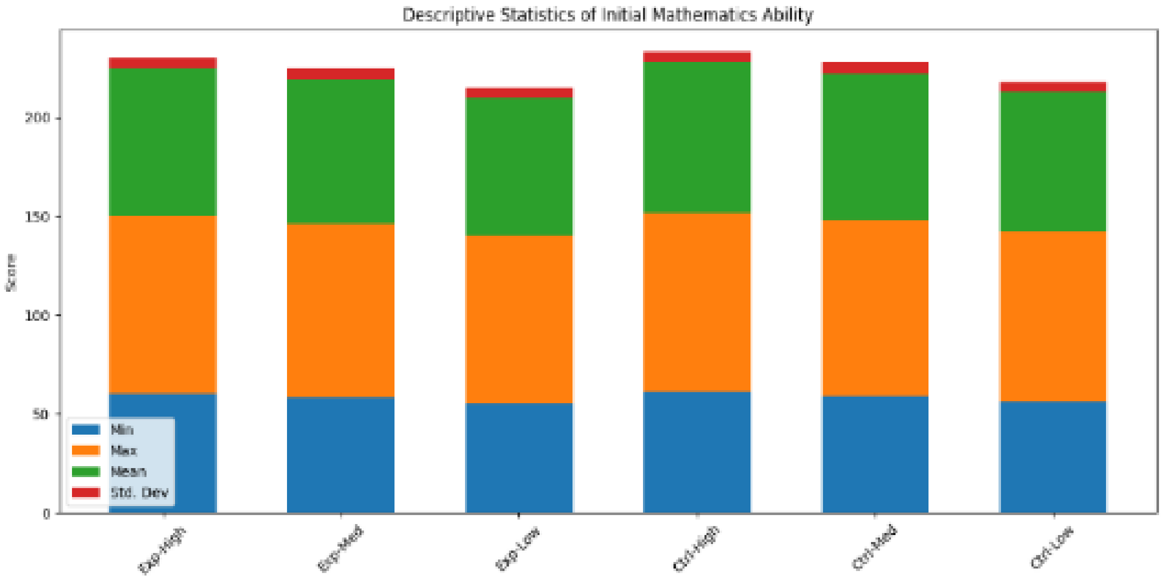


Figure 2. Descriptive statistics of initial mathematics ability

variables—other than the instructional approaches such as imbalances in IMA across groups, on the improvement of mathematical problem-solving skills and digital literacy. Therefore, an IMA test was administered to all participating students prior to the implementation of the learning intervention. The descriptive statistics for IMA scores in both groups are presented in Figure 4.

Based on Figure 4, both groups showed similar IMA scores. This is evident in comparable Min–Max ranges across categories, small differences in mean scores, and low, uniform standard deviations, indicating stable score dispersion. For example, the mean scores of students with high IMA in the experimental group (Exp-High) and the control group (Ctrl-High) were nearly identical, namely $\bar{x} = 75$ and $\bar{x} = 76$, respectively.

Inferential statistical testing was then conducted to strengthen confidence in these findings. The Shapiro–Wilk normality test showed that the experimental group obtained $W = .967, p = .278$, while the control group obtained $W = .973, p = .354$. Additionally, Levene's test for equality of variances confirmed that the IMA data were homogeneous, $F(1, 70) = 1.45, p = .232$. Thus, the use of parametric statistical techniques, such as the independent samples *t-test* and *two-way ANOVA* on *gain scores,* was deemed appropriate. An independent samples t-test was subsequently conducted to examine whether there was a significant difference in IMA scores between the experimental and control groups. The results indicated that there was no statistically significant difference between the two groups, $t(70) = 1.873, p = .070 > .05, Cohen's\ d = .44$. Therefore, both groups were considered equivalent at baseline prior to the intervention.

Analysis of mathematical problem-solving skills

During the learning process, the experimental group received instruction through Nearpod-assisted PBL within the TPACK framework, whereas the control group received direct instruction. Students' mathematical problem-solving skills were assessed using pretest and posttest instruments focused on statistical problem-solving tasks. Descriptive statistics for pretest and posttest scores are presented in Table 3.

Although descriptive results show improvements in both groups, the primary analysis focused on gain scores (Posttest – Pretest) to directly measure students' improvement. Before the inferential analysis, gain scores in both groups were examined for normality and homogeneity. The Shapiro–Wilk test indicated that gain scores were normally distributed in both groups (experimental: $W = .972, p = .184$; control: $W = .965, p = .127$). Furthermore, Levene's test demonstrated that the variances of the gain scores were equal across groups, $F(1, 70) = 2.13, p = .149$. These findings confirm that the assumptions of normality and homogeneity were met ($p > .05$), justifying the application of an independent samples t-test. Therefore, an independent samples t-test was conducted to compare the gain score between the experimental and control groups.

Table 3

Average pre- & post-test scores by IMA

IMA Level	Experiment Group		Control Group	
	Pre-test	Post-test	Pre-test	Post-test
Combined	63.11	81.89	62.47	74.36
Low	56.00	75.22	55.10	68.44
Moderate	63.44	81.33	62.77	73.22
High	70.00	88.44	69.33	80.11

Table 4

Average *gain* score in mathematical problem-solving skills by teaching approach & IMA

IMA Level	PBL-TPACK supported by Nearpod Experiment Group	Direct Control Group
Low	19.22	13.34
Moderate	17.89	10.45
High	18.44	10.78

The experimental group demonstrated higher gain scores ($M = 18.51$) compared to the control group ($M = 11.52$). An independent samples t-test confirmed that this difference was statistically significant, $t(70) = 4.87, p < .001$, $d = 1.15$. Students who received instruction through the Nearpod-assisted PBL enactment within the TPACK framework demonstrated significantly greater improvement in mathematical problem-solving skills than those who received direct instruction.

As shown in Table 4, gain scores across all IMA levels were consistently higher in the experimental group than in the control group. This pattern suggests that the Nearpod-assisted PBL enactment within the TPACK framework contributed more substantially to students' improvement on statistical problem-solving tasks. These findings indicate that the instructional approach had a meaningful impact on students' mathematical problem-solving development.

Analysis of interaction effect of learning model and IMA levels on students' gain score

To further examine whether students' improvement in mathematical problem-solving skills differed by learning model and initial mathematics ability (IMA), a two-way ANOVA was conducted on gain scores, with learning model (experimental vs. control) and IMA level (low, moderate, high) as the independent variables. The analysis revealed a significant main effect of learning model, $F(1, 66) = 28.73, p < .001 < \alpha, \eta_p^2 = .303$, indicating that students in the experimental group demonstrated greater improvement than those in the control group.

A significant main effect of IMA level was also observed, $F(2, 66) = 6.48, p = .003 < \alpha, \eta_p^2 = .164$, suggesting that improvement differed across students with low, moderate, and high initial mathematics ability. Importantly, a significant interaction effect between the learning model and IMA level was found, $F(2, 66) = 4.12, p = .021 < \alpha, \eta_p^2 = .111$, indicating that the effectiveness of the instructional model varied depending on students' initial ability levels.

Tukey HSD post hoc analysis indicated that students in the experimental group with moderate IMA achieved significantly higher gain scores than those in the control group (mean difference $= 7.44, p = .012$). Similarly, students with high IMA in the experimental group outperformed their counterparts ($p = .004$). However, for students in the low IMA category, the difference in gain scores between the experimental and control groups did not reach statistical significance ($p > .081$).Although descriptively, the experimental group showed greater improvement.

Figure 5 shows the interaction between the learning model and the IMA level on the gain scores. The non-parallel slopes indicate that the magnitude of improvement varied across IMA categories. Although all IMA groups benefited from the Nearpod-assisted PBL enactment within the TPACK framework, the increase in gain scores was more pronounced among students with moderate or high initial mathematics ability than among those in the low-IMA category.

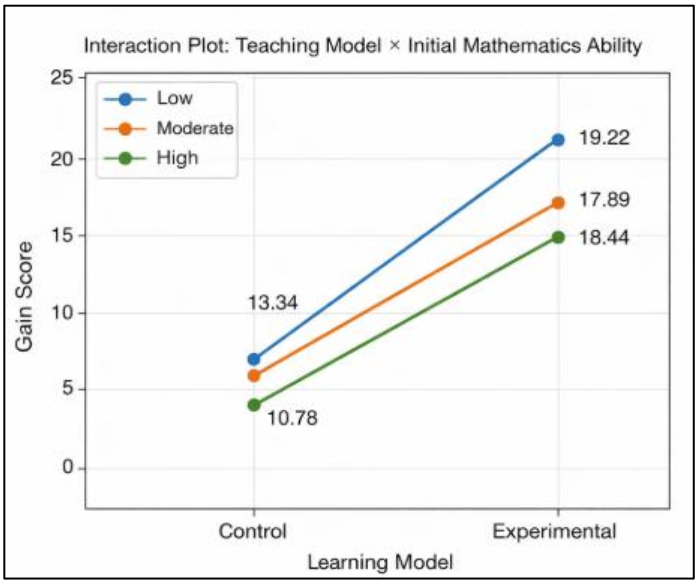


Figure 3. Interaction effect

Table 5

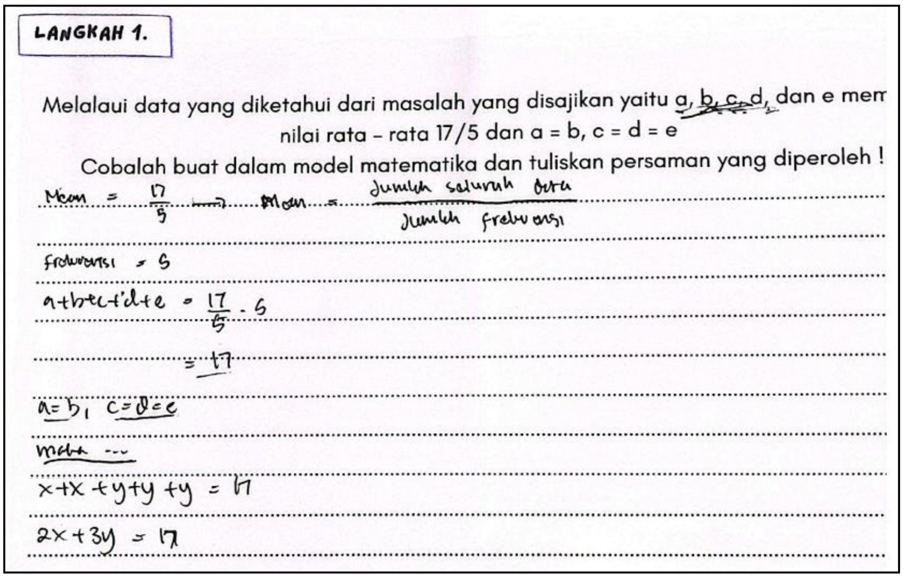
Mean digital literacy scores based on the four pillars of digital literacy

Digital Literacy Aspect	Brief Description of the Aspect	Experimental Class	Control Class
Digital Skills	Ability to access, operate, and utilize devices and digital features during learning	4.21	3.58
Digital Ethics	Ethical behavior, digital etiquette, and responsibility in online interactions	4.08	3.47
Digital Culture	Ability to collaborate, appreciate diverse perspectives, and participate constructively in digital environments	4.15	3.52
Digital Safety	Awareness and practices of data security, personal privacy, and digital protection	4.02	3.41
Overall Mean		4.12	3.50

Analysis of digital literacy scores

The fourth analysis examined whether a significant difference in digital literacy scores emerged between students taught through Nearpod-assisted PBL enactment within the TPACK framework and those taught through direct instruction. Prior to hypothesis testing, assumption checks were conducted. The Shapiro–Wilk test indicated that digital literacy scores were normally distributed in both groups (experimental: $(W = .968, p = .215;$ control: $W = .971, p = .310)$. Levene's test confirmed homogeneity of variance $(F(1,70) = 1.78, p = .186)$. Overall, the data met the assumptions of normality and homogeneity (p > .05), supporting the use of parametric testing. Therefore, an independent samples t-test was performed.

The results revealed a statistically significant difference between the experimental and control groups, $t(70) = 3.98,\ p < .001$, with $Cohen's\, d = 0.94$, indicating a large effect size. Students in the experimental group obtained a higher overall mean digital literacy score $(M = 4.12)$ compared to the control group (M = 3.50). Descriptive analysis across the four pillars showed consistently higher scores in the experimental group, as presented in Table 5.



LANGKAH 1.

Melalaui data yang diketahui dari masalah yang disajikan yaitu a, b, c, d, dan e mem nilai rata - rata 17/5 dan a = b, c = d = e

Cobalah buat dalam model matematika dan tuliskan persaman yang diperoleh !

Mean = $\frac{17}{5}$ ⟶ Mean = $\frac{\text{Jumlah seluruh data}}{\text{Jumlah frekuensi}}$

frekuensi = 5

$a+b+c+d+e = \frac{17}{5} \cdot 5$

$= 17$

a = b, c = d = e

maka ...

$x+x+y+y+y = 17$

$2x+3y = 17$

Figure 6. Example of student response

The test scores of students a, b, 71, 74, and 74 are known. These five test scores have an average of 70, and the mode is unique, which is 74. What is the value of a + b?

Figure 7. Nearpod visualization

A shown in Figure 6, these findings indicate that the structured implementation of PBL within the TPACK framework, supported by Nearpod, significantly contributed to students' digital literacy development across all national literacy dimensions. Digital literacy was analyzed at the group level because the study did not hypothesize differential effects across initial mathematics ability categories.

DISCUSSION

The findings of this study demonstrate that Nearpod-assisted PBL enacted within the TPACK framework significantly enhanced students' mathematical problem-solving skills compared with direct instruction. Beyond statistical significance, the results provide empirical evidence of how content, pedagogy, and technology interacted to transform students' conceptual understanding in statistical modeling tasks as shown in Figure 7.

From a Content Knowledge (CK) perspective, the statistical topic of the grouped-data mode requires students to reconstruct frequency relationships and formulate symbolic equations rather than merely identifying the modal class by following a procedure. The student's work in Figure 6 illustrates this conceptual restructuring. Students translated contextual information into an algebraic representation, $(e.g., 2x + 3y = 17)$ indicating a shift from procedural computation to relational modeling. This representational development suggests that students engaged in deeper structural reasoning about relationships among data, which aligns with the substantial improvement observed in gain scores.

From a Pedagogical Knowledge (PK) standpoint, the structured Problem-Based Learning stages were central to guiding this transformation. The phases of problem orientation, structured inquiry, collaborative modeling, presentation, and reflection provided progressive cognitive scaffolding. Empirical synthesis studies have shown that structured scaffolding significantly enhances learning outcomes in inquiry-based environments, particularly when tasks require higher-order reasoning (Belland et al., 2017). The interaction between the learning model and initial mathematics ability indicates that this pedagogical structuring did not operate uniformly across students. Learners with moderate and high prior ability appeared better positioned to use inquiry-based modeling processes effectively, suggesting that prior conceptual readiness moderated the instructional impact. This conditional effectiveness refines the understanding of PBL implementation, indicating that scaffolding depth and task complexity must be carefully calibrated to students' initial knowledge structures.

Technological Knowledge (TK) was operationalized through Nearpod's affordances, which mediated visualization and collaborative reasoning. As shown in Figure 7, interactive features such as Time to Climb externalized students' cognitive processing by requiring rapid interpretation and symbolic responses. Similarly, Draw-It and Collaborate Board enabled students to make their mathematical representations visible, comparable, and open to feedback. Rather than functioning as a mere delivery platform, Nearpod served as a representational mediator that increased the transparency of reasoning processes. This aligns with research showing that digital tools can reorganize mathematical representations when teachers deliberately orchestrate their use within task design (Drijvers et al., 2010). The simultaneous improvement in digital literacy further indicates that technological engagement was meaningfully integrated into problem-solving activities rather than operating as an add-on component.

Taken together, these findings demonstrate that TPACK integration in this study was not based on the mere co-presence of PBL and digital tools, but on the coordinated alignment of statistical content demands, inquiry-based pedagogy, and technology-mediated representation. Statistical modeling tasks were re-represented through structured inquiry and digital visualization, thereby operationalizing TPACK as an enacted instructional design rather than a theoretical abstraction.

Building on previous research, the present findings both maintain and extend existing evidence. Consistent with prior studies on Problem-Based Learning, the structured inquiry approach supported students' development of analytical strategies and independent reasoning. Similarly, previous research on Nearpod-based interactive learning reported improvements in numeracy and engagement. However, this study extends those findings by empirically examining interaction effects with initial mathematics ability and by explicitly aligning technological affordances with statistical modeling tasks. The conditional pattern of effectiveness observed here suggests that the impact of technology-enhanced PBL is influenced by students' prior conceptual readiness.

At the same time, the limited gains among students with low initial mathematics ability partially diverge from studies reporting uniformly positive effects of PBL. This discrepancy may be interpreted through the lens of Cognitive Load Theory, as complex modeling tasks combined with digital interaction may impose higher intrinsic and extraneous cognitive demands on learners with insufficient prior schema. This interpretation aligns with the argument that minimally guided instructional approaches in complex learning environments can overload working memory when learners lack sufficient prior knowledge structures (Kirschner et al., 2006). From a Vygotskian perspective, these students may require more intensive, gradual scaffolding to bridge the gap between their actual and potential developmental levels. Therefore, while the PBL-TPACK enactment proved effective overall, differentiated support mechanisms appear essential to ensure equitable benefits across ability groups. Meta-analytic findings further indicate that inquiry-based learning yields stronger outcomes when guidance is explicitly structured and progressively faded, rather than left implicit (Lazonder & Harmsen, 2016).

Beyond mathematical problem-solving, the significant improvement in digital literacy across the four national pillars suggests that embedding technology in inquiry-based tasks can foster both cognitive and digital competencies. Because digital tools were integrated into authentic modeling activities, students practiced ethical communication, collaboration, and responsible data handling in meaningful contexts. This integrated development supports the argument that digital literacy should not be taught in isolation but cultivated through structured disciplinary problem-solving.

Overall, this study contributes to the literature by providing empirical evidence that TPACK-based instructional enactment can transform statistical content learning when pedagogical structuring and technological affordances are deliberately aligned. The results refine the discourse on technology-integrated PBL by showing that effectiveness is conditional, conceptually mediated, and dependent on students' initial cognitive readiness.

CONCLUSIONS

This study was designed to address two interrelated problems in mathematics education: students limited statistical problem-solving ability and the underdeveloped integration of digital literacy into mathematics instruction. The findings demonstrate that a structured instructional enactment of TPACK—operationalized through Problem-Based Learning and mediated by Nearpod—provides a pedagogically coherent solution to these challenges.

The improvement in students' problem-solving was not attributable to technology use alone but to the deliberate alignment of statistical modeling tasks (CK), structured inquiry phases (PK), and technology-supported visualization and collaboration (TK). This coordinated enactment enabled students to move beyond procedural identification of the modal class toward relational and symbolic modeling. Thus, the study affirms that TPACK becomes instructionally meaningful only when content is cognitively transformed through pedagogical and technological design.

At the same time, the interaction findings indicate that instructional effectiveness is moderated by students' initial mathematics ability. The model was particularly effective for learners with moderate to high prior knowledge, suggesting that conceptual readiness influences how students benefit from inquiry-based digital environments. This underscores the need for differentiated scaffolding to ensure equitable learning gains.

Importantly, digital literacy improved alongside mathematical reasoning because technological engagement was embedded in authentic disciplinary tasks rather than treated as a separate objective. This integrated development supports the argument that digital competence in mathematics should emerge from structured problem-solving contexts.

In sum, this study empirically contributes to the TPACK discourse by showing that a structured operational instructional design—rather than a theoretical extension—can simultaneously transform statistical learning and digital literacy development. However, the effectiveness of such designs depends on intentional alignment and sensitivity to students' prior knowledge structures.

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AUTHOR'S DECLARATION

Authors' contributions	The initial conception of this study was collaboratively developed by all authors. The manuscript was primarily drafted by HAD with substantial contributions from NSU and FF. During the revision process, all authors were actively involved in refining the content, improving the analysis, and responding to reviewer comments. The final editing, formatting according to the journal template, and literature verification were carried out collaboratively by all

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Availability of data and materials	The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.
Competing interests	The authors declare that they have no competing interests.

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