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Article

Development of GeoGebra-Assisted E-Module in Multiple Integral Calculus Course

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Abstract

Limited interaction between students and lecturers during the learning process often leads to suboptimal information transfer. This issue becomes more critical when addressing multiple integral calculus, a subject that is abstract and requires strong visual comprehension. To address this challenge, innovative learning media that promote student autonomy and support the visualization of complex concepts are needed. This study aims to evaluate the feasibility of a GeoGebra-assisted electronic module (e-module) for a multiple integral calculus course. The research employed a development design based on Sugiyono's model, consisting of seven stages: identifying potential and problems, data collection, product design, design validation, design revision, product trial, and final product revision. The participants were 35 mathematics education students selected through purposive sampling. Data were collected using validation sheets to assess product quality, student response questionnaires to measure practicality, and learning outcome tests to determine effectiveness. The data were analyzed using descriptive statistics, with the percentage of students achieving a minimum score of 70% used as the indicator of effectiveness. The validation results categorized the module as "very valid," while student responses indicated that it was "very practical." Furthermore, 72.4% of students achieved learning outcomes above the minimum mastery level, which falls into the "good" category. Therefore, the GeoGebra-assisted e-module is considered feasible, practical, and effective as a digital learning resource to enhance students' conceptual understanding and visualization skills in multiple integral calculus.

Keywords: GeoGebra-assisted e-module; multiple integral calculus; digital learning media; mathematical visualization; conceptual understanding

1. INTRODUCTION

Multivariable calculus is a core component of advanced mathematics education, requiring students to integrate conceptual understanding, analytical reasoning, and spatial visualization. Learners are expected not only to perform symbolic manipulations but also to interpret geometric meanings underlying concepts such as regions of integration, partial derivatives, and multivariable optimization. However, the high cognitive demands of coordinating multiple representations often result in substantial learning difficulties, particularly when instructional support for spatial reasoning is insufficient (Mkhatshwa, 2022; Rodríguez-Nieto & Moll, 2025). In contemporary mathematics education, these challenges are further amplified by increasing expectations for flexible, independent, and technology-supported learning environments. Consequently, effective instruction in multivariable calculus must move beyond procedural fluency and explicitly support visualization and conceptual connections to promote meaningful and sustainable understanding.

A growing body of research has documented persistent student difficulties in multivariable calculus, especially in relating algebraic expressions to their geometric interpretations. Empirical studies report that students frequently struggle with understanding integration regions, interpreting graphical representations, and coordinating multiple mathematical representations (Mkhatshwa, 2022; Chomariyah & Khotimah, 2025). Moore-Russo et al. (2024) found that although instructors

recognize the importance of visualization, instructional resources remain largely text-based and procedurally oriented. Conversely, studies emphasizing explicit mathematical connections demonstrate that conceptually rich learning environments significantly enhance problem-solving performance (Rodríguez-Nieto & Moll, 2025). Furthermore, research on digital visualization tools indicates that interactive and dynamic representations can substantially improve students' comprehension of abstract multivariable concepts (Cheong et al., 2023; Sudihartinih et al., 2024).

Despite the growing attention to technology-enhanced learning in multivariable calculus, substantial gaps remain in how digital tools are pedagogically integrated into instructional design. Numerous studies indicate that technology is often positioned merely as a supplementary visualization aid rather than being systematically embedded within a coherent instructional framework that supports deep conceptual understanding. Comparative research demonstrates that learning gains are not determined by the mere availability of digital tools, but by the extent to which visualization, conceptual scaffolding, and instructional objectives are coherently aligned (Mencinger et al., 2024; Ní Shé et al., 2023). Furthermore, technology-supported collaborative learning environments and adaptive recommendation systems have rarely been integrated comprehensively into calculus modules, despite evidence of their potential to enhance student engagement and academic performance (Hsu & Hsu, 2025; Milenković & Vučičević, 2024). Other instructional approaches, such as problem-based learning, blended learning models, and global digital pedagogy frameworks, are frequently implemented in isolation without systematic expert validation or rigorous empirical evaluation of their practicality and effectiveness (Murdiyanto et al., 2023; Oktaviana et al., 2025; Yorulmaz, 2025). This situation reveals a clear research gap in the development of validated digital modules that integrate dynamic visualization, structured instructional design, and quantitative assessment within a comprehensive research and development framework.

The novelty of this study lies in the development of a GeoGebra-assisted electronic module for multivariable calculus that systematically integrates dynamic visualization, conceptual scaffolding, and empirical evaluation within a single instructional framework. Unlike previous studies that emphasize isolated technological interventions, this e-module positions visualization as the core learning mechanism for understanding integration regions and geometric-conceptual relationships. The approach extends prior work on visual and case-based digital modules (Takaendengan et al., 2024; Mannan et al., 2025) by incorporating expert validation and quantitative measurement of learning outcomes. In addition, the module is designed to support flexible and blended learning environments, aligning with recent evidence on effective digital and blended calculus instruction (Mitrović et al., 2024; Awaluddin et al., 2025).

Based on the theoretical context, empirical literature, and identified research gap, this study aims to develop and evaluate a GeoGebra-assisted electronic module for multivariable calculus learning. Specifically, the objectives are to: (1) produce an e-module that is valid in terms of content, language, and media design; (2) assess the practicality of the module from students' perspectives; and (3) examine its effectiveness in improving students' learning outcomes in multivariable calculus. By employing a research and development approach, this study seeks to contribute theoretically to technology-enhanced mathematics education and practically by providing a validated digital learning resource that can be sustainably implemented in multivariable calculus instruction.

2. METHODS

This study employed a **research and development (R&D)** methodology, which is widely recognized as an appropriate framework for designing, producing, and validating educational products through systematic and iterative procedures. R&D research emphasizes the integration of design, evaluation, and revision cycles to ensure that the developed product meets both theoretical standards and practical needs in educational settings (Umar et al., 2023; Loeneto et al., 2022). Accordingly, this approach was selected to guide the development of a GeoGebra-assisted electronic module intended to support learning in the Folding Integral Calculus course.

The development process in this study was conducted through **seven main stages**, adapted from commonly accepted R&D practices in educational technology research. These stages included: (1) identification of potentials and problems, (2) data collection, (3) product design, (4) design validation, (5) design revision, (6) product trial, and (7) product revision. Such staged development is consistent with contemporary R&D frameworks that emphasize expert validation and user feedback as critical components for improving instructional quality and product feasibility (Umar et al., 2023; Loeneto et al., 2022). The overall sequence of the development stages is illustrated in Figure 1.

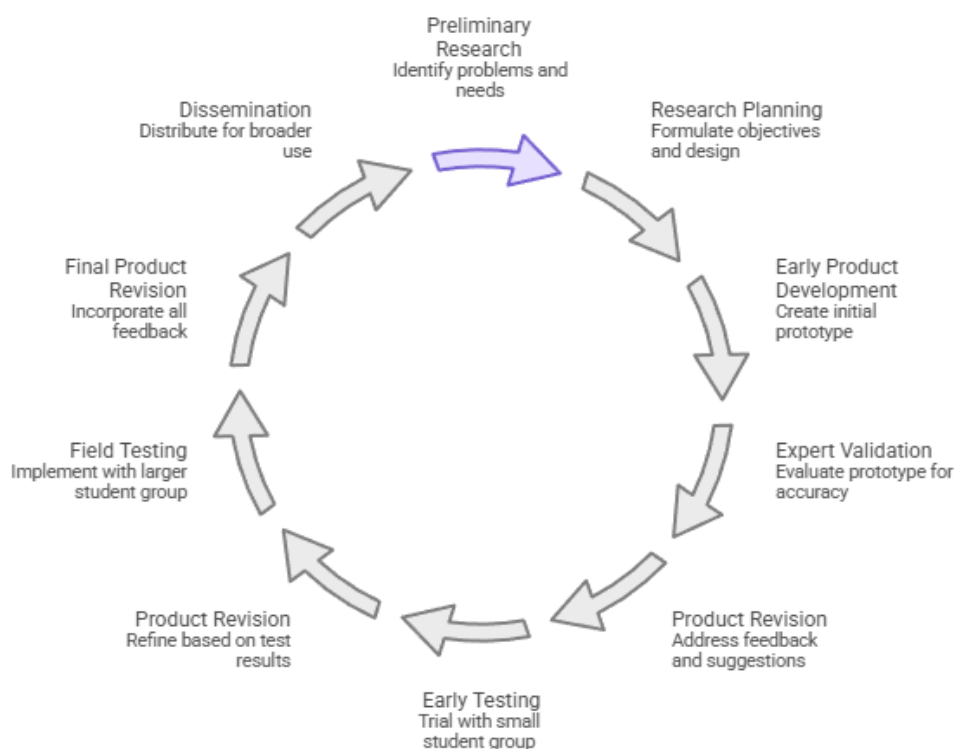


Figure 1. Research and Development Steps (Sugiyono, 2013).

To collect research data, **questionnaire and test methods** were employed. The questionnaires consisted of expert validation instruments and student response instruments. Expert validation focused on evaluating the appropriateness of the e-module in terms of content accuracy, language clarity, and media design, following established validation practices in educational media development (Laksana, 2024; Astuti et al., 2020). Student response questionnaires were used to assess the practicality and usability of the e-module from the learners' perspectives. In addition, achievement tests were administered to measure students' learning outcomes after the implementation of the GeoGebra-assisted e-module in the Folding Integral Calculus course.

The collected data were analyzed using **quantitative descriptive analysis**, primarily through percentage-based calculations to determine levels of validity, practicality, and learning success. Percentage scores obtained from expert validation were interpreted qualitatively according to predetermined criteria, as presented in Table 1. Teaching materials were considered suitable for use if they achieved at least the *quite valid* category, which aligns with commonly applied standards in instructional media evaluation studies (Laksana, 2024; Astuti et al., 2020).

Table 1. Criteria for Validation of Teaching Materials Based on Percentage.

Validation Criteria	Validity Level	Percentage Range
Very valid	Can be used without revision	$85\% < X \leq 100\%$
Quite valid	Can be used with minor revisions	$70.00\% < X \leq 85\%$

Invalid	Recommended not to be used (needs major revision)	$50\% < X \leq 70.00\%$
Invalid	Not to be used	$0\% < X \leq 50\%$

Furthermore, a **practicality test** was conducted to evaluate the feasibility of the developed e-module from users' perspectives. Teaching materials were categorized as practical if they achieved at least the *quite practical* criterion, as shown in **Table 2**. Practicality assessment is an essential component of R&D studies, as it reflects the extent to which instructional products can be effectively implemented in real learning contexts (Umar et al., 2023).

Table 2. Criteria for Practical Teaching Materials.

Practicality Criteria	Level of Practicality
75.01% – 100%	Very practical
50.01% – 75.00%	Quite practical
25.01% – 50.00%	Less practical
0% – 25.00%	Impractical

The indicator of research success was defined as the extent to which the GeoGebra-assisted e-module supported student learning outcomes in the Folding Integral Calculus course. Students who obtained scores of ≥ 70 were categorized as achieving the *Good* criterion. The learning success rate was calculated based on mastery levels, as presented in Table 3.

Table 3. Learning Success Rate Criteria.

Mastery Rate	Category
85% – 100%	Excellent
70.00% – 84%	Good
55% – 69%	Enough
46% – 54%	Less
0% – 45%	Very less

The percentage of learning outcomes was calculated using the following formula:

$$\%X_j = \frac{N_j}{N} \times 100\%$$

where represents the percentage of students achieving scores ≥ 70 , N_j denotes the number of students who achieved scores ≥ 70 , and N refers to the total number of students.

3. RESULT

This research was conducted through seven main stages, namely: (1) identification of potentials and problems, (2) data collection, (3) product design, (4) design validation, (5) design revision, (6) product trials, and (7) product revision. The results obtained at each stage are described as follows.

Identification of Potentials and Problems

The initial stage focused on identifying potential and problems encountered in the learning process of the Folding Integral Calculus (KIL) course. Several supporting potentials were identified, including: (a) the researcher's academic background as a lecturer in Mathematics Education, (b) the availability of facilities and infrastructure to support the development of digital learning media, and

(c) adequate mastery of information technology, particularly the GeoGebra application, for developing visual-based instructional materials.

Conversely, the primary problem identified was that student learning outcomes in the Folding Integral Calculus course in the previous academic year were suboptimal. Students had difficulty understanding concepts and visualizing regions of integration, particularly in double integrals. This condition served as the primary rationale for developing a GeoGebra-assisted electronic module to improve students' conceptual and spatial understanding.

Data Collection

At this stage, learning materials related to double integrals were systematically collected. The materials covered three main subtopics: (1) double integrals over rectangular regions, (2) double integrals over non-rectangular regions, and (3) double integrals in polar coordinates. The collected data consisted of theoretical explanations, sample problems and solutions, practice exercises, and evaluation questions for each learning activity. The main references were drawn from well-established calculus textbooks, including *Calculus* by Purcell et al., which has been academically validated and widely used in higher education.

Product Design

The product design stage began with the development of a printed module containing learning objectives, usage instructions, material explanations supported by visual illustrations, worked examples, practice problems, and answer keys. To enhance conceptual and spatial understanding, GeoGebra was integrated as a visual aid, particularly to illustrate regions of integration and the geometric interpretations of double integrals.

After completing the printed module, the development continued with the creation of an electronic module (e-module). Two supporting applications were used: Sigil to convert the module into an interactive e-book format and Adobe Photoshop to design an attractive, professional cover. The result of this stage was a prototype of a GeoGebra-assisted e-module ready for validation.

Design Validation and Revision

The e-module prototype was validated by three independent experts, consisting of a material expert, a linguist, and a learning media expert. The list of validators is presented in Table 4.

Table 4. E-Module Validators.

No.	Validator	Area of Expertise	Position
1	Dr. Ananda Putra, S.Si., M.T.	Calculus Content Expert	Mathematics Lecturer
2	Dr. Andi Sanjaya, S.T, M.Pd.	Linguistics	Lecturer of Mathematics Education
3	Dr. Ardansyah, S.Pd., M.Pd.	Learning Media	Lecturer of Educational Technology

The validation process of the developed e-module involved expert reviews from material, linguistic, and media perspectives to ensure its quality and feasibility for implementation. From the material expert validation, the initial evaluation resulted in a score of 67.4%, which fell into the *less valid* category and indicated the need for major revisions. The expert recommended several improvements, including correcting the use of inappropriate terminology, adding explicit learning objectives for each learning activity, revising images that were considered inaccurate, and strengthening contextual explanations to better support conceptual understanding. Following these revisions, a second round of validation was conducted and yielded a score of 84.2%, categorized as *quite valid*. This result demonstrates that the e-module had become suitable for use, requiring only minor revisions.

In terms of linguistic validation, the e-module achieved a score of 86.7%, which was classified as *very valid*. This finding indicates that the e-module demonstrated clear and communicative language use, consistency with students' developmental levels, and compliance with Indonesian language conventions. Consequently, no revisions were deemed necessary from a linguistic standpoint. Meanwhile, the media expert validation produced a score of 77.33%, placing the e-module in the *quite*

valid category. The media expert suggested several refinements, such as improving font type and size, enhancing the relevance of the cover design, adjusting color composition, and ensuring greater layout consistency. After these recommendations were implemented, the e-module was considered appropriate and eligible to proceed to the field-testing stage. Overall, revisions were conducted iteratively based on expert feedback until the e-module met the established validity criteria in terms of content, language, and media.

Product Trial and Revision

The product trial was conducted with 29 fifth-semester students of the Mathematics Education Study Program, UIN Syahada Padangsidempuan, during the 2025/2022 academic year. The trial was implemented over four meetings and concluded with a learning outcome test. The results are presented in Table 5.

Table 5. Results of E-Module Trial.

Score Range	Number of Students	Percentage (%)
80–100	6	20.77
70–79	15	51.77
60–69	4	13.88
50–59	4	13.88
Total	29	100.00

Based on Table 5, 21 students (72.4%) achieved scores ≥ 70 , which falls into the *Good* category according to the learning success criteria. These results indicate that the GeoGebra-assisted e-module was effective in improving student learning outcomes in the Folding Integral Calculus course.

In addition, student responses were collected using a practicality questionnaire. The analysis yielded a score of 82.4%, categorized as *very practical*. This result suggests that the e-module was perceived as easy to use, attractive, and supportive of the learning process.

4. DISCUSSION

The findings of this study demonstrate that the development of a GeoGebra-assisted electronic module for the Folding Integral Calculus (KIL) course effectively addresses persistent conceptual and pedagogical challenges in multivariable calculus learning. Difficulties related to interpreting integration regions, determining limits of integration, and coordinating algebraic and geometric representations have been widely documented in previous research on double and multivariate integrals (Jones & Dorko, 2015; Khemane et al., 2023). In response to these challenges, the present study provides empirical evidence that a systematically designed and validated GeoGebra-assisted e-module can serve as an effective instructional intervention. Accordingly, this discussion is structured around three interrelated aspects: product validity, practicality, and learning effectiveness.

From the perspective of content validity, the iterative expert validation process played a decisive role in improving the instructional quality of the developed e-module. The initial material expert score (67.4%) indicated that, despite adequate conceptual coverage, the prototype lacked instructional precision, particularly in the formulation of learning objectives, contextual explanations, and the accuracy of visual representations. These weaknesses are critical in multivariable calculus learning, as poorly structured representations often hinder students' ability to generalize concepts from single integrals to double or triple integrals (Jones & Dorko, 2015). After targeted revisions, the increase in the validity score to 84.2% reflects a substantial improvement in the alignment between mathematical content, visualization, and learning goals. This finding reinforces the argument that systematic expert validation is essential in the development of advanced calculus learning materials,

especially for cognitively demanding topics such as changing the order of integration and defining non-rectangular domains (Khemane et al., 2023).

The linguistic validation results further strengthen the instructional robustness of the e-module. The high linguistic validity score (86.7%) indicates that the module employed clear, communicative, and developmentally appropriate language. In abstract mathematical contexts, linguistic clarity is crucial for minimizing extraneous cognitive load and enabling students to focus on conceptual reasoning rather than interpreting ambiguous explanations. Previous studies on GeoGebra-supported calculus instruction emphasize that effective learning occurs when dynamic visualizations are complemented by precise and well-structured verbal explanations (Tatar & Zengin, 2016; Alessio et al., 2022). The absence of required linguistic revisions therefore suggests that the e-module was already well-positioned as a self-instructional resource capable of supporting independent learning.

In terms of media validity, the score of 77.33% indicates that the visual and structural design of the e-module was generally appropriate, although refinement was necessary. Suggestions related to font readability, color composition, layout consistency, and cover relevance align with findings reported by Milenković et al. (2022), who demonstrated that visualization software enhances learning outcomes only when supported by well-designed visual interfaces. After revision, the improved media design enhanced the ergonomic quality of the module, which is particularly important for facilitating students' interaction with three-dimensional representations of integration regions and coordinate transformations. Well-designed visual elements thus function not merely as aesthetic components but as cognitive tools that mediate mathematical understanding (Medina Herrera et al., 2024).

Beyond validity, the practicality test results indicate that the e-module was highly feasible for classroom use, as reflected by a score of 82.4% categorized as very practical. Students perceived the module as easy to use, engaging, and supportive of independent learning. This finding is consistent with recent studies on calculus e-modules, which report that interactive digital materials promote learner autonomy and motivation in higher education mathematics (Apriandi et al., 2024; Lestari et al., 2024). In post-pandemic learning environments, where flexibility and blended learning models are increasingly emphasized, such practicality becomes a critical indicator of instructional sustainability. The integration of GeoGebra enabled students to explore double integrals dynamically, supporting constructivist learning processes in which knowledge is actively constructed through manipulation and visualization rather than passively received (Lepellere, 2024; Lepellere, 2025).

Most importantly, the learning outcome data provide empirical evidence of the effectiveness of the developed e-module. With 72.4% of students achieving scores ≥ 70 , the learning success rate reached the *Good* category. This improvement is particularly meaningful given that previous cohorts exhibited low achievement and conceptual difficulties in the KIL course. The findings align with prior research showing that GeoGebra-supported instruction significantly enhances students' conceptual understanding of definite and double integrals (Tatar & Zengin, 2016; de Carvalho et al., 2024). Interactive visualization appears to have played a central role in helping students accurately determine integration limits and interpret geometric regions—core competencies in folding integral calculus—thereby bridging the gap between procedural computation and spatial-conceptual reasoning (Milenković et al., 2022; Medina Herrera et al., 2024).

Taken together, these results corroborate and extend existing literature on GeoGebra-based calculus learning. While previous studies have explored GeoGebra applications for double integrals or general calculus topics (Alessio et al., 2022; de Carvalho et al., 2024), the present study contributes a more comprehensive approach by systematically integrating expert validation, instructional scaffolding, and empirical testing within the specific context of Folding Integral Calculus. Compared to many existing e-modules that primarily emphasize procedural skills or isolated competencies (Aprianti, 2024; Arifin et al., 2025), the developed e-module addresses the complex interplay between visualization, conceptual understanding, and independent learning in a unified instructional design.

Nevertheless, this study is limited in scope, as the development process was conducted only up to the seventh stage of the research and development model and involved a relatively small sample drawn from a single institution. Consequently, the generalizability of the findings remains limited. Consistent with recommendations from prior e-module development studies in higher education mathematics (Apriandi et al., 2024; Lestari et al., 2024), future research should extend the implementation to broader contexts through large-scale trials, comparative experimental designs, and longitudinal investigations. Such studies are necessary to examine the long-term impact of GeoGebra-assisted e-modules on students' conceptual retention, spatial reasoning, and higher-order mathematical thinking. Despite these limitations, the present findings provide strong empirical evidence that GeoGebra-assisted e-modules constitute an effective, practical, and theoretically grounded instructional innovation for enhancing learning outcomes in Folding Integral Calculus courses.

The novelty of this study lies in the development of a GeoGebra-assisted electronic module specifically designed for Folding Integral Calculus, which systematically integrates three-dimensional visualization, expert-validated instructional scaffolding, and empirical evaluation of learning outcomes within a single instructional framework. Unlike prior studies that focus primarily on GeoGebra use for isolated calculus topics or procedural skill enhancement, this study addresses the core conceptual and spatial challenges of folding integral calculus, particularly in determining integration regions and limits across different coordinate systems. By combining iterative expert validation, high practicality from the learners' perspective, and demonstrated effectiveness in improving learning outcomes, this research offers a validated and context-specific digital learning solution that extends existing GeoGebra-based calculus literature and provides a robust instructional model for advanced calculus courses in higher education.

5. CONCLUSIONS

This study was conducted to address persistent conceptual and pedagogical challenges encountered by students in the Folding Integral Calculus (KIL) course, particularly in understanding integration regions, determining limits of integration, and coordinating algebraic and geometric representations. To achieve this objective, a GeoGebra-assisted electronic module was developed using a research and development approach, incorporating systematic design, expert validation, and empirical testing. The study aimed to produce a valid, practical, and effective digital learning resource capable of supporting conceptual understanding and independent learning in multivariable calculus. The findings indicate that the developed e-module meets established quality standards. Expert validation results confirmed that the e-module achieved adequate content accuracy, linguistic clarity, and media design quality after iterative revisions. In addition, student responses demonstrated high practicality, indicating that the e-module was perceived as easy to use, engaging, and supportive of the learning process. These results suggest that the integration of GeoGebra-based visualization within a structured instructional design can effectively enhance the feasibility and usability of digital learning materials in higher education mathematics.

Empirical testing further revealed that the implementation of the GeoGebra-assisted e-module led to improved student learning outcomes in the KIL course. A substantial proportion of students achieved the expected mastery level, indicating that the e-module was effective in facilitating students' understanding of double integrals and related spatial concepts. The interactive visualizations embedded in the e-module played a critical role in bridging the gap between procedural computation and spatial-conceptual reasoning, which is a central difficulty in folding integral calculus learning. The primary contribution of this study lies in the development of a validated and context-specific GeoGebra-assisted e-module that systematically integrates three-dimensional visualization, instructional scaffolding, and empirical evaluation within a single learning framework. This study extends existing research on GeoGebra-based calculus learning by focusing explicitly on the unique conceptual demands of Folding Integral Calculus and by

demonstrating the importance of expert validation and practicality testing in ensuring instructional effectiveness.

The findings offer both theoretical implications for calculus education and practical guidance for lecturers seeking to implement technology-enhanced learning resources. Despite its contributions, this study is limited by its scope, as the development process was conducted only up to the seventh stage of the research and development model and involved a single institutional context. Future research is therefore recommended to conduct large-scale implementations, comparative experimental studies, and longitudinal investigations to examine long-term effects on conceptual retention and higher-order mathematical thinking. In conclusion, the GeoGebra-assisted e-module developed in this study represents a meaningful and effective instructional innovation that enhances learning quality in Folding Integral Calculus courses and provides a solid foundation for further advancements in technology-supported calculus education.

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