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Development of a Deep Learning Based Mathematics Module for Statistics Learning to Enhance Conceptual Understanding and Support SDG 4: Quality Education for Grade 10 Students

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Abstract: Improving students' conceptual understanding of mathematics remains a challenge in Indonesian secondary education, particularly in statistics. This study aimed to develop and evaluate a printed mathematics module that applies Indonesia's pedagogical Deep Learning approach—mindful, meaningful, and joyful learning—to statistics for Grade 10 students. The study used Research and Development with the Four-D model: Define, Design, Develop, and Disseminate. The module was reviewed by material, media, and language experts and then tried out with six students and implemented with one mathematics teacher and 30 Grade 10 students at SMAN 2 Koto Baru. Data were collected using validation and practicality questionnaires, observations, interviews, and pretest–posttest tests. Expert assessment used a five-point scale and produced mean scores of 4.50 for content, 4.60 for media, and 4.25 for language, all categorized as very valid. Teacher and student practicality means were 4.76 and 4.71, respectively, both categorized as very practical. The mean pretest and posttest scores were 56.40 and 82.75, producing an N-Gain of 0.61 (moderate). The module therefore demonstrated high content and media validity, high practicality, and moderate learning improvement. Its contribution lies in embedding the three Deep Learning principles across explanation, contextual activities, reflection, practice, and assessment.

Keywords: Conceptual understanding; Deep learning; Mathematics module; SDG 4; Statistics learning

Introduction

Mathematics learning is expected to develop not only procedural fluency but also conceptual understanding, reasoning, problem solving, and the ability to connect mathematical ideas with situations outside the classroom. Evidence from mathematics education research indicates that meaningful and contextual learning can strengthen students' understanding because learners are encouraged to connect new ideas with prior knowledge and real situations (Hidayat & Iksan, 2015; Koskinen & Pitkäniemi, 2022; Polman et al., 2021). In Indonesia, these needs are particularly important because mathematics achievement and numeracy remain areas of concern, while classroom practice can still emphasize procedures and final answers rather than explanation, interpretation, and transfer (Noor & Abadi, 2022; Siahaan et al., 2022).

The need is also relevant to statistics learning. Statistical competence requires students to interpret tables and graphs, reason from data, communicate conclusions, and apply quantitative information to contextual problems. These competencies are closely related to conceptual understanding and mathematical literacy rather than calculation alone. Previous

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Indonesian studies have shown that contextual and realistic approaches can improve mathematical conceptual understanding, while systematic learning materials can support more structured learning experiences (Anggraeni et al., 2021; Delina et al., 2018; Septiana et al., 2022). International research similarly emphasizes that active learning, meaningful contexts, guided activities, and feedback can improve learning outcomes and conceptual performance (Freeman et al., 2014; Hattie & Timperley, 2007; Mayer, 2004).

The problem was identified at SMAN 2 Koto Baru. Based on the 2025 Education Report Card, school numeracy achievement was in the medium category. Daily assessment data for statistics indicated that 72% of students were in the sufficient-to-very-poor categories. The initial questionnaire showed that 86% of students had difficulty explaining problem-solving steps, 76% reported that learned material was easily forgotten, 71% rarely studied independently, and 67% reported that mathematics learning was rarely connected with daily life. At the same time, 100% of students expressed interest in attractive learning modules and 90% preferred printed modules. These findings indicate a need for teaching materials that provide clearer conceptual scaffolding, contextual applications, reflection, and opportunities for independent learning.

Teaching materials are therefore an important part of the instructional solution. Research on modules and e-modules has reported positive effects on learning outcomes, motivation, conceptual understanding, and learning independence when materials are systematically organized and aligned with learner needs (Fiteriani et al., 2019; Mubarok & Sudibjo, 2022; Priyatno, 2024). Recent JPPIPA studies likewise demonstrate that systematically developed modules and electronic learning materials can achieve strong validity and practicality and can support active learning, conceptual mastery, and learning outcomes (Aldilla & Usmeldi., 2024; Dibyantini et al., 2023; Yantoro et al., 2024).

A further consideration is the meaning of the term Deep Learning in this manuscript. In international literature, deep learning commonly refers to artificial intelligence and machine learning. In this study, however, Deep Learning refers specifically to Indonesia's pedagogical Pembelajaran Mendalam policy, which emphasizes mindful, meaningful, and joyful learning. The Ministry of Primary and Secondary Education defines this approach as learning that develops students through conscious, meaningful, and joyful experiences, including understanding, application, and reflection. The policy is therefore pedagogical rather than computational and should not be interpreted as an AI-based learning algorithm (Kementerian Pendidikan Dasar dan Menengah, 2025). This clarification is essential for an international readership.

Previous studies have developed mathematics modules using approaches such as Problem-Based Learning, Project-Based Learning, STEM, STEAM, Realistic Mathematics Education, and reflective learning (Effendi & Yoto, 2024; Mardhiyatirrahmah et al., 2020; Oktafianto, 2024; Priyatno, 2024). These studies provide evidence that structured instructional materials can improve learning; however, they do not directly address the integration of Indonesia's three Deep Learning principles across the complete instructional sequence of a printed statistics module. Recent scholarship on Deep Learning in education suggests that the three principles should be integrated rather than treated as isolated activities, while mindful learning should include reflection and self-regulation, meaningful learning should connect concepts to authentic contexts, and joyful learning should support active and emotionally positive engagement (Andayanie et al., 2025).

The novelty of this study is therefore twofold. First, it develops a printed Grade 10 statistics module that explicitly operationalizes mindful, meaningful, and joyful learning across explanation, contextual problems, guided practice, reflection, and assessment. Second, it evaluates the resulting product through the three development-quality dimensions of validity, practicality, and learning improvement. This is important because a pedagogical Deep Learning approach cannot be demonstrated merely by naming the three principles; the principles need to be visible in the design of learning materials and evaluated through systematic development procedures. The study consequently addresses a practical gap between the national policy framework and concrete mathematics teaching materials for secondary-school statistics.

Method

This study employed Research and Development (R&D) using the Four-D model proposed by Thiagarajan, Semmel, and Semmel (1974) (Indaryanti et al., 2025; Syam & Furwana, 2022). The model consists of Define, Design, Develop, and Disseminate stages. The product was a printed mathematics module for Grade 10 statistics. The Four-D model was selected because its sequence provides a clear route from needs analysis to prototype design, expert appraisal, developmental testing, and dissemination.

Development Procedure

Table 1. Four-D development flows used in the study

Define	Design	Develop	Disseminate
Needs, learner, curriculum, and content analysis	Prototype, activities, assessment, and instruments	Expert validation, revision, limited trial, and field trial	Implementation and scientific dissemination

At the Define stage, the researchers analyzed student needs, student characteristics, curriculum documents, statistics content, classroom conditions, and the availability of existing teaching materials. Data were obtained from classroom observation, teacher interviews, student questionnaires, and curriculum documents. At the Design stage, the module structure, content sequence, learning activities, contextual problems, reflection activities, exercises, formative assessments, and final evaluation were prepared. The three Deep Learning principles were mapped onto each component.

At the Develop stage, the prototype was reviewed by material, media, and language experts. The revised module was then tested with six students in a limited trial and implemented with one mathematics teacher and 30 Grade 10 students in class XE5 at SMAN 2 Koto Baru. At the Disseminate stage, the product was implemented in the target classroom and the research findings were prepared for scientific dissemination. The dissemination reported in this study was limited; therefore, the module should not yet be interpreted as broadly generalized across schools.

Participants and Instruments

The validators consisted of experts in mathematics content, educational media, and language. One mathematics teacher participated in the practicality assessment, while six students participated in the limited trial and 30 students participated in the field implementation. Instruments included a needs-analysis questionnaire, expert validation sheets, teacher and student practicality questionnaires, observation sheets, interview guidelines, and pretest–posttest instruments.

Data Analysis

Validation and practicality used a five-point Likert scale. Mean scores were calculated as the sum of item scores divided by the number of items. The reported product was categorized as very valid or very practical when the mean score fell within the highest category of the five-point scale. To improve transparency, the scale used for expert and practicality assessment is explicitly reported as 1–5.

Effectiveness was examined using normalized gain (N-Gain), calculated as $g = (S_{post} - S_{pre}) / (S_{max} - S_{pre})$, where S_{pre} is the pretest mean, S_{post} is the posttest mean, and S_{max} is the maximum possible score. An N-Gain of 0.70 or higher was interpreted as high, 0.30–0.69 as moderate, and below 0.30 as low. Because the study did not report an inferential statistical test, claims are limited to observed learning improvement and are not described as statistically significant.

Result and Discussion

Result

Define Stage

Need Analysis

The needs analysis identified three central instructional problems: students' difficulty explaining statistical problem-solving steps, weak learning independence, and limited connection between mathematics and everyday contexts. Students also expressed a clear preference for attractive printed learning materials. The teacher interview indicated that available materials were general and did not sufficiently support independent, contextual, and reflective learning. These findings justified the development of a structured module rather than simply adding more exercises to existing materials.

Curriculum and Learner Analysis

The curriculum analysis showed that statistics learning requires students to interpret data, analyze information, and solve contextual problems, not merely perform calculations. Learner analysis indicated heterogeneous academic abilities and a preference for illustrations, contextual examples, gradual exercises, and opportunities for independent study. The design therefore emphasized scaffolding, multiple representations, contextual tasks, and reflection. Such guidance is consistent with evidence that learners benefit from structured instructional support, especially when they are still developing prior knowledge (Kirschner et al., 2006; Mayer, 2004).

Design Stage

Module Structure and Deep Learning Integration

The module contains module identity, learning outcomes, learning objectives, apperception, conceptual explanations, contextual activities, exercises, reflection, summaries, formative assessments, and final evaluation. The three Deep Learning principles were operationalized as follows: mindful learning through explicit learning goals, attention to prior knowledge, self-checks, and reflection; meaningful learning through authentic statistics contexts, interpretation of tables and graphs, and connections to students' daily

experiences; and joyful learning through attractive visual presentation, varied activities, gradual challenges, and opportunities for active participation. This operationalization follows the policy description of Pembelajaran Mendalam as mindful, meaningful, and joyful learning and is consistent with research emphasizing contextual meaning, active engagement, and self-regulation (Kementerian Pendidikan Dasar dan Menengah, 2025; Panadero, 2017; Polman et al., 2021).

Integration of Deep Learning Principles

Based on the results of the needs analysis, a preliminary design (prototype) of the mathematics learning module on statistics material was prepared. The module is designed to follow the structure of the learning module which consists of module identity, learning outcomes, learning objectives, perception, presentation of material, learning activities, exercises, reflections, summaries, formative assessments, and evaluations.



Figure 1. Module cover



Figure 2. Module contents

Development Stage

Expert Validation

The modules that have been developed are then validated by several experts consisting of material experts, media experts, and linguists. The validation results of each expert are presented separately in Table 2.

Table 2. Validation results by material experts

Assessment Aspects	Score	Category
Material suitability	4.50	Very valid
Depth of material	4.40	Very valid
Conceptual accuracy	4.60	Very valid
Relationship with CP	4.50	Very valid
Average	4.50	Very valid

The material expert assessment produced a mean score of 4.50, indicating very high content validity. The strongest aspect was conceptual accuracy (4.60), while material depth was 4.40. The results indicate that the

statistical content was judged appropriate, sufficiently deep, conceptually accurate, and aligned with the intended learning outcomes.

Table 3. Validation results by media experts

Assessment Aspects	Score	Category
Design display	4.60	Very valid
Readability	4.50	Very valid
Illustration suitability	4.70	Very valid
Visual appeal	4.60	Very valid
Average	4.60	Very valid

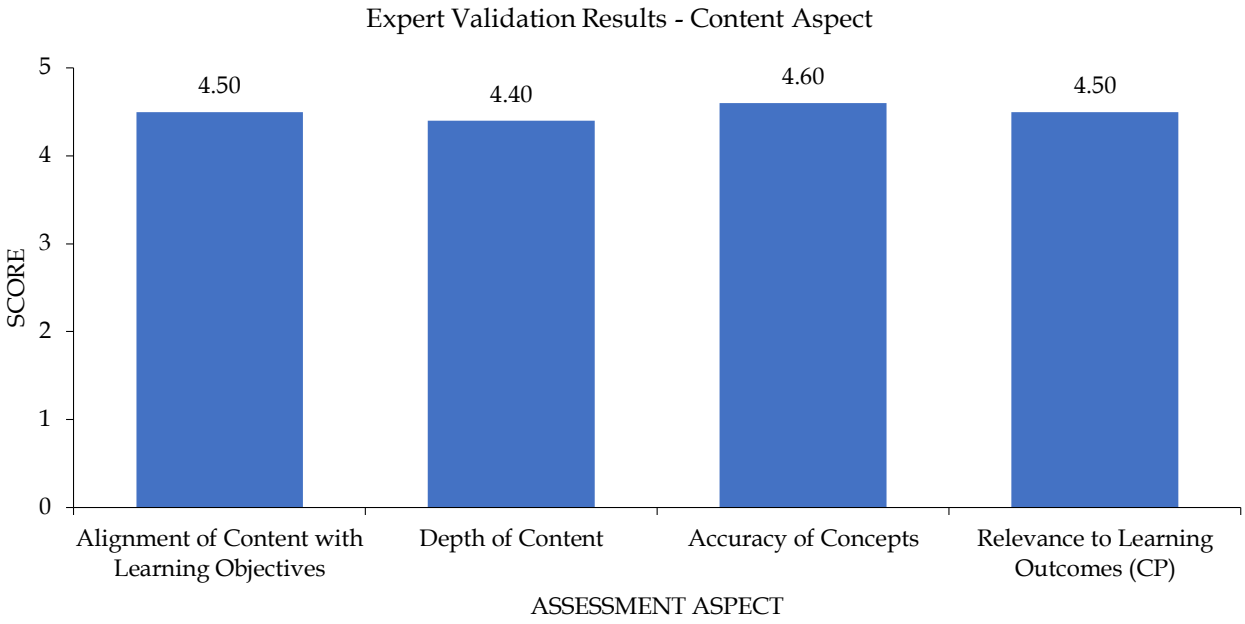


Figure 3. Material validation graph

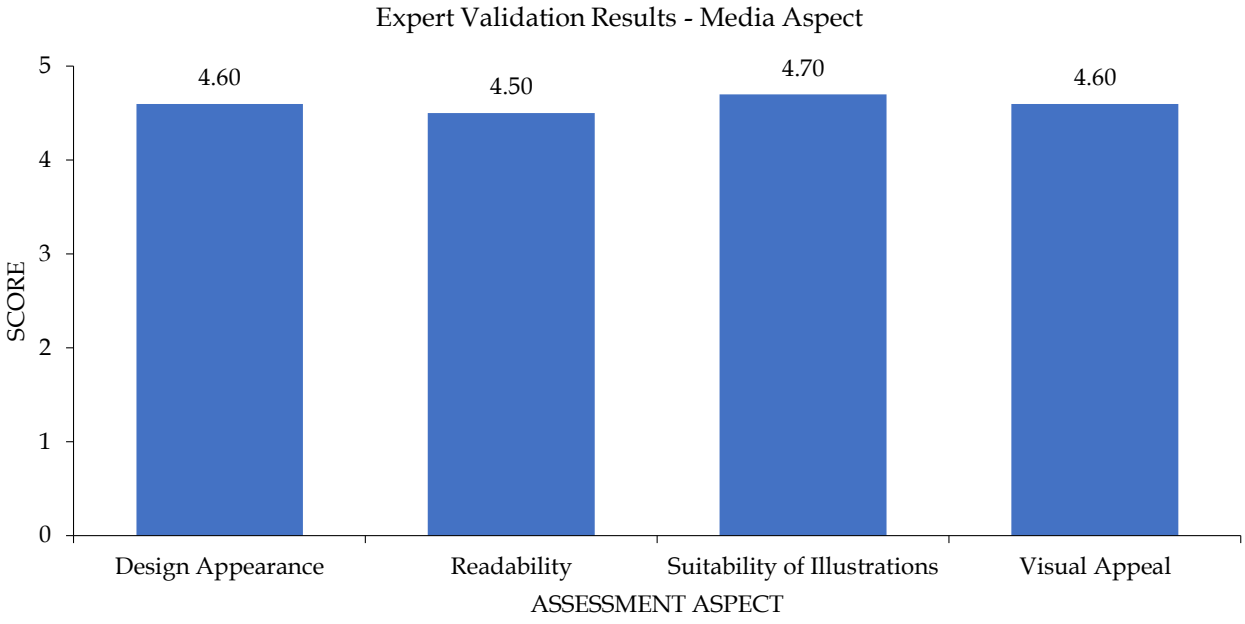


Figure 4. Media validation graph

The media expert mean score was 4.60. Illustration suitability received the highest score (4.70), suggesting that the visual elements were considered appropriate for supporting the content. The results are consistent with the role of well-designed instructional materials in reducing unnecessary cognitive load and supporting meaningful processing of verbal and visual information (Mayer & Moreno, 2003).

Language validation produced a mean score of 4.25. The validators nevertheless suggested improving terminology consistency and simplifying some sentences. These revisions were incorporated before the practicality test.

Table 4. Validation results by language

Assessment Aspects	Score	Category
Language Clarity	4.30	Very valid
Conformity of rules	4.20	Very valid
Comprehension of sentences	4.30	Very valid
Consistent terms	4.30	Very valid
Average	4.25	Very valid

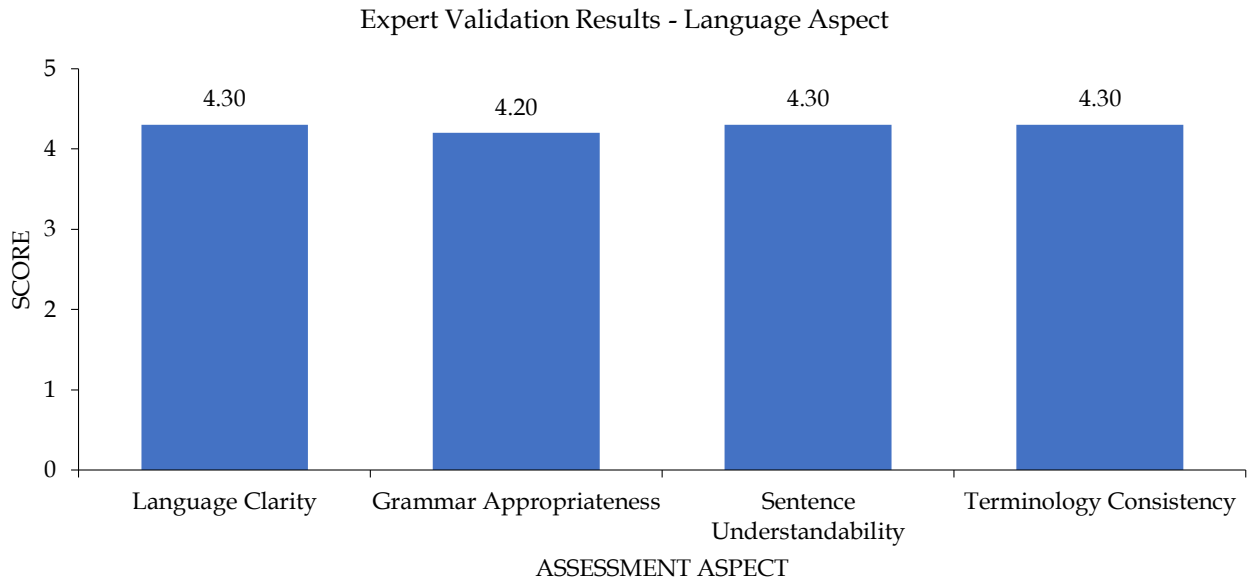


Figure 5. Language validation results graph

Practicality Test

After being revised, the modules are tested on teachers and students to determine the level of practicality.

Table 5. Results of the practicality of the module by the teacher

Assessment Aspects	Score	Category
Ease of use	4.76	Very practical
Material suitability	4.80	Very practical
Clarity of presentation	4.70	Very Practical
Learning implementation	4.78	Very Practical
Average	4.76	Very Practical

The teacher rated the module 4.76 on average, indicating very high practicality. Material suitability received the highest score (4.80). The teacher's response suggests that the module was sufficiently systematic for classroom use and that its presentation supported lesson implementation.

Table 6. Results of the practicality of the module by the students

Assessment Aspects	Score	Category
Ease of use	4.72	Very practical
Material suitability	4.68	Very practical
Clarity of presentation	4.75	Very practical
Learning implementation	4.70	Very practical
Average	4.71	Very practical

Students gave an average practicality score of 4.71. The highest score was for clarity of presentation (4.75), followed by ease of use (4.72). The findings indicate that the module was perceived as accessible and understandable by the target learners. This is important because teaching materials intended to support independent learning need clear structure, manageable tasks, and explicit opportunities for monitoring learning (Dunlosky et al., 2013; Panadero, 2017).

Effectiveness Test

The effectiveness of the module was analyzed using the results of the pretest and posttest.

Table 7. Result of pretest, posttest, N-Gain

Remarks	Average
Pretest	56.40
Posttest	82.75
N-Gain	0.61
Category	Medium

The mean posttest score increased by 26.35 points compared with the pretest. The N-Gain of 0.61 falls in the moderate category. This result indicates a meaningful improvement in student performance after the module was implemented, although the magnitude of improvement was not high. Because no inferential test was reported, the result should be interpreted as observed improvement rather than a statistically significant effect. The finding is nevertheless compatible with research showing that active, contextual, and guided learning can improve conceptual performance (Freeman et al., 2014; Koskinen & Pitkäniemi, 2022; Theobald et al., 2020).

Dissemination Stage

After being declared valid, practical, and effective, the module is implemented in mathematics learning class X of SMAN 2 Koto Baru. The product is then disseminated through scientific publications as a form of disseminating research results.

Discussion

The first major finding is that the module achieved very high validity across content, media, and language. The content mean of 4.50 indicates strong alignment between the statistics material and intended learning outcomes, while the media mean of 4.60 indicates that the visual and structural design was considered suitable. The language mean of 4.25 was the lowest of the three dimensions, but it remained in the very-valid category after revision. This pattern supports the view that development quality depends on the alignment of content, presentation, language, and learner characteristics rather than on content quality alone. Comparable JPPIPA studies have also reported that systematic development and expert appraisal can produce learning modules with strong validity and usability (Aldilla & Usmeldi., 2024; Nursafitri & Ansori, 2024; Yantoro et al., 2024).

The second finding concerns practicality. Both teacher (4.76) and student (4.71) assessments were very practical. The relatively high scores for material suitability, clarity, and ease of use suggest that the module's structured sequence reduced barriers to classroom implementation. This is important for independent learning because materials must provide sufficient guidance while still allowing students to work autonomously. The result is consistent with the literature on self-regulated learning, which emphasizes planning, monitoring, strategy use, and reflection (Panadero, 2017), and with research on effective learning techniques that highlights structured practice and retrieval rather than passive rereading alone (Dunlosky et al., 2013).

The third finding is the moderate learning improvement reflected in the N-Gain of 0.61. The improvement can be interpreted in relation to the module's instructional architecture. Mindful elements required students to attend to learning goals, prior knowledge, self-checks, and reflection; meaningful elements connected statistical concepts to contextual data and real-life interpretation; and joyful elements provided attractive presentation and varied learning activities. Meaningful learning in mathematics is strengthened when contexts, concrete representations, social interaction, and appropriate guidance help students see why mathematical ideas matter (Koskinen & Pitkäniemi, 2022; Polman et al., 2021). Active learning also tends to produce stronger performance than passive lecture-oriented instruction (Freeman et al., 2014).

The findings also support the policy relevance of the study. Indonesia's current Pembelajaran Mendalam framework defines learning through mindful, meaningful, and joyful experiences and emphasizes understanding, application, and reflection. The present module translates those policy principles into concrete printed learning activities for statistics. This is an important contribution because policy concepts become educationally useful only when they can be operationalized into materials, tasks, interactions, and assessments. Recent Indonesian scholarship similarly argues that Deep Learning should be implemented as an integrated pedagogical framework rather than as three disconnected classroom techniques (Andayanie et al., 2025; Kurnianingsih et al., 2026).

At the same time, the results should be interpreted cautiously. The field implementation involved one teacher and 30 students in one school, and the effectiveness analysis relied on a one-group pretest–posttest comparison summarized through N-Gain. Therefore, the study establishes product feasibility and observed improvement but does not provide strong causal evidence that the module alone produced the improvement. This limitation is important for interpreting the term 'effective' and for avoiding overgeneralization. Future experimental or quasi-experimental studies with control groups, larger samples, and delayed posttests are needed.

The study contributes to the existing literature by combining development research, a printed mathematics module, and the pedagogical Deep

Learning framework in a statistics context. Earlier work on mathematics modules has often centered on specific instructional models such as STEM, STEAM, PBL, PjBL, or RME (Effendi & Yoto, 2024; Mardhiyatirrahmah et al., 2020; Priyatno, 2024). The present design instead uses mindful, meaningful, and joyful learning as cross-cutting design principles. In this sense, the contribution is not the creation of another isolated learning model but the operationalization of a national pedagogical framework within a complete instructional product.

Conclusion

This study developed a printed Grade 10 mathematics module for statistics using the Four-D model and the Indonesian pedagogical Deep Learning framework of mindful, meaningful, and joyful learning. The module obtained very high validity, with mean scores of 4.50 for content, 4.60 for media, and 4.25 for language, and very high practicality, with mean scores of 4.76 from the teacher and 4.71 from students. The mean pretest score increased from 56.40 to 82.75, producing an N-Gain of 0.61 in the moderate category. These results indicate that the module is highly valid and practical and is associated with moderate learning improvement. The main contribution is the systematic integration of mindful, meaningful, and joyful principles across explanations, contextual activities, reflection, practice, and assessment. Because the study involved one school and a limited field sample, future research should test the module with larger and more diverse samples, compare it with alternative instructional conditions, and examine longer-term effects on conceptual understanding, mathematical reasoning, critical thinking, and self-regulated learning.

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Author Contributions
Conceptualization, E.F. and J.; methodology, software, formal analysis, investigation resources, data curation, writing original draft preparation, writing review and editing, visualization, E.F.; validation, F.Y.J., M.F.A., and R. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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