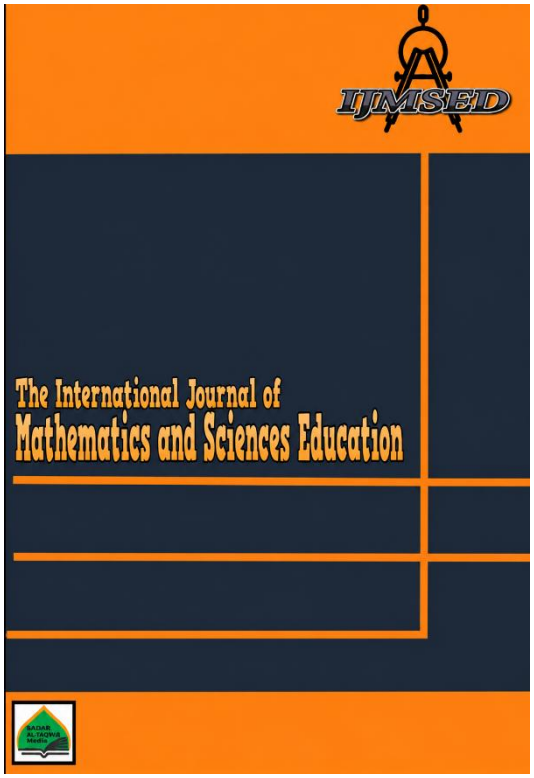
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From production room to feasible region: A project-based interactive e-module for linear programming in vocational agribusiness classrooms

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From production room to feasible region: A project-based interactive e-module for linear programming in vocational agribusiness classrooms

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Abstract
Vocational students often learn linear programming as a graphical routine disconnected from production problems. This study used ADDIE to develop an interactive Canva e-module that embeds food-processing optimisation in six stages of project-based learning for Grade X agribusiness students in Indonesia. Needs analysis identified mathematising production situations as the main difficulty. Eight validators reviewed the prototype, and revisions addressed usability and interactivity following expert review and student trials. Aiken's V was 0.77 for content and 0.78 for media. In a six-meeting one-group field trial with 15 students, participants rated the module's practicality at 83.47%. Mathematical understanding increased from 54.20 to 64.93 and learning independence from 96.27 to 125.13 (both p-values below .001). Wilcoxon tests also corroborated both improvements observed in the field trial. Normalised gains were low for understanding (0.22) and moderate for independence (0.42). Exploratory analyses suggested that students improved most in representing contextual problems as feasible-region graphs. Gains in model formulation and identification of optimal values were smaller and statistically inconclusive. The low internal consistency of the understanding test and the absence of a comparison group limit interpretation to feasibility and observed pre–post improvement. Five design principles are proposed for testing in future controlled studies across multiple sites.

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1. Introduction

Mathematics in vocational secondary schools carries a double mandate: students must master the same algebraic ideas as their general-school peers and use them in the production problems of their occupational field. Linear programming is a clear case: translating limited resources into linear inequalities and searching the feasible region for

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an optimum is the mathematical form of everyday food-processing decisions, such as how many batches of two products to make when flour, sugar, and machine time are limited. Yet Indonesian studies report that linear programming is still taught largely as a fixed graphical routine and that students struggle to model contextual problems, choose the correct inequality sign, and interpret the optimum (Sugiarto et al., 2021; Rahman et al., 2021; Sari & Afriansyah, 2022). Indonesian 15-year-olds perform weakest in formulating real situations mathematically (OECD, 2023), the most demanding step of the modelling cycle (Cevikbas et al., 2022; Schukajlow et al., 2023).

Project-based learning (PjBL) responds to this gap by organising learning around a driving question, a planned investigation, and a public product (Markula & Aksela, 2022). Meta-analyses indicate that PjBL improves achievement, affective outcomes, and thinking skills, although effects vary with implementation quality (Guo et al., 2020; Zhang & Ma, 2023), and classroom studies report gains in engagement (Almulla, 2020), science learning (Krajcik et al., 2023), and twenty-first-century skills in mathematics (Rehman et al., 2023). Teachers nevertheless find mathematics projects the hardest to design because authentic problems rarely align with curricular procedures (Viro et al., 2020; Saad & Zainudin, 2022); in vocational schools, where the production room supplies the authentic context, this difficulty is sharper but also more promising (Kohen & Orenstein, 2021; Baidowi et al., 2023).

Digital materials can reduce this design burden. Digital tools in secondary mathematics and science produce positive effects, particularly when combined with teacher guidance and used for representation and practice (Hillmayr et al., 2020); GeoGebra has consistently improved achievement and conceptual understanding (Tamur et al., 2020; Zulnaidi et al., 2020; Birgin & Uzun Yazıcı, 2021; Juandi et al., 2021); and blended designs show moderate effects on achievement and engagement (Attard & Holmes, 2020; Cao, 2023; Putri et al., 2025). However, online components often fail when students lack self-regulation (Rasheed et al., 2020), outcomes depend on how deliberately teachers embed technology (Viberg et al., 2023), and reviews of artificial intelligence and adaptive tools conclude that pedagogical structure, not technology itself, determines the outcome (Hwang & Tu, 2021; Hidayat et al., 2022).

This conditionality is linked to learning independence. Self-regulated learning (SRL) is the process through which learners set goals and monitor and regulate their cognition, motivation, and behaviour (Zimmerman, 2002; Panadero, 2017), and it predicts achievement in online and blended settings (Anthonysamy et al., 2020; Xu et al., 2023). It is related to, but distinct from, motivation and task value (Eccles & Wigfield, 2020) and engagement (Fredricks et al., 2004). In Indonesian mathematics education, learning independence (kemandirian belajar) denotes a broader disposition combining initiative, sustained engagement, persistence, and valuing what is learned. We use the term in this sense, as the motivational and behavioural facet of SRL in Pintrich's framework (Pintrich et al., 1993), not as SRL as a whole; cognitive strategy use and metacognitive monitoring are not claimed as outcomes. Self-regulation training improves performance and motivation (Theobald, 2021), scaffolded mathematics environments improve learning

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behaviour and achievement (Hwang et al., 2021), and immediate feedback, which digital materials can automate, is among the strongest levers (Wisniewski et al., 2020). The second concern is whether a digital module can carry this scaffolding for vocational project work.

Three ideas frame the design. First, the six PjBL syntaxes (essential question, project plan, schedule, monitored work, testing, and evaluation) organise the module, with content pages used alongside the project stages (Markula & Aksela, 2022; Saad & Zainudin, 2022). Second, following the distinction between instrumental and relational understanding (Skemp, 1976), mathematical understanding is defined as the ability to move between a production situation, its algebraic model, its graph, and its optimum while knowing why each step works. It is operationalised through three indicators corresponding to stages of the modelling cycle (Cevikbas et al., 2022; Schukajlow et al., 2023): identifying model elements and formulating the model, representing systems and contextual problems as feasible-region graphs, and applying the corner-point algorithm to determine and interpret the optimum (Appendix Table A1). Third, learning independence is supported through structure and feedback (Xu et al., 2023; Wisniewski et al., 2020). The expected mechanism is that context motivates, project structure distributes responsibility, and dynamic visualisation with feedback supports the hardest representational step.

Indonesian development studies have begun to combine these strands, notably a PjBL mathematics e-module evaluated for creative thinking (Mustika, 2022) and a PjBL module for vocational high schools aimed at critical thinking (Baidowi et al., 2023). Such studies show that project-based materials can be judged valid and practical, but they typically report validity and practicality as aggregate percentages, which can hide validator disagreement and obscure what was revised and why (Spatioti et al., 2022; Tinoca et al., 2022), and infer effectiveness from significance alone, without effect sizes, normalised gains, or analyses of indicators and individual students (Burkholder et al., 2020; Kraft, 2020). The present study contributes a documented design case: a PjBL e-module for an under-studied vocational topic, an explicit feature-to-stage design logic that can itself be tested, a traceable account of how rater disagreement and user feedback changed successive prototypes, and an analysis of change at the levels of variables, indicators, and students from which provisional design principles are derived.

Accordingly, this study reports the full ADDIE cycle of an interactive PjBL e-module on linear programming for Grade X students in the Agribusiness of Agricultural Product Processing (APHP) programme at a public vocational school in Sumbawa, Indonesia. Four research questions guided the study:

RQ1 (Analysis and Design). What curricular demands, learner characteristics, and needs shaped the e-module, and how were they translated into its design?

RQ2 (Development). How valid is the e-module according to content, media, language, and practitioner validators, and how practical is it in a small-group trial?

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RQ3 (Implementation). How practical is the e-module in a full field trial, and do students' mathematical understanding and learning independence change significantly after its use?

RQ4 (Evaluation). How large and how evenly distributed are these changes across indicators and students, and what is the final form of the product?

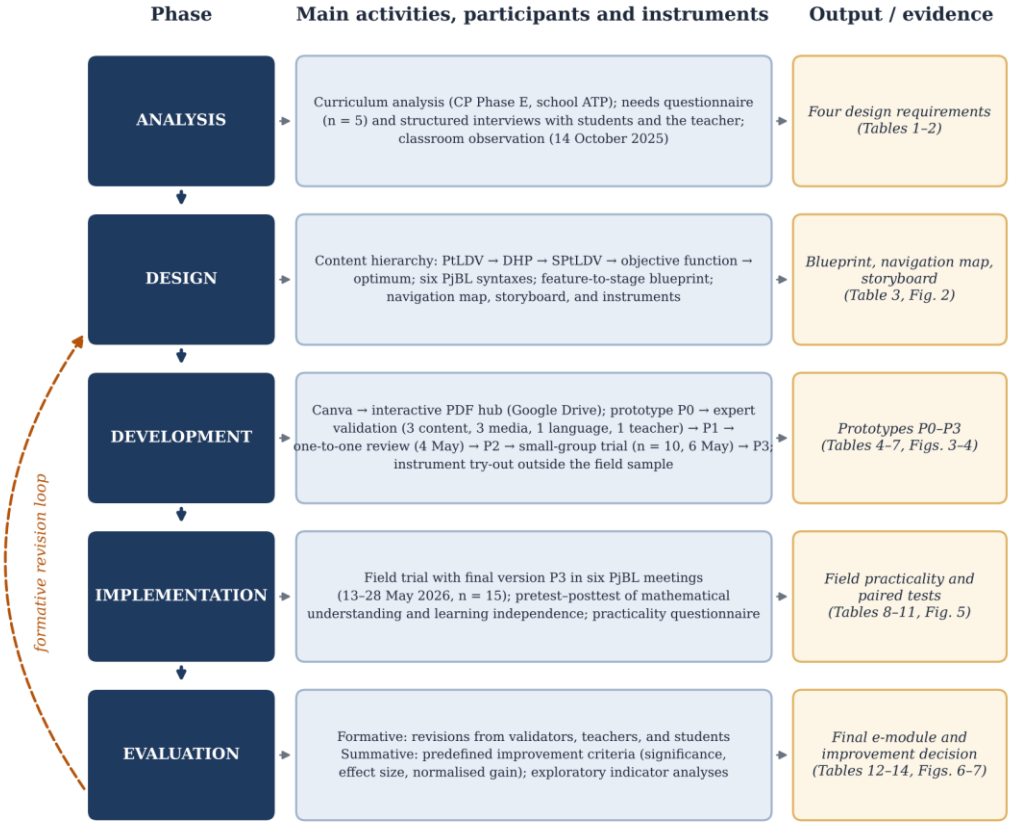
2. Method

2.1 Research Design

The study used a research and development design structured by the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), a widely applied framework for designing digital and distance learning materials (Spatioti et al., 2022). Formative evaluation accompanied development and produced four product versions. Prototype P0, built in Canva, was rated by eight validators (7–30 April 2026); P1 addressed their comments and was re-rated by the dissenting content validator; P2 resulted from a one-to-one review (4 May 2026) and was used in the small-group trial (6 May 2026); and the revisions from that trial produced P3, used in the field trial from 13 May 2026 (Table 7). Although the study borrows the iterative logic of design-oriented research (Tinoca et al., 2022), it is not design-based research: it comprises one development cycle before a single field enactment, so the design principles in Section 4 are provisional conjectures. Figure 1 summarises the procedure, participants, instruments, and outputs of each phase.

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Figure 1
ADDIE development procedure, instruments, and outputs of each phase



The study took place at SMK Negeri 1 Labangka, a public vocational school in Sumbawa Regency, West Nusa Tenggara, in the 2025/2026 academic year. The needs analysis was conducted on 14 October 2025 and the field implementation in six meetings between 13 and 28 May 2026; the pretest in the first meeting also provided the initial-ability profile reported in Section 3.1.

2.2 Participants

The only Grade X APHP class (15 students) formed the field-trial group through total sampling. Five of these students, chosen with the teacher to represent high, medium, and low achievement, completed the needs questionnaire and interview, and the class mathematics teacher was interviewed. Eight validators reviewed the prototype: three content experts, three media experts, one language expert, and the class teacher as practitioner. All expert validators held a master's or doctoral degree in mathematics education, language education, or educational technology; because the content experts were not food-processing specialists, a productive APHP teacher checked the vocational contexts in the one-to-one review. No validator belonged to the development team, and the practitioner had not taken part in designing the product. The one-to-one review involved three Grade XI APHP students, two mathematics teachers, and one productive APHP teacher. The small-group trial involved ten purposively selected students of three ability levels: eight Grade XI APHP students who had studied linear programming the

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previous year and two Grade X students, S3 and S12, who later belonged to the field-trial class. These two did not encounter the outcome measures in that session, and a sensitivity analysis excluding them is reported in Section 3.4. Both outcome instruments were tried out with ten Grade XI APHP students outside the field sample. Field-trial students are coded S1–S15.

2.3 Instruments

Seven instruments were used (Appendix Table A2). An 11-item dichotomous needs questionnaire and a structured interview guide examined learning habits, prior use of digital materials, interest in vocational projects, and preferred features, and observation notes documented facilities, device ownership, internet access, and the dominant teaching pattern. Five-point validation sheets assessed the content (15 items), media (15 items), language (9 items), and practitioner (8 items) aspects, with space for comments, and a 20-item practicality questionnaire on the same scale covered content, appearance, language, and use. All items were positively worded. Each instrument was developed from a blueprint reviewed by a content expert.

The mathematical understanding test comprised five contextual essay items on APHP production problems, each scored 0–20 with an analytic rubric (maximum 100; Appendix Table A1): items 1 and 3 assessed identifying model elements and formulating the model (40 points), items 2 and 4 representing systems and contextual problems as feasible-region graphs (40 points), and item 5 determining and interpreting the optimum value (20 points). The pretest and posttest were parallel forms from the same blueprint, differing only in products and coefficients; in the try-out, item difficulty indices of the two forms differed by no more than .03 (mean P = .684 and .697), item–total correlations ranged from .50 to .83, and Cronbach's α was .73. Scripts were scored by the first author, without blinding to testing occasion and without a second rater. The learning independence questionnaire had 32 positively worded five-point items (total 32–160) in four eight-item indicators: confidence and initiative, enthusiasm and active engagement, persistence and resilience, and awareness of the value of mathematics. The indicators were adapted from the motivation and resource-management scales of the Motivated Strategies for Learning Questionnaire (Pintrich et al., 1993) and from Indonesian indicators of learning independence. In the try-out (α = .94), items 14, 15, and 29 were revised before use (the thesis describes item 29 as dropped, whereas the field data contain 32 items. The first author, not the class teacher, administered the questionnaires individually; students were told that their answers would not affect their grades, and the teacher did not see individual responses. Acquiescence and socially desirable responding cannot be excluded. In the field data, the questionnaire was highly consistent (α = .92 initial, .94 final), but the understanding test was not (α = .35 pretest, .38 posttest): corrected item–total correlations ranged from −.10 to .50, item 5 correlated negatively with the rest on both occasions, and the standard error of measurement was about 8.8 points at pretest and 8.3 at posttest. Total and indicator understanding scores are therefore interpreted cautiously.

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2.4 Data Analysis

Validity percentages (obtained divided by maximum score) were interpreted as very valid (85.01–100%), valid (70.01–85.00%), fairly valid (50.01–70.00%), less valid (30.01–50.00%), or not valid (≤ 30.00%); practicality percentages used the same bands. Because percentages can conceal rater disagreement, Aiken's (1985) V was computed for each item as $V = \Sigma s / [n(c - 1)]$, where s is a rater's score minus the lowest rating (1), c = 5 is the number of categories, and n is the number of raters, and item values were averaged to component and aspect level. V was interpreted as very high (V > .80), high (.70 < V ≤ .80), moderate (.40 < V ≤ .70), low (.20 < V ≤ .40), or very low (V ≤ .20). With three raters per content and media panel, V reflects both rating level and agreement and is imprecise; for the single-rater language and practitioner aspects, V is only a rescaled mean rating. Components with moderate or lower V were treated as revision triggers.

The two primary analyses, specified in the thesis research plan before data collection, were two-tailed paired-samples t-tests (α = .05) on the total scores. Because non-significant Shapiro–Wilk tests in a sample of 15 cannot establish normality, the paired differences were also inspected through standardised differences and leave-one-out recalculation of t, and Wilcoxon signed-rank tests (normal approximation with tie correction, no continuity correction) served as a robustness check. Effect sizes were Cohen's dz with a 95% confidence interval from the noncentral t distribution, Hedges' corrected gz (Lakens, 2013), and $r = |Z|/\sqrt{N}$ for the Wilcoxon test. Individual normalised gain, g = (post − pre)/(max − pre), was classified as high (g ≥ 0.70), moderate (0.30 ≤ g < 0.70), low (0 < g < 0.30), no change, or decrease, and both the mean of individual gains and the gain of the means are reported (Burkholder et al., 2020). For learning independence (minimum 32), percentages of the maximum possible range (POMP) are also reported. Indicator-level changes were exploratory and are reported with mean differences, 95% confidence intervals, and Holm-adjusted p values within each outcome (Holm, 1979). The research plan predefined three improvement criteria: (a) p < .05, (b) dz ≥ 0.50, and (c) mean g ≥ 0.30; meeting all three was labelled criteria met, and meeting (a) and (b) only, criteria partly met. Analyses were run in IBM SPSS Statistics 22 and reproduced from the raw item data in Python with SciPy 1.18. Validator comments, interview notes, and field notes from the one-to-one review and small-group trial were coded deductively by aspect (content, PjBL structure, media, language, and use) by the first author and checked by the co-authors, retaining positive, negative, and contradictory comments; each coded comment was linked to the revision it produced (Table 7).

2.5 Ethical Considerations

Written permission was obtained from the principal of SMK Negeri 1 Labangka, and activities took place within the regular timetable and covered the scheduled curriculum content. The study followed generally accepted ethical principles for educational research and involved minimal risk to participants. Responses were anonymised with codes and are reported only in aggregate or coded form, and no identifiable photographs of students are reported.

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3. Results

Results are presented by ADDIE phase, each with the evidence it produced and the decision it led to.

3.1 Analysis Phase: Curriculum Demands, Learner Characteristics, and Needs

The curriculum analysis was based on the Phase E mathematics learning outcomes in the Decree of the Head of the Agency for Standards, Curriculum, and Educational Assessment (BSKAP) No. 046/H/KR/2025. Linear programming belongs to the Algebra and Functions element, which requires students to solve problems involving systems of two-variable linear inequalities. The school's learning-objective flow (ATP) for Grade X APHP operationalises this as modelling and solving optimisation problems with feasible-region graphs and the corner-point method, using only prerequisites students had already learned (systems of linear equations, graphing straight lines, and substitution). The content was sequenced into five learning objectives over 12 lesson hours: linear inequalities and their graphs, the feasible region of one inequality, the feasible region of a system with non-negativity constraints, reconstructing a system from its graph, and modelling and solving contextual problems. The APHP context offered natural optimisation problems, such as combining sweet bread and frozen bread production under limited flour, sugar, and machine capacity.

Teacher and student interviews identified translating word problems into inequalities, choosing the direction of the inequality sign, identifying constraints, and determining the feasible region and its optimum as the main obstacles, echoing earlier linear programming studies (Sugiarto et al., 2021; Sari & Afriansyah, 2022). The field-trial pretest (13 May 2026), the same administration analysed in Section 3.4, confirmed this profile: mean 54.20 (SD = 10.94, median = 53, range 36–69), with three students (20%) classified as high, nine (60%) as medium, and three (20%) as low using the mean ± one standard deviation. Table 1 summarises the needs questionnaire.

Table 1

Results of the Needs Questionnaire on the Interactive E-Module (n = 5)

No.	Statement	Yes	No	% Yes
1	Teachers usually deliver material through printed books or photocopies.	5	0	100
2	Teachers have provided material as digital files, applications, or phone-based modules.	0	5	0
3	Teacher explanations and available books help students understand mathematics.	5	0	100
4	Students enjoy creative project tasks related to the APHP field.	5	0	100
5	Teachers often let students design tasks according to their interests.	0	5	0
6	Students have learned and completed tasks through an interactive e-module.	0	5	0
7	Students are interested in learning mathematics at any time on their phones.	4	1	80

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No.	Statement	Yes	No	% Yes
8	Learning on a phone is more practical and enjoyable than writing on paper.	3	2	60
9	Students are more motivated when a module contains APHP videos, animations, and pictures.	4	1	80
10	Students hope to learn independently with a digital module that scores their work immediately.	4	1	80
11	Students need guidance on how to use a digital module before using it.	5	0	100

Note. Data collected on 14 October 2025 from five students representing high, medium, and low initial ability.

Learning relied entirely on printed materials, and no student had used an interactive e-module (items 1, 2, and 6). Interest was high: all students liked APHP project tasks, and 80% were interested in phone-based learning with videos and animations (items 4, 7, and 9). Readiness was uneven: only 60% considered phone learning more practical than paper, and all wanted guidance before using a digital module (items 8 and 11). Interviews added that students feared making technical errors when submitting work online, and observation confirmed universal smartphone ownership, school internet access, and lecture-dominated teaching with photocopied modules. Table 2 synthesises these findings into four design requirements.

Table 2

Synthesis of Analysis-Phase Findings into Design Requirements

Source of evidence	Key finding	Design requirement
Curriculum analysis	Linear programming requires progression from inequality graphs to feasible regions and contextual modelling (5 objectives, 12 lesson hours).	R1: Present content hierarchically from prerequisite concepts to modelling and optimisation.
Teacher and student interviews (October 2025); pretest (May 2026)	Main errors in mathematising word problems, inequality signs, and non-negativity constraints; later confirmed by the pretest (mean 54.20; 60% medium ability).	R2: Embed every concept in APHP production problems with step-by-step scaffolding.
Needs questionnaire and interview (n = 5)	No prior use of digital modules; strong interest in APHP projects, phones, videos, and instant scoring.	R3: Provide video, graphical visualisation, and immediate feedback accessible on smartphones.
Questionnaire item 11, interview, observation	All students need guidance; fear of technical errors; device ownership and internet available.	R4: Include explicit instructions for use and teacher-guided orientation in the first meeting.

Note. R = requirement.

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3.2 Design Phase: From Requirements to a Product Blueprint

The four requirements were translated into design decisions on content, PjBL structure, media, language, and support (Table 3). The central decision was to treat technology as the means of running the PjBL syntax: videos and driving questions served the essential question, input boxes served planning and scheduling, GeoGebra links served the construction of feasible regions, and quizzes and reflection forms served testing and evaluation. Content and project chapters were designed to be used in parallel, with each project stage linking back to the content pages it requires (Table 8).

Table 3

Design Blueprint of the Interactive PjBL E-Module

Aspect	Design decision	Rationale
Content	Hierarchical sequence: linear inequality → feasible region → system of inequalities → objective function → optimum value; each concept opened by an APHP problem (sweet and frozen bread, chips, fruit jam).	R1, R2; modelling difficulties reported in interviews
PjBL syntax	Six syntaxes (essential question, project planning, scheduling, monitoring, testing results, evaluating experience) organised as a dedicated chapter with page markers.	All students liked APHP projects (Table 1, item 4)
Media	Designed in Canva and published as an interactive PDF via a Google Drive link; YouTube videos, GeoGebra links, answer boxes, quizzes with feedback, navigation buttons.	R3; no prior e-module use; interest in phones (items 6–7)
Language	Short, direct sentences; second-person address; driving and reflective questions; technical terms explained with APHP examples.	Varied initial ability; need for independent study
Support	Instructions for use at the beginning and an orientation session in the first meeting.	R4; all students need guidance (item 11)

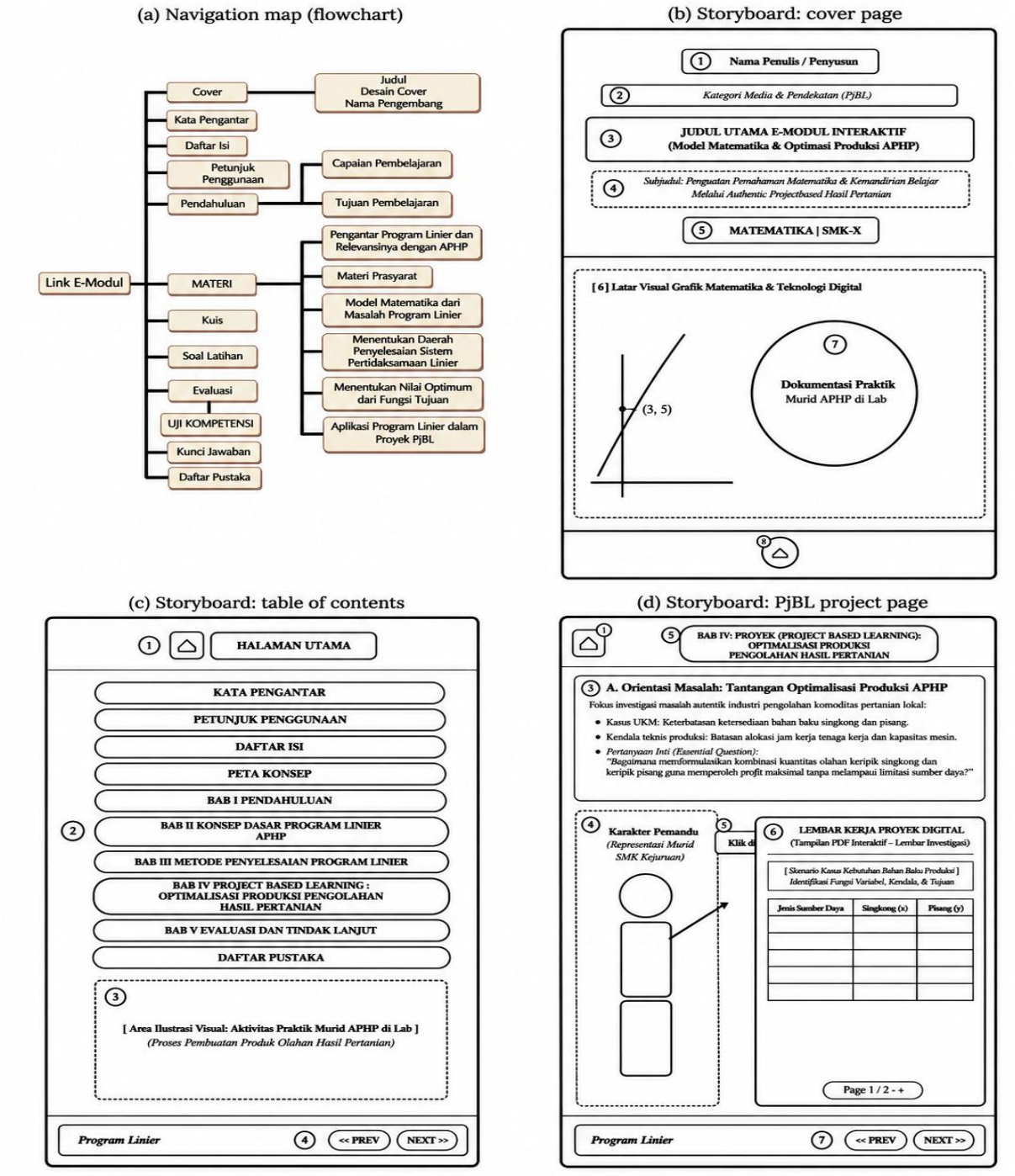
The blueprint was elaborated into a navigation map (Figure 2a), which organises the e-module as a hub linking its front matter, five content units, quizzes, exercises, evaluation, competency test, answer key, and references, and into storyboards (Figures 2b–2d) that fix the position of every page element, including the navigation buttons and, on the project page, the problem orientation, guiding character, and digital project worksheet.

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Figure 2

Design-phase outputs: navigation map and storyboards of the e-module



3.3 Development Phase: Production, Expert Validation, and Small-Group Trial

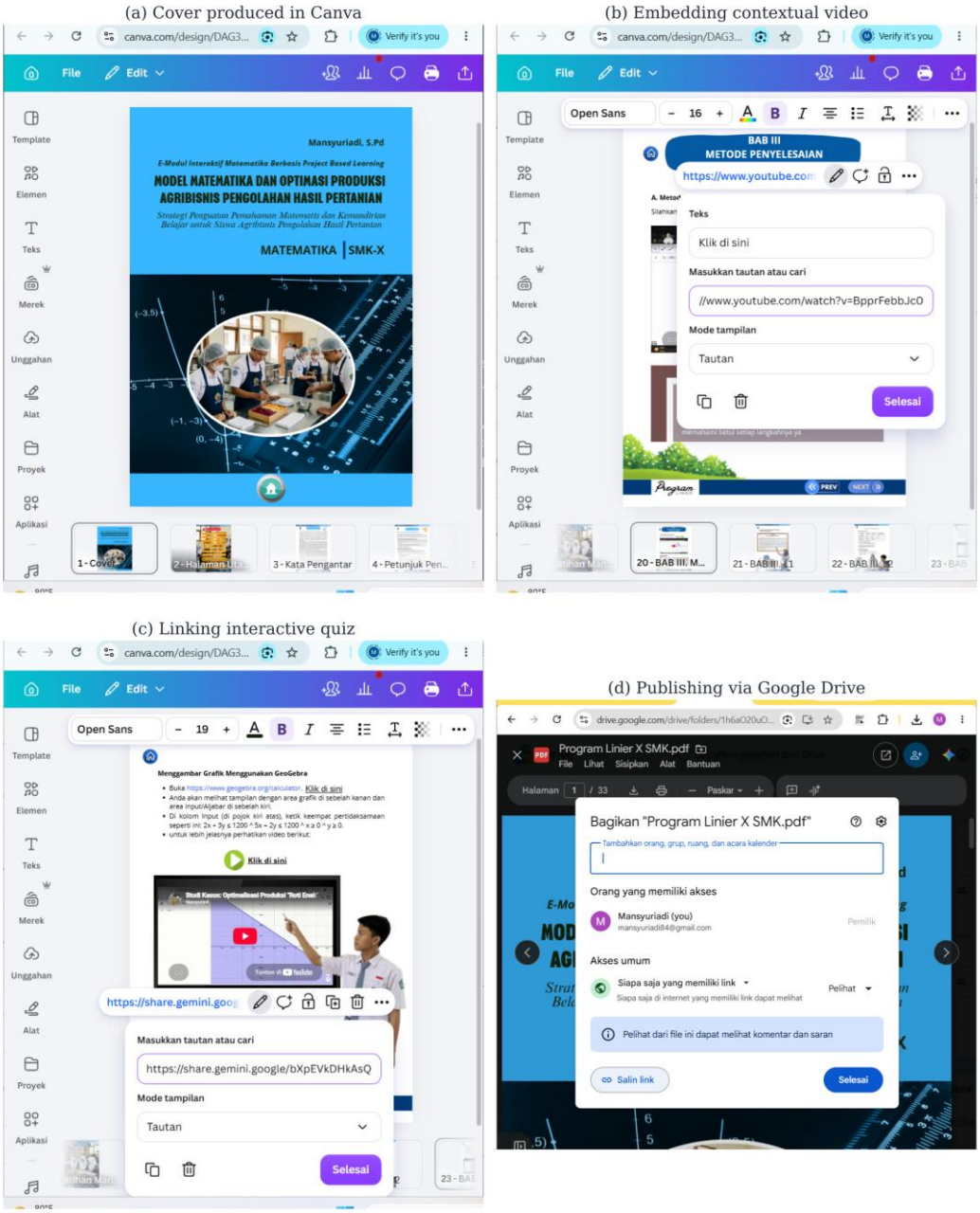
Production and publication. The storyboard was realised in Canva (Figure 3): page layouts, illustrations of APHP production rooms, navigation buttons, answer boxes, YouTube videos, GeoGebra applets, and quizzes were composed and linked, and the document was exported as a PDF with active links, uploaded to Google Drive, and shared with the class through its messaging group. The PDF functions as a hub rather than a self-contained application (Appendix Table A3): navigation works inside the PDF, whereas

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GeoGebra Web, YouTube, and Google Forms (quizzes with automatic feedback, the reflection sheet, and report submission) require an internet connection. The answer boxes are PDF form fields, but the Google Drive preview does not save entries, which explains why entries could be lost in the small-group trial.

Figure 3

Development of the e-module in Canva and its publication through Google Drive



Expert validation. Table 4 reports the validation of prototype P0. Content, media, and language were valid (81.33–82.22%) and the practitioner assessment very valid (95.00%); the unweighted mean of the four aspects was 85.19% and the pooled percentage, weighting each aspect by its number of items (443 of 535), was 82.80%. P0 was therefore valid, with practitioner judgement more favourable than expert judgement.

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After revision, the dissenting content validator re-rated the content of P1 at 82.67% (valid). No other re-ratings were made, so no further expert validity evidence exists for P2 or P3.

Table 4

Expert and Practitioner Validation of the E-Module

Aspect	Validator	Items	Score	Max.	%	Category
Content	V1	15	68	75	90.67	Very valid
	V2	15	41	75	54.67	Fairly valid
	V3	15	74	75	98.67	Very valid
	Aspect total		183	225	81.33	Valid
Media	V1	15	66	75	88.00	Very valid
	V2	15	56	75	74.67	Valid
	V3	15	63	75	84.00	Valid
	Aspect total		185	225	82.22	Valid
Language	V1	9	37	45	82.22	Valid
Practitioner	Teacher	8	38	40	95.00	Very valid
Overall	Pooled (all items)		443	535	82.80	Valid

Note. Five-point scale. Categories: very valid 85.01–100%; valid 70.01–85.00%; fairly valid 50.01–70.00%. All scores concern prototype P0; the dissenting content validator (V2) later re-rated the revised content (P1) at 62/75 (82.67%, valid).

Table 4 also shows marked disagreement: content validator V2 rated 14 of the 15 items 2 or 3 (54.67%), far below V1 and V3, with a milder pattern on media (74.67%). Aiken's V was therefore used to examine agreement by component (Table 5).

Table 5

Aiken's V by Aspect and Component

Aspect	Component	V	Category
Content (V = .77)	Fit with curriculum and student context	.75	High
	Depth and correctness of concepts	.78	High
	Presentation, language, and readability	.75	High
	Support for the PjBL approach	.75	High
	Support for understanding and learning independence	.81	Very high
Media (V = .78)	Visual appearance and aesthetics	.79	High
	Ease of use (usability)	.67	Moderate
	Interactivity and engagement	.69	Moderate
	Technical functionality	.94	Very high
Language (V = .78)	Straightforwardness	.75	High
	Communicativeness	.83	Very high
	Interactivity of language	.75	High
Practitioner (V = .94)	Classroom applicability	.94	Very high

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Note. Very high V > .80; high .70 < V ≤ .80; moderate .40 < V ≤ .70. Content and media panels: three raters each. *Single rater: V is a rescaled mean rating, not an index of agreement.*

Most components reached high or very high values, but ease of use (.67) and interactivity (.69) were moderate, consistent with the media experts' comments that the next and previous buttons were missing and that external links needed checking; these became the first revision priority. With three-member panels these values are imprecise, and single-rater values describe rating levels rather than agreement.

One-to-one review. On 4 May 2026, three Grade XI APHP students, two mathematics teachers, and one productive APHP teacher used P1 on their own phones and completed the practicality questionnaire (84.89%, 85.00%, and 87.69%, respectively). They reported a GeoGebra button that did not open, weak label contrast on dim screens, an overlong instruction for step 3 of the project worksheet, and missing non-negativity constraints in some worked models. The APHP teacher noted that yeast was given in kilograms instead of grams and that the oven constraint should match the production unit's real capacity of two large trays per baking cycle. These comments were incorporated into P2 (Table 7).

Small-group trial. On 6 May 2026, ten students used P2 on their own phones, completed the activities, and filled in the practicality questionnaire (Table 6).

Table 6

Practicality of the E-Module in the Small-Group Trial (n = 10)

Aspect	Items	Score	Max.	%	Category
Content	1–5	210	250	84.00	Practical
Appearance	6–10	200	250	80.00	Practical
Language	11–15	200	250	80.00	Practical
Use	16–20	218	250	87.20	Very practical
Overall	1–20	828	1,000	82.80	Practical

Note. Very practical 85.01–100%; practical 70.01–85.00%.

The e-module was practical overall (82.80%). Use was the strongest aspect (87.20%), matching comments that students could learn anywhere without carrying a book, whereas appearance and language were the weakest (80.00%), with the lowest items concerning unambiguous instructions (item 15, 68%) and on-screen readability (item 11, 70%). Individual totals ranged from 63 to 91. Observation identified three further problems: answer boxes were too small, the technical instructions contained typing errors, and entries could be lost when the connection dropped.

Formative revisions. Table 7 links each input to the revision it produced and the resulting prototype version, and Figure 4 shows examples of revised pages.

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Table 7

Formative Inputs and Resulting Revisions

Source	Input	Revision
Content experts (P0 → P1)	Enrich local contexts close to students' experience.	Problems replaced with APHP production-room cases (sweet and frozen bread, chips, fruit jam) and made more open-ended.
	Strengthen conceptual, not only procedural, understanding (feasible region, corner points, optimal solution).	Reasons added for each step; interpretation questions on the optimum in production terms.
	Standardise solution steps; complete scaffolding.	Solution steps and variable units standardised; worked examples and hints added to modelling exercises.
	Give every project phase detailed guidance and success indicators.	Each PjBL syntax received work instructions and success indicators.
Media experts (P0 → P1)	Inconsistent colours; next and previous buttons missing; external links must be checked.	Uniform colour scheme; home, next, and previous buttons and page markers added; all YouTube, GeoGebra, and Google Forms links retested.
Language expert (P0 → P1)	Use measurable operational verbs; simplify rigid terms.	Objectives and indicators reworded; technical terms paired with communicative equivalents.
Students, one-to-one (P1 → P2)	"The button to open the GeoGebra simulation on the feasible-region page does not work"; weak contrast of graph labels; step 3 instruction too long.	Link repaired and retested; label contrast increased; step 3 instruction split into shorter steps (AUTHOR TO CONFIRM).
Mathematics teachers, one-to-one (P1 → P2)	Non-negativity constraints not written explicitly in some worked models; concern that project planning would take up mathematics lesson time.	$x \geq 0$ and $y \geq 0$ added to every model; planning and scheduling tasks shortened (AUTHOR TO CONFIRM).
APHP teacher, one-to-one (P1 → P2)	Yeast quantity given in kilograms rather than grams; the oven constraint should follow the production unit's real capacity (two large trays per baking cycle).	Units corrected to grams; oven-capacity constraint rewritten to the real capacity of the production unit (AUTHOR TO CONFIRM).
Students, small group (P2 → P3)	Small answer boxes; typing errors; risk of losing entries offline.	Answer boxes enlarged; errors corrected; instructions for saving drafts added.

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Figure 4

Examples of e-module pages after formative revision



The revisions changed the character of the tasks as well as their appearance: closed commands such as "Determine the values of x and y!" were replaced by questions requiring justification, such as which product combination in the drawn feasible region gives the maximum profit and why. Each source of evidence, namely the moderate V

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values, the dissenting validator, and user comments, thus produced a traceable change before classroom use; for example, the APHP teacher's oven-capacity comment was treated as a threat to project authenticity, and the constraint was rewritten before the field trial.

3.4 Implementation Phase: Field Practicality and Statistical Testing

The final version (P3) was implemented with all 15 students in six 2 × 45-minute meetings (12 lesson hours). The class mathematics teacher facilitated group work while the first author observed. Students formed four heterogeneous groups of three or four students (AUTHOR TO CONFIRM); each chose a processed-food product, divided roles with the Gantt-chart template in Chapter IV, collected stock, recipe, and profit-margin data from the school's teaching-factory production unit, and produced a written optimisation report and presentation. The lesson plans allocated about 25 minutes to formulating constraints and the objective function (meeting III), 50 minutes to graphing and GeoGebra verification (meeting IV), and 25 minutes to corner-point computation (meeting V). Table 8 presents the implementation sequence.

Table 8

Implementation Sequence of the E-Module

Meeting	Date	Content and PjBL syntax	Main student activities
I	13 May 2026	Orientation; Syntax 1: essential question	Pretest and initial questionnaire; orientation to e-module features; observing an APHP optimisation problem.
II	14 May 2026	Modelling; Syntax 2: designing the project plan	Translating word problems into systems of inequalities and objective functions; forming groups; drafting project ideas.
III	20 May 2026	Feasible-region graphs; Syntax 3: scheduling	Agreeing schedules and roles; drawing inequalities by hand and checking feasible regions with GeoGebra.
IV	21 May 2026	Optimum value; Syntax 4: monitoring progress	Computing optima with the corner-point test; drafting reports; teacher monitoring and correcting substitution errors.
V	27 May 2026	Performance; Syntax 5: testing results	Presenting project reports; questions between groups; teacher confirmation of calculations.
VI	28 May 2026	Evaluation; Syntax 6: evaluating the experience	Joint reflection; posttest, final questionnaire, and practicality questionnaire.

In meeting V, every group presented its production context, model, feasible-region graph, and recommendation, and observation notes indicate that all six PjBL stages were enacted as scheduled. Usage logs were not available, so evidence of individual use of GeoGebra or quiz feedback is limited to observation notes and group products. All 15 students completed all outcome and practicality instruments, with no missing responses (attendance across the six meetings: AUTHOR TO INSERT from the attendance register). Table 9 reports field practicality.

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The worked "Roti Enak" case in Chapter III, on which the group projects were modelled, illustrates the complete chain. Sweet bread (x packs) and frozen bread (y packs) yield Rp3,000 and Rp4,000 profit per pack; each pack needs 0.5 kg of flour and 200 g or 300 g of sugar, respectively, with 100 kg of flour and 50 kg of sugar available. The constraints $x + y \leq 200$, $2x + 3y \leq 500$, $x \geq 0$, and $y \geq 0$, with the objective $Z = 3{,}000x + 4{,}000y$, give corner points O(0, 0), A(0, 166.67), B(100, 100), and C(200, 0), so the recommendation is 100 packs of each type (Rp700,000), using all the flour and sugar. Because packs are counted in whole numbers, a corner such as A could not be produced as such; the module did not systematically ask students to check integrality or the feasibility of rounded plans, and this check is added in the next revision cycle (DP5).

Table 9

Practicality of the E-Module in the Field Trial (n = 15)

Aspect	Items	Score	Max.	%	Category	Change from small group
Content	1–5	320	375	85.33	Very practical	+1.33
Appearance	6–10	302	375	80.53	Practical	+0.53
Language	11–15	307	375	81.87	Practical	+1.87
Use	16–20	323	375	86.13	Very practical	−1.07
Overall	1–20	1,252	1,500	83.47	Practical	+0.67

Note. Change is expressed in percentage points relative to Table 6 and is descriptive only, because the samples, product versions, and conditions differed.

Field practicality (83.47%) remained in the practical category; content and use reached the very practical band, and appearance remained the weakest aspect (80.53%), with the lowest items concerning contextual pictures (item 8, 73%), on-screen readability (item 11, 75%), and unambiguous instructions (item 15, 75%). Because the small-group and field samples, product versions, and conditions differed, the comparison in Table 9 cannot show that the revisions improved the product.

Table 10 presents descriptive statistics and normality tests for both outcomes.

Table 10

Descriptive Statistics and Shapiro–Wilk Normality Tests (n = 15)

Statistic	MU pretest	MU posttest	LI initial	LI final
Minimum	36	48	63	99
Maximum	69	80	121	150
Median	53	69	96	120
Mean	54.20	64.93	96.27	125.13
SD	10.94	10.57	17.95	15.88
Shapiro–Wilk W (p)	.926 (.240)	.911 (.142)	.949 (.509)	.945 (.446)
Difference scores: mean (SD)	10.73 (9.97)		28.87 (22.86)	
Difference scores: W (p)	.938 (.363)		.926 (.236)	
Cronbach's α	.35	.38	.92	.94

Note. MU = mathematical understanding (five items, maximum 100); LI = learning independence (32 items, maximum 160).

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Mathematical understanding rose from 54.20 to 64.93 and learning independence from 96.27 to 125.13, and the minimum scores rose markedly (from 36 to 48 and from 63 to 99). Shapiro–Wilk tests on the difference scores were non-significant (p = .363 and .236), the largest standardised differences were 2.13 (S1) and 2.54 (S3), and leave-one-out t values ranged from 3.79 to 4.58 for understanding and from 4.46 to 5.49 for learning independence, so no single student determined the result. Table 11 reports the inferential tests.

Table 11

Paired-Samples t-Tests and Wilcoxon Signed-Rank Tests

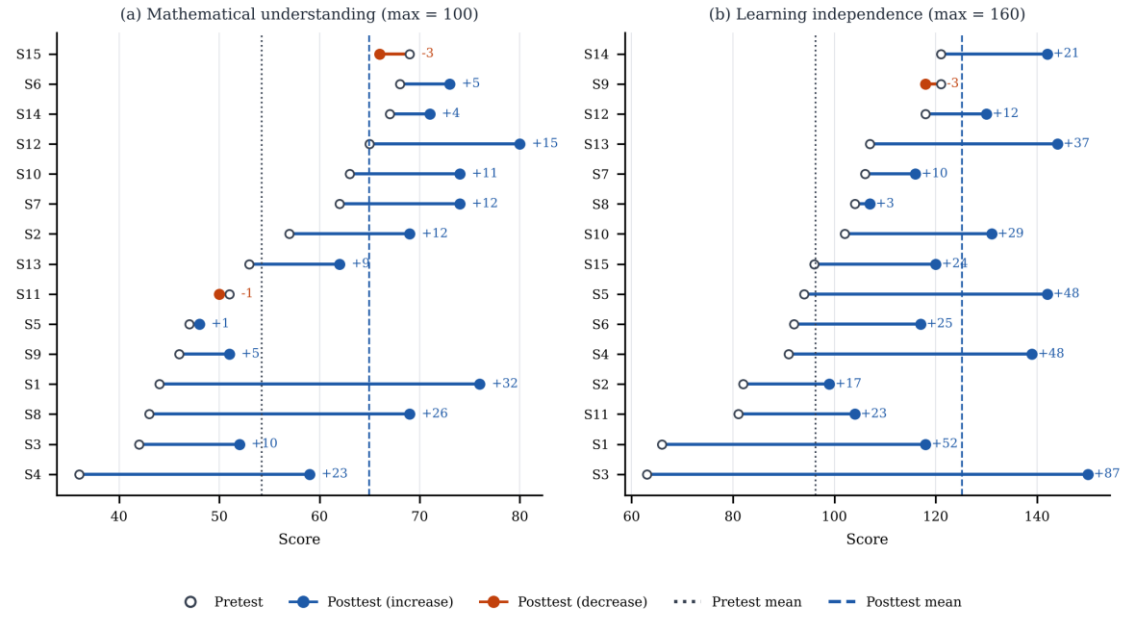
Var.	Mean diff. [95% CI]	t(14)	p	dz [95% CI] (Hedges' gz)	Wilcoxon Z	p	r	+/−/ties
MU	10.73 [5.21, 16.26]	4.17	< .001	1.08 [0.42, 1.71] (1.02)	−3.15	.002	.81	13/2/0
LI	28.87 [16.21, 41.52]	4.89	< .001	1.26 [0.56, 1.94] (1.19)	−3.32	< .001	.86	14/1/0

Note. Two-tailed tests. dz = mean difference / SD of differences, with a 95% CI from the noncentral t distribution; gz = dz × [1 − 3/(4(n − 1) − 1)]; Wilcoxon Z from the normal approximation with tie correction and no continuity correction (asymptotic p); r = |Z|/√N; +/−/ties = students with positive, negative, and zero differences.

Both null hypotheses were rejected: for mathematical understanding, t(14) = 4.17, p < .001, dz = 1.08, 95% CI [0.42, 1.71]; for learning independence, t(14) = 4.89, p < .001, dz = 1.26, 95% CI [0.56, 1.94]. The Wilcoxon tests agreed (r = .81 and .86), and excluding S3 and S12 did not change the conclusions (understanding: t(12) = 3.53, p = .004, dz = 0.98; learning independence: t(12) = 5.41, p < .001, dz = 1.50). Figure 5 shows the change for each student, and Appendix Table A4 lists the anonymised paired scores.

Figure 5

Individual pretest–posttest change in mathematical understanding and learning independence



Note. Students are ordered by initial score; values show the change in score points.

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Individual trajectories differed (Figure 5). In understanding, 13 students improved and two declined slightly (S11 by 1 point and S15 by 3 points), within the measurement error of the test. All three low-scoring students (S3, S4, and S8) improved by 10 to 26 points, but this pattern rests on three students, and the negative correlation between pretest score and gain ($r = -.49$, $p = .062$) is also expected from regression to the mean. In learning independence, 14 students improved and one (S9) declined by 3 points. Initial and final scores correlated moderately for understanding ($r = .57$, $p = .026$) but not for learning independence ($r = .09$, $p = .747$), which may reflect measurement error, genuine changes in rank order, or a response shift (Howard, 1980).

3.5 Evaluation Phase: Gains by Indicator, Improvement Decision, and Final Product

Table 12 reports change by indicator and the distribution of individual gains.

Table 12

Change by Indicator and Distribution of Individual Normalised Gains

Indicator	Max.	Pre (%)	Post (%)	<g>	t(14)	p (Holm)
MU1 Identifying model elements and formulating the model (items 1 and 3)	40	25.60 (64.0)	28.53 (71.3)	0.20	1.33	.206 (.206)
MU2 Representing systems and contextual problems as feasible-region graphs (items 2 and 4)	40	20.27 (50.7)	25.67 (64.2)	0.27	4.25	< .001 (.002)
MU3 Applying the corner-point algorithm to the optimum (item 5)	20	8.33 (41.7)	10.73 (53.7)	0.21	1.79	.095 (.190)
Mathematical understanding (overall)	100	54.20 (54.2)	64.93 (64.9)	0.23	4.17	< .001
LI1 Confidence and initiative	40	24.33 (60.8)	29.93 (74.8)	0.36	3.42	.004 (.004)
LI2 Enthusiasm and active engagement	40	23.60 (59.0)	31.20 (78.0)	0.46	4.11	.001 (.002)
LI3 Persistence and resilience	40	23.80 (59.5)	31.40 (78.5)	0.47	5.12	< .001 (< .001)
LI4 Awareness of the value of mathematics	40	24.53 (61.3)	32.60 (81.5)	0.52	4.62	< .001 (.001)
Learning independence (overall)	160	96.27 (60.2)	125.13 (78.2)	0.45	4.89	< .001
Individual g, MU (mean 0.22)	High 0; moderate 5; low 8; no change 0; decrease 2					
Individual g, LI (mean 0.42)	High 2; moderate 7; low 5; no change 0; decrease 1					

Note. <g> = class-average normalised gain, (post mean − pre mean)/(max − pre mean). Indicator tests are exploratory; Holm-adjusted p values within each outcome are given in parentheses, and the overall rows are the primary analyses. Mean differences [95% CI]: MU1 2.93 [−1.81, 7.68]; MU2 5.40 [2.67, 8.13]; MU3 2.40 [−0.48, 5.28]; LI1 5.60 [2.09, 9.11]; LI2 7.60 [3.64, 11.56]; LI3 7.60 [4.41, 10.79]; LI4 8.07 [4.33, 11.81]. Because the LI minimum is 32, the POMP values for the total LI scale, (score − 32)/128, were 50.2% initially and 72.8% finally. Individual g categories: high ≥ 0.70; moderate 0.30–0.69; low 0.01–0.29.

The exploratory indicator analysis qualifies the overall result. The clearest change in understanding was in representing systems and contextual problems as feasible-region graphs, from 50.7% to 64.2% of the maximum (mean difference 5.40, 95% CI [2.67, 8.13], <g> = 0.27, Holm-adjusted $p = .002$), almost entirely through item 4, which required

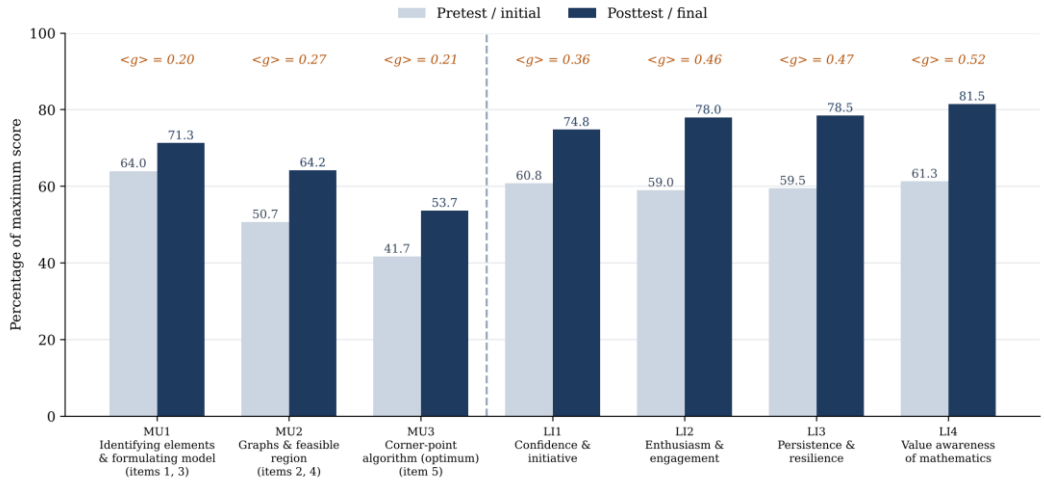
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moving from a production context to a model and its graph (8.27 to 13.47 points), whereas item 2, which supplied the system, hardly changed (12.00 to 12.20). Identifying model elements and formulating the model started highest and rose from 64.0% to 71.3% (<g> = 0.20), and determining the optimum value remained the weakest competency (53.7%; <g> = 0.21; Figure 6); the confidence intervals for both changes included zero. Because these indicators rest on one or two items of low reliability, the contrasts are tentative. All four learning independence indicators improved after Holm adjustment, most in awareness of the value of mathematics (0.52) and persistence (0.47), and least in confidence and initiative (0.36).

An anonymised before-and-after excerpt of one student's answer to item 3 or item 4 (for example, S4, whose item 3 score rose from 6 to 16, or S8, from 10 to 18), with a short commentary on changes in variable definition, constraint formulation, graph interpretation, or justification.

Figure 6

Attainment of each indicator before and after implementation (percentage of the indicator maximum)



Note. MU = mathematical understanding; LI = learning independence; g = class-average normalised gain.

Table 13 applies the predefined improvement criteria defined in Section 2.4.

Table 13

Decision Based on the Predefined Improvement Criteria

Criterion	Mathematical understanding	Learning independence
(a) Significant difference, $p < .05$	$p < .001$ — met	$p < .001$ — met
(b) Effect size $dz \geq 0.50$	$dz = 1.08$ — met	$dz = 1.26$ — met
(c) Mean normalised gain $g \geq 0.30$	$g = 0.22$ — not met	$g = 0.42$ — met
Decision	Criteria partly met (low gain)	Criteria met (moderate gain)

The predefined criteria were met for learning independence and partly met for mathematical understanding: the improvement in understanding was reliable and large relative to its variability but closed only about one-fifth of the distance to the maximum

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and appeared mainly in the representational indicator. In a one-group design, these results describe pre–post change and do not establish that the e-module caused it. The next revision cycle should therefore prioritise the optimum-value stage and the link between model elements and their meaning in the production context.

Final product. Table 14 specifies the final e-module, and Figure 7 shows its principal pages.

Table 14

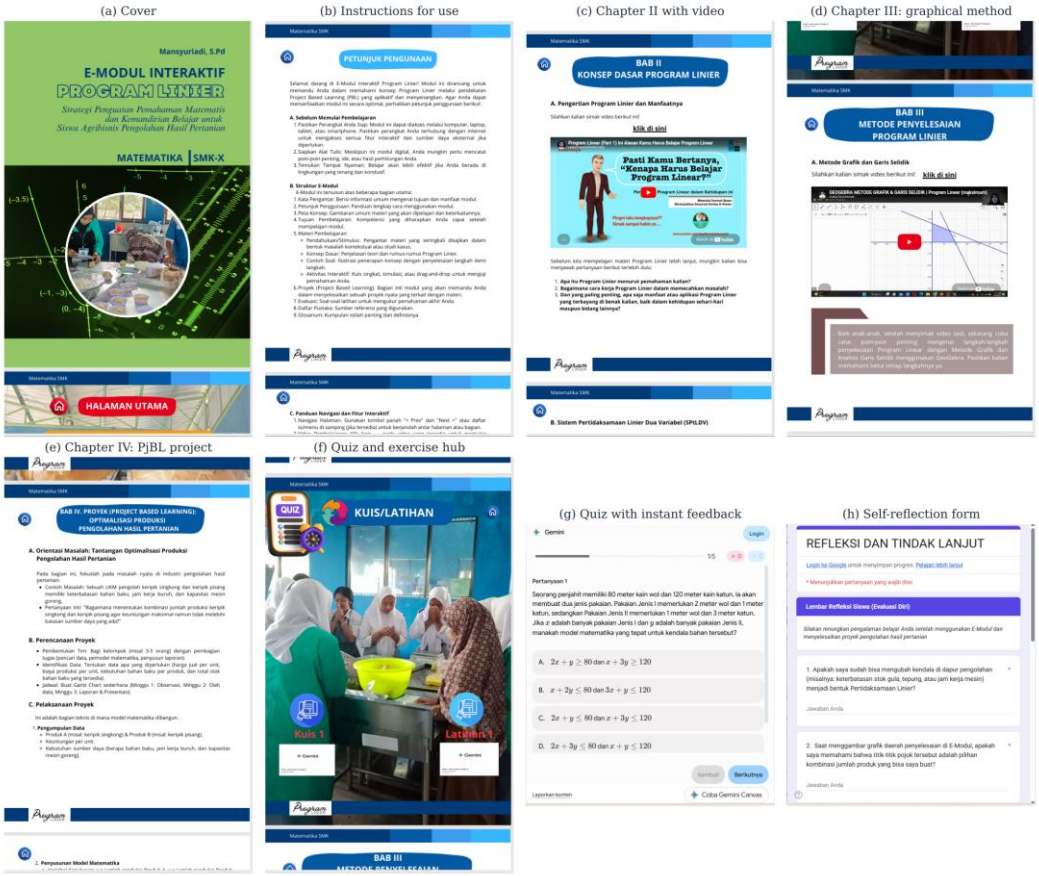
Specification of the Final Interactive PjBL E-Module

Part	Component	Content and interactive features
Opening	Cover; front matter	Title, author, APHP illustration, home button; foreword, instructions for use, PjBL flow, contents, concept map, learning outcomes and objectives.
Core	Chapter I Introduction	Description of the module and the relevance of optimisation to APHP production.
	Chapter II Basic concepts	Linear inequalities and systems; apperception video; GeoGebra guide for feasible regions; objective function; modelling case; Quiz 1.
	Chapter III Solution methods	Graphical and iso-profit-line methods; corner-point test; "Roti Enak" case on flour and sugar; Quiz 2.
	Chapter IV PjBL project	Six-syntax project guide: essential question, roles and Gantt-chart schedule, data collection, formulation of the system, feasible-region analysis, report framework.
Closing	Chapter V Evaluation; end matter	Contextual problem-solving tasks, report upload (Google Forms), self-reflection sheet, summary, glossary, references, author profile.
Access	Format and distribution	Interactive PDF hub produced in Canva; distributed through a Google Drive link and QR code; GeoGebra Web, YouTube, and Google Forms (quizzes, reflection, report upload) require internet access; text, examples, and project guide readable offline after download; field-trial version P3 (May 2026).

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Figure 7

Final product: principal pages of the interactive PjBL e-module on linear programming



4. Discussion

This study designed an interactive PjBL e-module to help vocational agribusiness students model and solve linear programming problems and work more independently. The findings are interpreted below and condensed into design principles.

Grounding the design in vocational production problems. Students' main difficulty was mathematisation rather than computation, in line with Indonesian studies of linear programming (Sugiarto et al., 2021; Rahman et al., 2021; Sari & Afriansyah, 2022) and with modelling research (Cevikbas et al., 2022; Schukajlow et al., 2023). The design response, making the APHP production room the source of every problem and placing the PjBL syntaxes at the structural centre of the module, follows the characterisation of PjBL around a driving question and a public product (Markula & Aksela, 2022) and addresses teachers' difficulty in finding mathematics projects that are authentic yet curriculum-aligned (Viro et al., 2020; Kohen & Orenstein, 2021). It extends PjBL modules for vocational schools (Baidowi et al., 2023) and PjBL e-modules for general mathematics (Mustika, 2022) to a topic and occupational field that have received little attention.

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Validation as a source of design information rather than a gate. Reporting validator-level scores, a pooled percentage, and Aiken's V led to a more cautious and more useful conclusion than an aggregate figure would have: P0 was valid rather than very valid, one content validator dissented about conceptual depth and support for PjBL, and component-level V, though imprecise with three raters, pinpointed usability and interactivity as revision targets. This reflects formative evaluation within ADDIE, in which each round of evaluation informs the next design decision (Spatioti et al., 2022; Tinoca et al., 2022). Validators and users also detected different problems: the language expert judged the language valid, yet students rated it among the weakest aspects, and only users revealed the broken GeoGebra link, small answer boxes, lost entries, and unrealistic recipe units. Because only one content validator re-rated P1, the validity of the final version rests on that re-rating and on the traceability of the revisions.

Practicality and the conditions of independent digital work. The e-module was rated practical in both trials, although ratings of a resource introduced by students' own teachers may be inflated by acquiescence. Access, however, is not readiness: initially only 60% of students preferred phone learning to paper, and all wanted guidance. Insufficient self-regulation and technical confidence are the main reasons why online components fail (Rasheed et al., 2020), and the teacher's way of embedding a tool decides whether it supports engagement (Attard & Holmes, 2020; Viberg et al., 2023). The orientation session, explicit instructions, standardised navigation, and draft-saving guidance were therefore conditions for independent work rather than cosmetic features, consistent with reducing extraneous cognitive load in instructional materials (Castro-Alonso et al., 2021); the remaining weaknesses in picture quality and readability show that this work is unfinished.

Where understanding grew, and why. The clearest change, moving from a production context to a model and its feasible-region graph, occurred in the step the design targeted most directly: students drew feasible regions by hand, checked them with GeoGebra, and used them in their projects in meetings II to IV. This is consistent with evidence that dynamic mathematics software improves understanding most when used for repeated exploration and verification (Tamur et al., 2020; Juandi et al., 2021; Zulnaidi et al., 2020; Birgin & Uzun Yazıcı, 2021), but with low-reliability indicators and no comparison group, the contribution of visualisation, verification, or project use cannot be isolated.

The other two indicators show the limits of the current version. Formulating the model started highest and changed modestly, suggesting that the module rehearsed partly known definitions without pushing students to explain what a constraint or an objective function means in a production decision. Determining the optimum, which chains solving for intersection points, substituting corner points, and interpreting the result, remained the weakest competency. One hypothesis, untested because time on task was not logged, is insufficient feedback-rich practice: only about 25 minutes were planned for corner-point computation. Immediate, task-level feedback is a strong lever for such procedural

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consolidation (Wisniewski et al., 2020), and adaptive support is increasingly used for it in mathematics (Hwang & Tu, 2021; Hidayat et al., 2022).

Why learning independence gained more than understanding. Learning independence improved with a moderate gain and a large effect, most in awareness of the value of mathematics and in persistence. Both are plausible, though untested, consequences of the design: the production context made the usefulness of linear programming visible, and the schedule, role division, and public presentation required sustained work. This agrees with evidence that PjBL affects affective and self-regulatory outcomes at least as strongly as achievement (Guo et al., 2020; Zhang & Ma, 2023), that projects increase engagement (Almulla, 2020; Krajcik et al., 2023; Rehman et al., 2023), and that structured support for planning and monitoring strengthens self-regulation (Anthonysamy et al., 2020; Hwang et al., 2021; Xu et al., 2023). The smallest gain, in confidence and initiative, suggests that the gradual release of control needed for self-regulation to transfer requires a longer period (Theobald, 2021). Being self-reported, this outcome needs behavioural confirmation.

Who benefited from the e-module. The improvement of all three low-scoring students resembles reports that technology-supported instruction benefits low- and high-achieving students in different ways (Reinhold et al., 2020) and that the effects of digital and blended designs are heterogeneous (Hillmayr et al., 2020; Cao, 2023; Putri et al., 2025). Here, however, the pattern rests on three students and is also expected from regression to the mean, so it cannot be attributed to the scaffolding. It nevertheless suggests differentiating tasks, for example with extensions involving multiple optimal solutions or changing resource limits for students who complete the core tasks.

Interpreting significance, effect size, and gain together. The effect sizes (d_z = 1.08 and 1.26) are large by convention but are within-group changes from one class that also include maturation, testing, and ordinary instruction, so they are not comparable to between-group effects from controlled interventions (Kraft, 2020), and their intervals are wide. The normalised gain counterbalances them by relating improvement to the room for improvement, although its value depends on how it is averaged (Burkholder et al., 2020); applying several predefined criteria therefore gave a more defensible conclusion. Measurement adds further caution: the low internal consistency of the understanding test (α = .35–.38) makes its total a coarse summary of three competencies, and the negligible initial–final correlation for learning independence (r = .09) admits several explanations, including a response shift (Howard, 1980).

Design principles. Table 15 condenses the evidence into five provisional design principles for PjBL e-modules in vocational mathematics, each stating what the design should do, the consistent evidence from this study, and what would be needed to test it. Because the evidence supports feasibility without isolating the contribution of any single feature, none of the principles is regarded as established.

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Table 15

Provisional Design Principles for Project-Based Interactive E-Modules in Vocational Mathematics

Design principle	Supporting evidence in this study	Status and test needed
DP1 Draw every problem from the students' own production setting and let the project question drive the content sequence.	100% interest in APHP projects; largest independence gain in value awareness (<g> = 0.52).	Hypothesis; compare APHP-context and generic-context versions of the same tasks.
DP2 Assign each interactive feature to a specific PjBL stage rather than adding features generically.	Feature-to-stage blueprint (Table 3); practicality in the practical to very practical range in both trials.	Hypothesis; compare stage-assigned features with the same features offered without stage assignment, using usage logs.
DP3 Pair hand-drawn feasible regions with immediate dynamic verification.	Clearest exploratory change: graphs and feasible regions (<g> = 0.27, Holm p = .002), mainly item 4.	Hypothesis; compare hand-drawing plus GeoGebra verification with either alone on a more reliable representation measure.
DP4 Treat rater disagreement and user complaints as revision triggers, not as noise.	Moderate Aiken's V for usability and interactivity and teacher and student comments produced traceable revisions across P0–P3.	Supported as a process; test whether such triggers improve re-ratings by the same panel.
DP5 Provide extended, feedback-rich practice and meaning-oriented prompts for the optimum and model-interpretation stages, including integrality and feasibility checks, with extension tasks for high achievers.	No reliable change in formulating models (Holm p = .206) or optimum value (Holm p = .190); integrality not treated; no delayed or transfer assessment.	Proposed for next cycle; test with delayed and transfer tasks.

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Contributions. Theoretically, the study illustrates how the PjBL syntax can serve as the organising structure of a digital module and proposes a mechanism for the pattern of outcomes: change was clearest where context, visualisation, and immediate verification converged, and weakest where the module relied on rehearsal or brief practice. Methodologically, it shows how validator-level scores, Aiken's V, indicator-level tests, and individual trajectories can turn each ADDIE phase into a source of design decisions. Practically, it offers vocational mathematics teachers an accessible production pipeline (Canva, interactive PDF, Google Drive) that can be adapted to other agribusiness topics.

Limitations. The field trial involved one class of 15 students in one school, and the one-group design cannot attribute improvements to the e-module; pretest experience, regular instruction, maturation, and teacher enthusiasm may also have contributed. The small-group trial mixed Grade XI students with two students who later joined the field trial. The understanding test had only five items and low internal consistency, its scoring was not blinded and relied on a single rater (AUTHOR TO CONFIRM), and indicator scores rest on one or two items. Without a delayed posttest or a transfer task in another occupational context, such as livestock feed mixing or cooperative logistics, retention and transfer remain unknown. Learning independence was measured only by self-report, usage logs were unavailable, the language and practitioner judgements came from single raters, the expert panels were small and did not re-rate the final version, and the module did not treat the integrality of production quantities systematically.

5. Conclusion

This study used the ADDIE model to develop an interactive e-module that embeds the six syntaxes of project-based learning in agribusiness food-processing optimisation problems for Grade X vocational students. Analysis identified the mathematisation of production problems as the main obstacle and showed interest in digital, contextual learning alongside a need for guidance. Development produced a prototype judged valid (pooled 82.80%; Aiken's V .77 and .78 for the three-member content and media panels) and was revised through four versions. In implementation, students rated the final version as practical (83.47%), and both outcomes increased significantly with large within-group effects; the predefined criteria were met for learning independence ($g = 0.42$) and partly met for mathematical understanding ($g = 0.22$), with change concentrated in representing contextual problems as feasible-region graphs. Given the low reliability of the test and the one-group design, these results indicate feasibility and pre–post improvement rather than causal effectiveness.

Teachers can use the e-module for linear programming in vocational classes if they add guided practice on the optimum-value stage, ask students to explain each model element in production terms, check whether optimal quantities are feasible as whole batches, and prepare enrichment tasks for higher-achieving students. The next development cycle should implement design principle DP5, use a longer understanding test scored by two raters blind to testing occasion, and be evaluated in quasi-experimental, multi-site studies with comparison classes, longer implementation, delayed

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and transfer assessments, usage logs, and behavioural measures of learning independence.

Statements and Declarations

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The study was conducted as part of the first author's master's thesis research.

Competing Interests:
The authors declare that they have no competing interests.

Ethics Approval:
This study was conducted in accordance with generally accepted ethical principles for educational research. It took place within regular, curriculum-aligned classroom activities, involved minimal risk to participants, and collected no personally identifiable information beyond anonymised codes. Written permission to conduct the study was obtained from the principal of SMK Negeri 1 Labangka, Sumbawa, Indonesia, and all activities were coordinated with the class mathematics teacher.

Informed Consent:
Parental or guardian written permission and student assent, as actually obtained. Students were informed about the purpose of the activities; individual responses were anonymised with codes and reported in aggregate form.

Data Availability:
The anonymised paired scores are reported in Appendix Table A4. The anonymised item-level dataset, the instruments and scoring rubric, and a stable copy of the final e-module version used in the field trial (P3, May 2026), with an inventory of its external resources, will be deposited in repository and DOI: AUTHOR TO INSERT on acceptance, subject to participant confidentiality and the permissions of third-party resources.

Author Contributions: All authors, including the second author (Endang Wahyuningrum) and the third author (Sudirman Sudirman), have read and approved the final version of the manuscript and agreed to its submission. Detailed contributions are provided on the separate title page.

Declaration of Generative AI Use:
During manuscript preparation, a generative AI tool was used to assist with language editing, text organisation, figure preparation, and reference formatting. The authors reviewed and verified all AI-assisted content and take full responsibility for the final publication.

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Appendix A. Supplementary Tables

Table A1

Alignment of Mathematical Understanding Indicators, Modelling Stages, Test Items, and Scoring Criteria

Indicator	Modelling-cycle stage	Items (pretest / posttest context)	Analytic scoring criteria (0–20 per item)
MU1 Identifying model elements and formulating the model	Understanding and simplifying the situation; mathematising	Item 1: identify decision variables, objective, and constraints (pineapple dodol and jam / corn crisps and corn syrup). Item 3: formulate the constraints and objective function under capital and storage limits (jackfruit and salak chips / beef and chicken floss).	Variables defined with units; each constraint formed with the correct inequality sign; non-negativity stated; objective function correct. AUTHOR: insert the point allocation of the scoring guide.
MU2 Representing systems and contextual problems as feasible-region graphs	Working mathematically with representations	Item 2: graph a given system and shade its feasible region. Item 4: model a raw-material problem and represent it as a feasible-region graph (peanut snacks / dragon-fruit and mango juice).	Intercepts correct; boundary lines drawn; test point used; feasible region shaded; corner points identified. AUTHOR: insert point allocation.
MU3 Applying the corner-point algorithm to determine and interpret the optimum	Working mathematically; interpreting and validating	Item 5: determine production quantities and maximum profit by the corner-point method (pineapple and strawberry jam / mango and kedondong preserves).	Corner points computed; objective evaluated at each; optimum selected; result interpreted as a production recommendation. AUTHOR: insert point allocation.

Note. Each item is scored 0–20 (maximum 100). The parallel forms share the blueprint and differ only in products and coefficients. AUTHOR TO ADD an example of a scored student response.

Table A2

Summary of Instruments

Instrument	Items and response format	Source or development	Validity and reliability evidence
Needs questionnaire	11 dichotomous (yes/no) items	Developed from a blueprint covering existing materials, project interest, digital experience, and needed features	Blueprint review; descriptive use only

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Instrument	Items and response format	Source or development	Validity and reliability evidence
Interview guides and observation notes	Structured guides for the teacher and students; observation checklist	Developed for the needs analysis	Triangulated with the questionnaire
Validation sheets	Content 15, media 15, language 9, practitioner 8 items; 1–5 agreement scale; comment space	Developed from a blueprint for each aspect	Used to evaluate the e-module, not as outcome measures
Practicality questionnaire	20 positively worded items; 1–5 agreement scale; four aspects of five items	Developed from a blueprint	α = .89 (small group), .86 (field)
Mathematical understanding test	5 essay items scored 0–20; parallel pretest and posttest forms	Blueprint aligned with Table A1	Content review of blueprint; try-out (n = 10): item–total r = .50–.83, α = .73, |ΔP| ≤ .03 between forms; field α = .35 and .38
Learning independence questionnaire	32 positively worded items; 1–5 agreement scale; four indicators of eight items; range 32–160	Adapted from MSLQ motivation and resource-management scales and Indonesian indicators of learning independence	Try-out (n = 10): α = .94, items 14–15 reworded; field α = .92 and .94

Table A3

Interactive Functions, Responsible Tools, and Connectivity Requirements

Function	Tool	Internet needed	Usable offline after download
Reading content, worked examples, and project guide	PDF exported from Canva	Only to download	Yes
Navigation (home, next, previous, page markers)	Internal PDF links	No	Yes
Answer boxes for models and plans	PDF form fields	No	Yes in a PDF viewer that saves form data; not saved in the Google Drive preview
Contextual videos	YouTube	Yes	No
Dynamic graphs, feasible regions, iso-profit line	GeoGebra Web applets	Yes	No
Quizzes with automatic scoring and feedback; reflection; report upload	Google Forms	Yes	No
Distribution	Google Drive link, QR code, class messaging group	Yes	Not applicable

Note. Device requirement: a smartphone or computer with a web browser.

Table A4

Anonymised Paired Scores and Individual Normalised Gains (n = 15)

Code	MU pre	MU post	Change	g	LI pre	LI post	Change	g
S1	44	76	+32	0.57	66	118	+52	0.55
S2	57	69	+12	0.28	82	99	+17	0.22

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Code	MU pre	MU post	Change	g	LI pre	LI post	Change	g
S3	42	52	+10	0.17	63	150	+87	0.90
S4	36	59	+23	0.36	91	139	+48	0.70
S5	47	48	+1	0.02	94	142	+48	0.73
S6	68	73	+5	0.16	92	117	+25	0.37
S7	62	74	+12	0.32	106	116	+10	0.19
S8	43	69	+26	0.46	104	107	+3	0.05
S9	46	51	+5	0.09	121	118	−3	−0.08
S10	63	74	+11	0.30	102	131	+29	0.50
S11	51	50	−1	−0.02	81	104	+23	0.29
S12	65	80	+15	0.43	118	130	+12	0.29
S13	53	62	+9	0.19	107	144	+37	0.70
S14	67	71	+4	0.12	121	142	+21	0.54
S15	69	66	−3	−0.10	96	120	+24	0.38
Mean	54.20	64.93	+10.73	0.22	96.27	125.13	+28.87	0.42

Note. MU maximum 100; LI range 32–160. g = (post − pre)/(max − pre).

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