BUKTI KORESPONDENSI

ARTIKEL JURNAL INTERNASIONAL BEREPUTASI

Judul Artikel	:	**Visualization of Multivariable Calculus: Learning Needs Analysis for Geo Gebra-Assisted Teaching Material Development**
Jurnal	:	Kreano, Jurnal Matematika Kreatif-Inovatif
Penulis	:	Dini Andiani, Siti Dwi Rahayu Septiani, and Cecep Suwanda

No.	Perihal	Tanggal
1.	Bukti konfirmasi submit artikel dan artikel yang disubmit	15 September 2025
2.	Bukti konfirmasi review dan hasil review pertama	9 November 2025
3.	Bukti konfirmasi submit revisi pertama, respon kepada reviewer, dan artikel yang diresubmit	17 November 2025
4.	Bukti konfirmasi artikel accepted	24 Desember 2025
5.	Bukti konfirmasi artikel published online	30 Desember 2025

1. Bukti Konfirmasi Submit Artikel dan Artikel Yang Disubmit (15 September 2025)

Submission confirmation

From Dr. Detalia Noriza Munahefi, M.Pd. on 2025-09-15 11:15

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Visualization of Multivariable Calculus: Learning Needs Analysis for GeoGebra-Assisted Teaching Material Development

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Abstract

Students frequently encounter substantial challenges in studying Multivariable Calculus, especially when visualizing functions of several variables, interpreting partial derivatives, and applying the concept of extrema. This research investigates students' learning needs as the foundation for developing instructional materials supported by GeoGebra. Employing the Gravemeijer and Cobb design research framework within a qualitative descriptive approach, data were obtained from an online questionnaire administered to eight mathematics education students who had completed the Multivariable Calculus course. The analysis revealed that most participants reported moderate to high difficulty levels, particularly in visualization tasks and the comprehension of partial derivatives. In addition, students expressed a strong willingness to engage with GeoGebra-based resources, highlighting the relevance of three-dimensional visualization, interactive projects, and supplementary media such as video materials. Overall, the findings underscore the necessity of carefully designed learning environments that incorporate dynamic visualization tools to strengthen conceptual understanding and application.

Keywords: Multivariable calculus; GeoGebra; learning needs; learning design; *design research*

Abstrak

Mahasiswa kerap menghadapi tantangan yang cukup besar dalam mempelajari Kalkulus Peubah Banyak, khususnya pada aspek memvisualisasikan fungsi multivariabel, menafsirkan turunan parsial, serta menerapkan konsep nilai ekstrem. Penelitian ini bertujuan untuk mengkaji kebutuhan belajar mahasiswa sebagai dasar pengembangan bahan ajar yang didukung oleh GeoGebra. Dengan menggunakan kerangka design research Gravemeijer dan Cobb dalam pendekatan deskriptif kualitatif, data dikumpulkan melalui kuesioner daring yang diisi oleh delapan mahasiswa pendidikan matematika yang telah menempuh mata kuliah Kalkulus Peubah Banyak. Hasil analisis menunjukkan bahwa sebagian besar responden melaporkan tingkat kesulitan sedang hingga tinggi, terutama dalam tugas-tugas visualisasi dan pemahaman konsep turunan parsial. Selain itu, mahasiswa menyatakan kesediaan yang kuat untuk menggunakan bahan ajar berbasis GeoGebra, dengan menekankan pentingnya visualisasi tiga dimensi, proyek interaktif, serta media pendukung seperti video pembelajaran. Secara keseluruhan, temuan penelitian ini menegaskan perlunya lingkungan belajar yang dirancang secara cermat dengan mengintegrasikan alat visualisasi dinamis untuk memperkuat pemahaman konseptual dan kemampuan aplikasi mahasiswa.

Mathematics Clasification: ---- 97D70 ----

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INTRODUCTION

In an ideal situation, learning Multivariable Calculus in higher education should not only emphasize students' procedural abilities in performing mathematical calculations, but also foster deep conceptual understanding through mastery of various symbolic, numerical, graphical, and verbal representations as a coherent whole (Andiani, 2016, 2025; Andiani et al., 2020; Bedada & Machaba, 2022; Milenković & Vučićević, 2024). Students should be able to connect multivariable concepts such as functions of two variables, partial derivatives, gradients, multiple integrals, and extreme values, reflecting a meaningful understanding of advanced calculus (Bedada & Machaba, 2022).

Learning should also provide space for the development of three-dimensional visualization skills. Concepts such as contour planes, 3D surfaces, and gradients should be visualized interactively to enhance spatial understanding (Cheong et al., 2023, 2024; Herrera et al., 2024; Jones et al., 2022). Several studies have found that advanced visualization tools such as GeoGebra 3D or virtual reality can intuitively strengthen understanding of partial derivatives and multivariate change-law relationships.(Cheong et al., 2023, 2024; Jones et al., 2022; Sopiany & Rikayanti, 2018)

Furthermore, ideal learning prioritizes active and interactive learning experiences (Doolittle et al., 2023; Dubinsky & Hamid, 2024; Li & Ding, 2023; Martín-Alguacil & Avedillo, 2024; Ribeiro-Silva et al., 2022; Song & Cai, 2024). Students act as active explorers, rediscovering concepts through exploration, modeling, and discussion. *Active learning approaches* have improved conceptual understanding in multivariable calculus beyond traditional learning (Schoenherr et al., 2024).

In addition, the lecturer's role as a facilitator is essential in ideal conditions (Andiani, 2025). The facilitator should guide students to find conceptual understanding through reflection, not just provide procedures (Andiani, 2025). Assessment should also encompass mathematical representation and application skills, not just calculation skills (Andiani et al., 2020; Andiani, Ruhiyat, et al., 2024). However, this practice is often not optimally implemented, necessitating learning and assessment designs that better support higher-level mathematical competencies.

In the practice of teaching Multivariable Calculus, there is a clear gap between the ideal conditions of mastery of inter-representational connections, 3D visualization skills, use of interactive media, and assessments that assess conceptual understanding, and the real conditions experienced by many students (Borji et al., 2022; Chang et al., 2024; Cheong et al., 2023; Herrera et al., 2024; Malone et al., 2023). First, although visual representations are considered crucial for building spatial intuition in multivariable topics, recent empirical studies report that students still experience significant difficulties in visualizing three-dimensional surfaces and relating symbolic changes to geometric changes, resulting in weak conceptual understanding (Borji et al., 2022).

Second, recent research shows that dynamic visualizations such as virtual reality and GeoGebra 3D can significantly improve spatial intuition and understanding of multivariable concepts. However, these tools have not been widely adopted in classroom practice, leaving many courses dominated by symbolic teaching and procedural exercises (Andiani, Nurlaelah, et al., 2024; Cheong et al., 2023; Herrera et al., 2024; Jones et al., 2022; Schoenherr et al., 2024). Dominating by symbolic teaching and procedural exercises creates a gap between the pedagogical potential of visual technologies and their implementation in the classroom (Cheong et al., 2023).

Third, recent meta-analyses and comparative studies indicate that learning with well-designed visual representations improves concept transfer and mathematical reasoning. However, its effectiveness depends heavily on the instructional design and accompanying scaffolding—aspects that are often overlooked when technology is introduced as a "demo" without a structured learning strategy (Malone et al., 2023; Nickl et al., 2024; Rexigel et al., 2024; Schoenherr et al., 2024; Wang et al., 2025).

Fourth, surveys and qualitative studies show that assessment aspects in many calculus courses are still oriented toward procedural skills (calculation), resulting in under-stimulation of learning outcomes that measure the representation, modeling, and application of multivariable concepts. This situation widens the gap between ideal learning outcomes and actual student outcomes (Cheong et al., 2023; Herrera et al., 2024; Schoenherr et al., 2024; Spencer-Tyree et al., 2024).

Fifth, the empirical findings are in line with the results of the preliminary questionnaire in this study which showed students' readiness to use GeoGebra-based teaching materials as well as a real need for 3D visualization, interactive projects, and multimedia supporting materials, empirical evidence that confirms the need for planned and iterative learning design (see the questionnaire results in the Methods & Results Chapter) (Abuhassna & Alnawajha, 2023; Andiani, 2025; Andiani, Nurlaelah, et al., 2024; Jong, 2023; Leung et al., 2024; Peters-Burton et al., 2024; Tinoca et al., 2022).

In bridging the gap between the ideal and the reality of learning Multivariable Calculus, educational technologies such as GeoGebra are highly relevant. GeoGebra provides an interactive visual environment that allows students to explore multivariable functions through dynamic graphs, parameter manipulation, and three-dimensional visualization. Recent research has shown that using GeoGebra can improve students' conceptual understanding and facilitate the integration of mathematical representations (Bedada & Machaba, 2022; Hevardani et al., 2025). In fact, integrating GeoGebra with active learning strategies has been shown to improve spatial representation skills and increase student learning engagement (Bedada & Machaba, 2022; Cheong et al., 2023; Herrera et al., 2024).

In addition to the technological aspect, Gravemeijer & Cobb's approach within the *design research framework* also makes an important contribution (Cela-Ranilla et al., 2025; Komatsu et al., 2024; Mackey et al., 2023; Prediger et al., 2015). This approach emphasizes the instructional development cycle through three stages: *preliminary design*, *teaching experiment*, and *retrospective analysis*. By placing the student's learning experience as the center of attention, this approach allows researchers and lecturers to design, implement, and revise teaching materials iteratively based on empirical data (Andiani, Nurlaelah, et al., 2024; Gravemeijer & Cobb, 2006). In the context of Multivariable Calculus, this framework encourages the creation of teaching materials that are not only technologically innovative but also rooted in the real needs of students, so that learning is more meaningful and sustainable (Schoenherr et al., 2024).

Previous research has highlighted the importance of representation and visualization in calculus learning, including using computer-based media to support understanding multivariable concepts (Herrera et al., 2024; Schoenherr et al., 2024; Wong et al., 2024). Bedada's (2022) study demonstrated that the use of GeoGebra can improve students' understanding of basic calculus concepts, while Cheong et al. (2023) demonstrated that the integration of virtual reality technology can strengthen the understanding of partial derivatives through dynamic visualization (Bedada & Machaba, 2022; Cheong et al., 2023). Furthermore, Schoenherr's (2024) meta-analysis confirmed that using pedagogically designed visualizations has significantly impacted mathematical learning outcomes. However, most of these studies focused on applying specific technologies or media without integrating a systematic theoretical framework in developing learning designs (Schoenherr et al., 2024).

On the other hand, the *design research approach* introduced by Gravemeijer & Cobb (2006) offers a methodological framework that focuses on an empirically data-driven instructional development cycle (Gravemeijer et al., 2006; Gravemeijer & Cobb, 2006). Although it has been widely applied in mathematics education research, its application in Multivariable Calculus with GeoGebra support is still relatively rare, especially in higher education in Indonesia. Thus, this study occupies an important position as an effort to fill the gap in previous research by integrating GeoGebra technology and the Gravemeijer & Cobb approach within a needs analysis framework. Giving an important position as an effort to fill the gap in previous research by integrating GeoGebra technology and the Gravemeijer & Cobb approach within a *needs analysis framework* makes this study not only a replication of previous studies, but also an innovative step in designing a Multivariable Calculus learning design that is rooted in the real needs of students.

Based on the description of ideal conditions, empirical gaps found through questionnaires, and previous research studies, it can be formulated that the main problems in learning Multivariable Calculus lie in students' limitations in visualizing multivariable concepts, minimal experience using interactive technologies such as GeoGebra, and the dominance of procedural learning that does not support conceptual understanding. This condition indicates the need for an innovative approach that not only presents visual media but is also developed through a methodological framework rooted in the real needs of students.

In line with the formulation of the problem, the objectives of this study are: (1) to identify the difficulties and learning needs of students in understanding the material of Multivariable Calculus, especially in the aspects of representation and visualization; (2) to analyze students' perceptions and readiness towards the use of GeoGebra-assisted teaching materials; and (3) to provide an empirical and conceptual basis for the development of the design of GeoGebra-based Multivariable Calculus teaching materials with the Gravemeijer & Cobb approach. Thus, this study is expected to contribute to designing more contextual, interactive instructions, in line with the demands of advanced mathematics learning in higher education.

This research is expected to contribute to three main areas. First, an empirical contribution in the form of data on students' learning needs in Multivariable Calculus highlights explicitly the difficulties of multivariable visualization, mathematical representation, and technology use. This data is important because most studies of multivariable calculus have emphasized procedural aspects rather than exploring students' real needs (Borji et al., 2022). Second, a practical contribution in the form of a conceptual basis for designing GeoGebra-assisted teaching materials that are appropriate to the context of Indonesian students, so that visual media is not only a supplement, but an integral part of the learning strategy (Bedada & Machaba, 2022; Hevardani et al., 2025). Third, a theoretical contribution through the integration of the Gravemeijer & Cobb approach in the context of multivariable calculus learning, which is still relatively rarely studied at the higher education level. This integration is expected to enrich the literature on the application of *design research* in mathematics education, while opening up space for further research in the form of implementation and validation of interactive teaching material designs.

METHOD

This research was conducted using a qualitative approach that focused on analyzing students' learning needs as the basis for developing teaching materials for Multivariable Calculus using GeoGebra. The qualitative approach was chosen because it can reveal the phenomena of students' difficulties, needs, and perceptions in greater depth, which cannot always be measured through statistics alone.

The research subjects were eight Mathematics students at a university in West Java who had taken the Multivariable Calculus course. They comprised six female and two male students, all in their fourth semester. This characteristic is important because all respondents had direct experience studying Multivariable Calculus, so their answers reflected the reality of actual learning needs.

The research instrument was an online questionnaire developed using Google Forms. The questionnaire included four main sections: respondent identity, learning experiences and needs, availability of GeoGebra-based teaching materials, and expectations regarding teaching material design. Each section included closed-ended questions with a rating scale or multiple-choice options and open-ended questions that allowed respondents to express their opinions more freely.

The data collection procedure involved distributing a questionnaire link to students who met the criteria. All respondents completed the questionnaire independently within one week. The collected data was then downloaded and extracted into a response table for easier organization. Data validity was maintained through clear instructions to respondents and by checking the completeness of responses before analysis.

The questionnaire data were analyzed using qualitative descriptive analysis techniques. Quantitative responses, in the form of rating scales, were processed into percentages to illustrate student difficulties or needs trends. Meanwhile, open-ended responses were analyzed using thematic categorization to identify general patterns related to students' learning experiences, obstacles, and expectations regarding GeoGebra-assisted learning materials.

In addition to descriptive analysis, this study also refers to the Gravemeijer & Cobb *design research framework*. This framework interprets the questionnaire findings as the initial stage in the research cycle: *preliminary design*. The results of the student learning needs analysis serve as the basis for formulating the initial design of teaching materials, which will later be tested in *the teaching experiment stage* and evaluated through *retrospective analysis*.

The first year of research was limited to needs analysis and initial design. This limitation was based on time and resource constraints and the fact that the Multivariable Calculus course is only taught once a year. Therefore, the initial phase of this research focused on exploring student difficulties and developing instructional materials responsive to their needs.

To maintain reliability, data analysis was conducted iteratively by reviewing the categories until consistency was achieved. Content validity was strengthened by comparing the questionnaire results with the findings of literature studies on multivariable calculus learning difficulties and the role of visual technology in mathematics education. In this way, empirical data from students could be positioned within a broader research framework.

Overall, this research method describes the students' conditions and provides a conceptual and practical basis for developing GeoGebra-assisted teaching materials for Calculus of Multiple Variables. Thus, it becomes an integral part of the *design research paradigm*, which emphasizes the close relationship between needs analysis, instructional design, and ongoing evaluation.

RESULTS AND DISCUSSION

Results

Multivariable Calculus is a core course in Mathematics with a high level of complexity, primarily because it covers concepts such as functions of two variables, partial derivatives, multiple integrals, and extreme values. These materials require students to simultaneously master symbolic, numerical, graphical, and verbal representations and possess conceptual understanding that goes beyond procedural skills. However, recent studies, including one by Bedada (2022), indicate that students often struggle to connect mathematical symbols with geometric or spatial interpretations for multivariable concepts, resulting in a lack of in-depth conceptual understanding (Bedada & Machaba, 2022). This research makes it clear that learning needs analysis is not a secondary step but a foundation for designing more effective and targeted learning strategies.

Learning needs analysis is a diagnostic tool that reveals the gap between learning ideals and reality. Ideally, students should be able to visualize three-dimensional graphs, using symbolic, numerical, graphical, and verbal representations in an integrated manner. However, based on the data obtained, most students still excel only in procedural aspects performing calculations and following algorithmic steps while their visualization and representation skills remain weak. Weakness of visualization and representation skills is also supported by a recent study examining students' difficulties in optimizing multivariable functions, which found that poor visualization significantly contributes to misconceptions and obstacles in understanding functional change. (Mkhatshwa, 2023). Thus, needs analysis allows instructors to see which aspects must be realized in teaching materials to make responses to student difficulties more precise.

In line with global trends in mathematics education, the importance of a needs-based approach is increasingly emphasized. Recent research shows that mathematics instruction tailored to students' real needs can increase their engagement, motivation, and conceptual understanding (Herrera et al., 2024). Therefore, needs analysis in CBT learning is not merely a technical first step, but a fundamental strategy for improving the quality of mathematics education in higher education.

Spatial visualization skills are one of the key aspects revealed in needs analysis. Students often struggle to visualize multivariate function surfaces or read contour curves, even though these skills are crucial for understanding partial derivatives and multiple integrals. Cheong et al. (2023) demonstrated that integrating visual technologies such as VR or GeoGebra 3D can help students develop spatial intuition. However, their effectiveness is only optimal if tailored to their needs (Cheong et al., 2023). Effectiveness reinforces the urgency of needs analysis as a basis for technology utilization.

In addition to the visualization aspect, the needs analysis revealed students' dependence on procedural learning and lectures. This condition is consistent with the results of research by Hevardani et al. (2025), who found that although GeoGebra has been used in calculus courses, its successful use is highly dependent on learning designs tailored to students' needs (Hevardani et al., 2025). Thus, the needs analysis not only serves to identify barriers but also directs relevant pedagogical strategies.

A needs analysis also provides crucial information regarding student perceptions and readiness to use learning technology. Recent qualitative studies confirm that students are more motivated when learning materials align with their learning styles and technological readiness (Schoenherr et al., 2024). Without a needs analysis, technology integration risks becoming merely an add-on activity without significantly impacting student understanding.

From a methodological perspective, needs analysis aligns with Gravemeijer & Cobb's design research approach. The preliminary design stage of this research cycle emphasizes the importance of understanding student learning phenomena before designing learning interventions (Gravemeijer & Cobb, 2006). Therefore, needs analysis is not merely an administrative step, but an integral part of a research framework based on a cycle of design, experimentation, and retrospective analysis.

The needs analysis contributes to a practical dimension, generating concrete recommendations for developing teaching materials. For example, students in this study emphasized the need for teaching materials equipped with interactive 3D visualizations, GeoGebra-based mini-projects, and retrievable multimedia materials. This aspiration demonstrates that teaching materials relevant to students' needs will be more easily accepted and utilized in learning (Hevardani et al., 2025).

Thus, needs analysis in Calculus multivariable learning plays a dual role: strengthening the theoretical foundation by uncovering students' learning gaps, and providing practical input for direct input to design technology-based teaching materials. These findings reinforce the view that the success of mathematics learning innovations, particularly those supported by GeoGebra, is primarily determined by the extent to which the developed design aligns with students' needs. (Herrera et al., 2024; Schoenherr et al., 2024).

The results of the questionnaire analysis showed that the majority of students considered Multivariable Calculus to be a relatively challenging course. Seventy-five percent of respondents stated that the difficulty level was moderate to high. This finding reinforces the understanding that learning Multivariable Calculus requires a different approach than single-variable calculus.

The most prominent learning difficulty was partial derivatives, with 50% of respondents stating this was a significant obstacle. This difficulty indicates that students still struggle to understand the concept of partial derivatives in the context of geometry and its application in multivariable calculations. Furthermore, 37.5% of students reported difficulty visualizing multivariable functions. This obstacle reflects students' weak spatial skills in depicting three-dimensional surfaces, contour curves, and gradients. This finding aligns with Cheong et al. (2023), who stated that visualization skills are a key factor in understanding multivariable calculus (Cheong et al., 2023).

Another difficulty identified was understanding limits and continuity in multivariable functions. Twenty-five percent of respondents experienced difficulties in this area, indicating that students still struggle to generalize the concept of limits from one variable to many. Addressing this obstacle is important because it forms the basis for understanding partial derivatives and multiple integrals. As many as 37.5% of students also experienced difficulty applying extreme values. Difficulty applying extreme values indicates that although they understand the calculation procedures, applying the concepts in a multivariable context remains a challenge. Borji (2022) emphasized that students often fall into proceduralism without understanding the conceptual meaning behind the calculations (Borji et al., 2022).

Table 1 provides a visual representation of students' difficulty levels in each Multivariable Calculus topic. It displays the percentage of students who encountered difficulties with partial derivatives, multivariable function visualization, limits and continuity, and extreme values. This diagram makes it easy for readers to see the differences in difficulty levels between aspects of the material at a glance.

Based on the findings above, Table 1 below summarizes the percentage of students experiencing difficulties in each aspect of the Multivariable Calculus material. This table provides a clear picture of the areas that most require learning intervention and the development of GeoGebra-based teaching materials.

Table 1. Percentage of Student Difficulties Based on Learning Aspects

Learning Aspects	Percentage of Students Experiencing Difficulties	Information
Partial derivatives	50%	The main obstacle is the difficulty in understanding geometric and applicative concepts.
Visualization of multivariable functions	37.5%	Weak in drawing 3D surfaces, contour curves, and gradients
Limit & continuity	25%	Difficulty generalizing the concept of limit from 1 variable to many variables

Extreme values	37.5%	Understand the procedure, but have difficulty applying the concept

87.5% of respondents cited lecturer explanations as the most helpful primary source for learning media preferences. This data confirms that lecturers remain central to CDE learning. However, this pattern also indicates a high reliance on conventional methods.
In addition to the role of lecturers, 75% of respondents considered learning videos helpful. This preference indicates that students value the flexibility of digital media, which allows for independent material review. According to Medina Herrera et al. (2024), interactive videos can strengthen students' cognitive engagement in learning complex concepts (Herrera et al., 2024).

75% of respondents also recognized the benefit of using visual applications like GeoGebra. This demonstrates that students see great potential in interactive media, although their use remains limited. These findings support the view that technology integration needs to be systematic and tailored to student needs.

Based on the questionnaire results, Table 2 below summarizes the percentage of students who rated various learning media as the most helpful. This table provides a clear picture of the most effective media according to students' perceptions and serves as a reference in designing GeoGebra-based teaching materials.

Table 2. Percentage of Students Based on Learning Media

Instructional Media	Percentage of Students	Information
Lecturer's explanation	87.5%	Still, the primary source of learning
Learning videos	75%	Supports repetition and independent understanding
GeoGebra	75%	Interactive media, but the student experience is limited
Previous GeoGebra experience	62.5% never, 37.5% limited	Demonstrates the gap between technological potential and real-world experience.
Readiness for using GeoGebra-based teaching materials	100%	Strong signal of acceptance of technological innovation

However, students' experience with GeoGebra remains very low. Data shows that 62.5% of respondents have never used GeoGebra, while 37.5% have only experienced it to a limited extent. The few experiences in GeoGebra indicate a gap between the technology's potential and students' experiences. Despite limited experience, students had a positive perception of GeoGebra's effectiveness. Seventy-five percent of respondents agreed that GeoGebra could help them understand CDE material. The more agreement GeoGebra could help them understand CDE material demonstrates a willingness to adopt new technology if it proves beneficial. Student readiness is further strengthened by data showing that all respondents (100%) are willing to use GeoGebra-based teaching materials. Students' willingness indicates that technology-based innovations can be well-received if designed appropriately. Schoenherr (2024) emphasized that perceived usefulness is a greater determinant of technology acceptance than initial user experience (Schoenherr et al., 2024).

Students' expectations for learning materials varied, but most emphasized the need for interactive visualizations. Respondents suggested 3D graphics, GeoGebra-based mini-projects, and exploration activities that allow for active learning. In addition to visualization, students desire a connection between learning materials and real-world contexts. Several respondents emphasized connecting GeoGebra visualizations to everyday life applications or case studies. This aspiration aligns with Bedada (2022), who emphasized the need to contextualize mathematics learning in higher education (Bedada & Machaba, 2022).

Based on these findings, **Table 3** summarizes students' needs and expectations for the Multivariable Calculus teaching materials. This table presents aspects considered important by students, including the need for interactive visualizations, learning media, relevance to real-world contexts, and exploratory activities, thus forming the basis for designing GeoGebra-based teaching materials.

Table 3. Questionnaire Findings

Aspect	Questionnaire Findings	Implications for Teaching Materials
Visualization	37.5% difficulty with 3D visualization	Module with interactive 3D graphics
Interactive media	75% found GeoGebra useful	GeoGebra-based mini project
Learning activities	Students want active classes	Exploration activities, guided reinvention
Real context	Students want everyday life applications	Case studies related to KPB
Lecturer support	87.5% rely on lecturers	GeoGebra structured instructions & guides

Students also expect a variety of learning media, such as a combination of textbooks, instructional videos, and technology-based teaching materials. Using various learning media indicates a preference for a *blended learning approach* that offers flexibility in learning. Several respondents stated that lecturers' explanations must be more detailed and inclusive. They highlighted the differences in educational backgrounds in high schools (SMA/SMK/MA), which impact students' initial understanding. This situation underscores the need for initial assessments to adapt learning strategies.

The questionnaire results also indicated a need for more active learning. Respondents desired hands-on classroom practice to make learning more engaging and easier to understand. Medina Herrera et al. (2024) emphasized that active student engagement is closely linked to increased intrinsic motivation (Herrera et al., 2024).

Regarding learning resources, students emphasized the need for reference books and multimedia materials that can be reviewed. Students' willingness to consider learning resources indicates a need for learning resources that can be accessed independently outside class. The analysis also shows that while students value technology, they still need instructional support from their lecturers. Students' willingness to support from their lecturers indicates the importance of the lecturer's role as a facilitator, guiding technology use.

The questionnaire results revealed a gap between students' procedural and conceptual abilities. They were relatively capable of following calculation procedures, but still had difficulty understanding the underlying conceptual meaning. The affective aspect emerged from students' expectations for enjoyable and interactive learning. Several respondents emphasized that an active classroom atmosphere would make it easier to understand the material. Students' limited experience using GeoGebra presents both challenges and opportunities. If the teaching materials are well-designed, this limitation can be overcome through integrated step-by-step guides.

Student responses also emphasized the importance of a needs-based design approach. These empirical findings demonstrate that teaching materials development must begin with a concrete understanding of student barriers and preferences. Thus, the main results of this study include learning difficulties in representation, preferences for diverse learning media, limited experience but positive perceptions of GeoGebra, high readiness to adopt interactive teaching materials, and expectations for contextual and active learning.

These findings provide a strong foundation for developing GeoGebra-based Multivariable Calculus teaching materials within the Gravemeijer & Cobb framework. The needs analysis was conducted through a questionnaire to identify barriers and open up innovative design directions aligned with student needs. The findings of this questionnaire not only provide an empirical overview of student difficulties and needs but also serve as a starting point for applying Gravemeijer and Cobb's theoretical framework. In the *design research paradigm*, the preliminary design phase focuses on needs analysis, which is then used to design a learning prototype. Data on visualization difficulties, limited technological experience, and student expectations for interactive media directly serve as raw material for this initial design phase.

The Gravemeijer & Cobb framework emphasizes the close relationship between learning theory and practice. By analyzing the empirical gaps emerging from the questionnaire, researchers gained a sharper conceptual basis for developing GeoGebra-based teaching materials. For example, students' difficulties in understanding partial derivatives could be the focus of visual exploration in a prototype teaching material. At the same time, mini-project preferences could be integrated as learning activities that support active engagement. Furthermore, Gravemeijer and Cobb view *design research* as iterative, so each empirical finding is not just a final answer but input for the next development cycle. In the context of this research, the questionnaire results that revealed a gap between procedural and conceptual skills became reflection material to enrich the design of teaching materials that emphasize multiple representations.

The limited student experience with GeoGebra revealed through the questionnaire is also highly relevant within the *teaching experiment framework*. Gravemeijer & Cobb emphasize the importance of classroom experiments to test how students interact with the resulting designs. By recognizing from the outset that students are relatively new to GeoGebra, the design of teaching materials can include step-by-step guidance for more effective technology adoption. Furthermore, the questionnaire results demonstrate students' readiness to embrace technology-based innovation. Gravemeijer and Cobb believe this can be a key asset in developing *didactical phenomenology*, namely, understanding the learning phenomena that emerge when students encounter new mathematical representations. This readiness will be tested and further explored during the design implementation phase.

Students' expectations for interactive 3D visualizations, mini-projects, and multimedia materials align with Gravemeijer's principle of *guided reinvention*. Through designed exploratory activities, students receive information and can rediscover multivariable concepts through interaction with visual media and mathematical discussions. Thus, this study's theoretical contribution lies in strengthening the argument that the Gravemeijer & Cobb framework can be adapted for advanced calculus learning, which has been relatively understudied. Applying this framework in the context of CDE not only enriches the international literature but also broadens the scope of *design research applications* to the realm of multivariable calculus.

From a research perspective, the questionnaire data serve as the basis for the preliminary design phase in the second year. These results will be used to develop a prototype GeoGebra-based teaching material that targets explicitly students' key challenges, namely partial derivatives, extreme values, and visualization of multivariable functions. Thus, the research goes beyond describing needs and continues to design innovative solutions. The initial implementation phase (teaching experiment) will utilize these empirical findings as a reference. For example, the gap between procedural and conceptual skills will be tested through GeoGebra-based exploration activities. At the same time, student preferences for lecturer explanations will be considered when designing a combination of instructional strategies to ensure that the developed design remains contextual and aligned with the students' learning culture.

Next, the results of the initial implementation will be analyzed retrospectively to evaluate the effectiveness of the teaching materials. New findings from this phase will inform the next development cycle. Using an iterative approach, this research aims to produce increasingly mature teaching material designs over the years until they are ready for widespread implementation in the regular curriculum. Ultimately, this research provides empirical contributions in the form of student needs data and practical and theoretical contributions through the application of the Gravemeijer & Cobb framework. Furthermore, this research lays a strong foundation for a long-term research agenda to develop, implement, and validate GeoGebra-based Multivariable Calculus teaching materials, thereby improving the quality of advanced mathematics learning in higher education.

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Discussion

The findings of this study confirm that students still experience significant difficulties in understanding the Multivariable Calculus material, particularly in aspects of partial derivatives, extreme values, and the visualization of multivariable functions. These results align with Borji's (2022) study, which showed that students' primary difficulty lies in their limited ability to connect calculation procedures with the conceptual meaning behind mathematical symbols. (Borji et al., 2022). Thus, this study emphasizes the urgency of pedagogical interventions that strengthen conceptual representations.

The difficulty in three-dimensional visualization experienced by 37.5% of students is also consistent with the findings of Cheong et al. (2023), who emphasized that weak spatial skills can hinder the understanding of the concepts of gradients and surfaces of multivariable functions (Cheong et al., 2023). However, the results of this study add a new perspective that visualization barriers do not stand alone, but are closely related to a weak understanding of partial derivatives. Visualization barriers do not alone broaden the discussion on the interrelationships between concepts in multivariable calculus.

Students' preference for lecturer explanations (87.5%) demonstrates the dominance of traditional methods in KPB learning. However, the data also indicates students' openness to integrating digital media such as instructional videos (75%) and visual applications (75%). This finding is consistent with Hevardani et al. (2025), who found that combining traditional and technological strategies was more effective than using either alone. Thus, this study supports the direction of blended learning in the context of advanced mathematics learning.

Students' limited experience with GeoGebra (62.5% had never used it) contrasts with their positive perceptions of its potential. This finding aligns with research by Schoenherr (2024), which found that technology adoption in mathematics learning is determined more by perceived benefits than by prior experience (Schoenherr et al., 2024). In other words, even with minimal experience, students are still ready to embrace GeoGebra if tailored to their needs.

Students' expectations for interactive learning materials, such as 3D visualizations, mini-projects, and multimedia materials, support the findings of a systematic review by Medina Herrera et al. (2024), which emphasized that interactive technology can enhance cognitive engagement and learning motivation (Herrera et al., 2024). This study adds a local dimension, as students desire visualizations and contextualized and independently retrievable learning.

This research strengthens previous studies and makes a new contribution to the literature by integrating the needs analysis results into the Gravemeijer & Cobb framework. Previous research has focused more on student difficulties or media effectiveness separately. In this study, empirical data on student needs serve as the basis for the preliminary design phase, creating a direct bridge between instructional design theory and practice.

Furthermore, this study's findings pave the way for the development of more targeted GeoGebra-based KPB teaching materials. Difficulties in partial derivatives, for example, can be addressed with GeoGebra-based gradient visualization activities. Similarly, difficulties with extreme values can be addressed through interactive simulations of multivariable functions. This approach also tests the validity of Gravemeijer's *guided reinvention principle* in the context of advanced calculus learning, a previously understudied area.

The novelty of this research lies in integrating student needs analysis in learning Multivariable Calculus with the Gravemeijer & Cobb *design research framework*. Previous studies have focused on student learning difficulties (Borji, 2022) or the effectiveness of visual media (Cheong et al., 2023; Medina Herrera et al., 2024), but rarely link empirical data on student needs directly to the *preliminary design stage* of teaching materials (Borji et al., 2022; Cheong et al., 2023; Herrera et al., 2024). Thus, this research offers a new contribution in the form of a bridge between empirical findings and a theoretical framework that can serve as a systematic foundation for developing, implementing, and validating GeoGebra-based teaching materials in the context of multivariable calculus in Indonesian universities.

Implication of Research

The findings of this study have important implications in three main domains. Theoretically, these results extend the application of the Gravemeijer & Cobb framework in learning Multivariable Calculus, confirming that needs analysis can serve as a foundation for *preliminary design* relevant to students' real-world difficulties. Practically, the questionnaire data indicate the need to develop GeoGebra-based teaching materials that provide interactive visualizations and facilitate exploration activities, mini-projects, and links to real-world applications. This study provides an initial foundation for further research cycles in the form of implementation (*teaching experiments*) and retrospective analysis, which are expected to produce valid, effective, and generalizable teaching materials for advanced mathematics learning in higher education.

Limitation

This study has several limitations that should be noted. First, there were only eight respondents, so the data obtained is not representative of the broader student population. Second, the online questionnaire instrument provided a general overview of students' difficulties, perceptions, and expectations. However, it did not delve deeply into their learning experiences through interviews or direct observation. Third, this study is only at the needs analysis stage, so the effectiveness of the intervention in the form of GeoGebra-based teaching materials cannot yet be verified. These limitations open up opportunities for further research involving larger samples, incorporating qualitative data collection methods, and testing the validity of the learning design through classroom experiments and retrospective analysis.

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CONCLUSION

This study successfully identified students' main difficulties in learning Multivariable Calculus: limitations in understanding partial derivatives, extreme values, and the visualization of multivariable functions. The questionnaire results also showed that although students still rely heavily on traditional methods such as lecturer explanations, they have a positive perception and high readiness for using interactive technologies such as GeoGebra. Students' expectations for 3D visualization, mini-projects, and multimedia materials reinforce the urgency of developing technology-based teaching materials that are contextual and interactive. These findings are then positioned within the Gravemeijer & Cobb framework, emphasizing the importance of needs analysis as a basis for preliminary design. Thus, this study provides empirical contributions in the form of student needs data and practical and theoretical contributions to the development of more meaningful and sustainable Multivariable Calculus instruction.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the students who actively participated in completing the questionnaire, enabling this learning needs analysis to be successfully conducted. Appreciation is also extended to the Mathematics Study Program, Faculty of Mathematics and Natural Sciences, Universitas Bale Bandung, for providing facilities and access to the research. Special acknowledgment is given to the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek) through its Research and Community Service Information Base (BIMA) program, the official platform supporting research proposals and reporting. Access to BIMA has streamlined the administrative process for this research and facilitated systematic data management. The authors thank their colleagues for constructive feedback, methodological suggestions, and encouragement while preparing this manuscript. The support and collaboration of all parties will likely contribute positively to the advancement of calculus education in Indonesia.

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2. Bukti Konfirmasi Review dan Hasil Review Pertama (9 November 2025)

[Kreano] Your submission has been reviewed and we encourage you to submit revisions

From Amidi, S.Si., M.Pd. on 2025-11-09 23:33

Details Headers Plain text

The following email was sent to Dini Andiani from Kreano, Jurnal Matematika Kreatif-Inovatif regarding Visualization of Multivariable Calculus: Learning Needs Analysis for GeoGebra-Assisted Teaching Material Development.

You are receiving a copy of this notification because you are identified as an author of the submission. Any instructions in the message below are intended for the submitting author, Dini Andiani, and no action is required of you at this time.

Dear Dini Andiani,

Your submission Visualization of Multivariable Calculus: Learning Needs Analysis for GeoGebra-Assisted Teaching Material Development has been reviewed and we would like to encourage you to submit revisions that address the reviewers' comments. An editor will review these revisions and if they address the concerns adequately, your submission may be accepted for publication.

The reviewers' comments are included at the bottom of this email. Please respond to each point in the reviewers' comments and identify what changes you have made. If you find any of the reviewer's comments to be unjustified or inappropriate, please explain your perspective.

When you have completed your revisions, you can upload revised documents along with your response to the reviewers' comments at your submission dashboard. If you have been logged out, you can login again with the username diniandiani.

If you have any questions, please contact me from your submission dashboard.

We look forward to receiving your revised submission within 10 days.

Kind regards,

Amidi, S.Si., M.Pd.

The following comments were received from reviewers.

Reviewer 1:
Recommendation: Revisions Required

ABSTRACT

Minor Revision

Comment to Abstract

Please check the comment in article

INTRODUCTION

Minor Revision

Comment to Introduction

Please check the comment in article

METHOD

Minor Revision

Comment to method

Please check the comment in article

RESULT AND DISCUSSION

Minor Revision

Comment to Result and Discussion

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CONCLUSSION

Minor Revision

REFERENCES

- Please add, at least 15 references from SCOPUS, ACI, or International Journal.
- Please re-check your references based on your Mendeley/ Zotero/ reference manager.

GENERAL COMMENT TO AUTHOR

The length of the manuscript must be adjusted to the guidelines.

Reviewer 2:
Recommendation: Revisions Required

ABSTRACT

Major Revision

Comment to Abstract

INTRODUCTION

Major Revision

Comment to Introduction

METHOD

Major Revision. Need addtional Data.

Comment to method

RESULT AND DISCUSSION

Major Revision. Need additional data.

Comment to Result and Discussion

CONCLUSSION

Minor Revision

REFERENCES

- Please add, at least 15 references from SCOPUS, ACI, or International Journal.

GENERAL COMMENT TO AUTHOR

Reviewer1

Visualization of Multivariable Calculus: Learning Needs Analysis for GeoGebra-Assisted Teaching Material Development

Dini Andiani[1]*, Siti Dwi Rahayu Septiani[1], and Cecep Suwanda [1]

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Abstract

Students frequently encounter substantial challenges in studying Multivariable Calculus, especially when visualizing functions of several variables, interpreting partial derivatives, and applying the concept of extrema. This research investigates students' learning needs as the foundation for developing instructional materials supported by GeoGebra. Employing the Gravemeijer and Cobb design research framework within a qualitative descriptive approach, data were obtained from an online questionnaire administered to eight mathematics education students who had completed the Multivariable Calculus course. The analysis revealed that most participants reported moderate to high difficulty levels, particularly in visualization tasks and the comprehension of partial derivatives. In addition, students expressed a strong willingness to engage with GeoGebra-based resources, highlighting the relevance of three-dimensional visualization, interactive projects, and supplementary media such as video materials. Overall, the findings underscore the necessity of carefully designed learning environments that incorporate dynamic visualization tools to strengthen conceptual understanding and application.

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Keywords: Multivariable calculus; GeoGebra; learning needs; learning design; *design research*

Abstrak

Mahasiswa kerap menghadapi tantangan yang cukup besar dalam mempelajari Kalkulus Peubah Banyak, khususnya pada aspek memvisualisasikan fungsi multivariabel, menafsirkan turunan parsial, serta menerapkan konsep nilai ekstrem. Penelitian ini bertujuan untuk mengkaji kebutuhan belajar mahasiswa sebagai dasar pengembangan bahan ajar yang didukung oleh GeoGebra. Dengan menggunakan kerangka design research Gravemeijer dan Cobb dalam pendekatan deskriptif kualitatif, data dikumpulkan melalui kuesioner daring yang diisi oleh delapan mahasiswa pendidikan matematika yang telah menempuh mata kuliah Kalkulus Peubah Banyak. Hasil analisis menunjukkan bahwa sebagian besar responden melaporkan tingkat kesulitan sedang hingga tinggi, terutama dalam tugas-tugas visualisasi dan pemahaman konsep turunan parsial. Selain itu, mahasiswa menyatakan kesediaan yang kuat untuk menggunakan bahan ajar berbasis GeoGebra, dengan menekankan pentingnya visualisasi tiga dimensi, proyek interaktif, serta media pendukung seperti video pembelajaran. Secara keseluruhan, temuan penelitian ini menegaskan perlunya lingkungan belajar yang dirancang secara cermat dengan mengintegrasikan alat visualisasi dinamis untuk memperkuat pemahaman konseptual dan kemampuan aplikasi mahasiswa.

Mathematics Clasification: ---- 97D70 ----

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INTRODUCTION

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In an ideal situation, learning Multivariable Calculus in higher education should not only emphasize students' procedural abilities in performing mathematical calculations, but also foster deep conceptual understanding through mastery of various symbolic, numerical, graphical, and verbal representations as a coherent whole (Andiani, 2016, 2025; Andiani et al., 2020; Bedada & Machaba, 2022; Milenković & Vučićević, 2024). Students should be able to connect multivariable concepts such as functions of two variables, partial derivatives, gradients, multiple integrals, and extreme values, reflecting a meaningful understanding of advanced calculus (Bedada & Machaba, 2022).

Learning should also provide space for the development of three-dimensional visualization skills. Concepts such as contour planes, 3D surfaces, and gradients should be visualized interactively to enhance spatial understanding (Cheong et al., 2023, 2024; Herrera et al., 2024; Jones et al., 2022). Several studies have found that advanced visualization tools such as GeoGebra 3D or virtual reality can intuitively strengthen understanding of partial derivatives and multivariate change-law relationships.(Cheong et al., 2023, 2024; Jones et al., 2022; Sopiany & Rikayanti, 2018)

Furthermore, ideal learning prioritizes active and interactive learning experiences (Doolittle et al., 2023; Dubinsky & Hamid, 2024; Li & Ding, 2023; Martín-Alguacil & Avedillo, 2024; Ribeiro-Silva et al., 2022; Song & Cai, 2024). Students act as active explorers, rediscovering concepts through exploration, modeling, and discussion. *Active learning approaches* have improved conceptual understanding in multivariable calculus beyond traditional learning (Schoenherr et al., 2024).

In addition, the lecturer's role as a facilitator is essential in ideal conditions (Andiani, 2025). The facilitator should guide students to find conceptual understanding through reflection, not just provide procedures (Andiani, 2025). Assessment should also encompass mathematical representation and application skills, not just calculation skills (Andiani et al., 2020; Andiani, Ruhiyat, et al., 2024). However, this practice is often not optimally implemented, necessitating learning and assessment designs that better support higher-level mathematical competencies.

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In the practice of teaching Multivariable Calculus, there is a clear gap between the ideal conditions of mastery of inter-representational connections, 3D visualization skills, use of interactive media, and assessments that assess conceptual understanding, and the real conditions experienced by many students (Borji et al., 2022; Chang et al., 2024; Cheong et al., 2023; Herrera et al., 2024; Malone et al., 2023). First, although visual representations are considered crucial for building spatial intuition in multivariable topics, recent empirical studies report that students still experience significant difficulties in visualizing three-dimensional surfaces and relating symbolic changes to geometric changes, resulting in weak conceptual understanding (Borji et al., 2022).

Second, recent research shows that dynamic visualizations such as virtual reality and GeoGebra 3D can significantly improve spatial intuition and understanding of multivariable concepts.

Reviewer1

However, these tools have not been widely adopted in classroom practice, leaving many courses dominated by symbolic teaching and procedural exercises (Andiani, Nurlaelah, et al., 2024; Cheong et al., 2023; Herrera et al., 2024; Jones et al., 2022; Schoenherr et al., 2024). Dominating by symbolic teaching and procedural exercises creates a gap between the pedagogical potential of visual technologies and their implementation in the classroom (Cheong et al., 2023).

Third, recent meta-analyses and comparative studies indicate that learning with well-designed visual representations improves concept transfer and mathematical reasoning. However, its effectiveness depends heavily on the instructional design and accompanying scaffolding—aspects that are often overlooked when technology is introduced as a "demo" without a structured learning strategy (Malone et al., 2023; Nickl et al., 2024; Rexigel et al., 2024; Schoenherr et al., 2024; Wang et al., 2025).

Fourth, surveys and qualitative studies show that assessment aspects in many calculus courses are still oriented toward procedural skills (calculation), resulting in under-stimulation of learning outcomes that measure the representation, modeling, and application of multivariable concepts. This situation widens the gap between ideal learning outcomes and actual student outcomes (Cheong et al., 2023; Herrera et al., 2024; Schoenherr et al., 2024; Spencer-Tyree et al., 2024).

Fifth, the empirical findings are in line with the results of the preliminary questionnaire in this study which showed students' readiness to use GeoGebra-based teaching materials as well as a real need for 3D visualization, interactive projects, and multimedia supporting materials, empirical evidence that confirms the need for planned and iterative learning design (see the questionnaire results in the Methods & Results Chapter) (Abuhassna & Alnawajha, 2023; Andiani, 2025; Andiani, Nurlaelah, et al., 2024; Jong, 2023; Leung et al., 2024; Peters-Burton et al., 2024; Tinoca et al., 2022).

In bridging the gap between the ideal and the reality of learning Multivariable Calculus, educational technologies such as GeoGebra are highly relevant. GeoGebra provides an interactive visual environment that allows students to explore multivariable functions through dynamic graphs, parameter manipulation, and three-dimensional visualization. Recent research has shown that using GeoGebra can improve students' conceptual understanding and facilitate the integration of mathematical representations (Bedada & Machaba, 2022; Hevardani et al., 2025). In fact, integrating GeoGebra with active learning strategies has been shown to improve spatial representation skills and increase student learning engagement (Bedada & Machaba, 2022; Cheong et al., 2023; Herrera et al., 2024).

In addition to the technological aspect, Gravemeijer & Cobb's approach within the *design research framework* also makes an important contribution (Cela-Ranilla et al., 2025; Komatsu et al., 2024; Mackey et al., 2023; Prediger et al., 2015). This approach emphasizes the instructional development cycle through three stages: *preliminary design*, *teaching experiment*, and *retrospective analysis*. By placing the student's learning experience as the center of attention, this approach allows researchers and lecturers to design, implement, and revise teaching materials iteratively based on empirical data (Andiani, Nurlaelah, et al., 2024; Gravemeijer & Cobb, 2006). In the context of Multivariable Calculus, this framework encourages the creation of teaching materials that are not only technologically innovative but also rooted in the real needs of students, so that learning is more meaningful and sustainable (Schoenherr et al., 2024).

Previous research has highlighted the importance of representation and visualization in calculus learning, including using computer-based media to support understanding multivariable concepts (Herrera et al., 2024; Schoenherr et al., 2024; Wong et al., 2024). Bedada's (2022) study demonstrated that the use of GeoGebra can improve students' understanding of basic calculus concepts, while Cheong et al. (2023) demonstrated that the integration of virtual reality technology can strengthen the understanding of partial derivatives through dynamic visualization (Bedada & Machaba, 2022; Cheong et al., 2023). Furthermore, Schoenherr's (2024) meta-analysis confirmed that using pedagogically designed visualizations has significantly impacted mathematical learning outcomes. However, most of these studies focused on applying specific technologies or media without integrating a systematic theoretical framework in developing learning designs (Schoenherr et al., 2024).

On the other hand, the *design research approach* introduced by Gravemeijer & Cobb (2006) offers a methodological framework that focuses on an empirically data-driven instructional development cycle (Gravemeijer et al., 2006; Gravemeijer & Cobb, 2006). Although it has been widely applied in mathematics education research, its application in Multivariable Calculus with GeoGebra support is still relatively rare, especially in higher education in Indonesia. Thus, this study occupies an important position as an effort to fill the gap in previous research by integrating GeoGebra technology and the Gravemeijer & Cobb approach within a needs analysis framework. Giving an important position as an effort to fill the gap in previous research by integrating GeoGebra technology and the Gravemeijer & Cobb approach within a *needs analysis framework* makes this study not only a replication of previous studies, but also an innovative step in designing a Multivariable Calculus learning design that is rooted in the real needs of students.

Based on the description of ideal conditions, empirical gaps found through questionnaires, and previous research studies, it can be formulated that the main problems in learning Multivariable Calculus lie in students' limitations in visualizing multivariable concepts, minimal experience using interactive technologies such as GeoGebra, and the dominance of procedural learning that does not support conceptual understanding. This condition indicates the need for an innovative approach that not only presents visual media but is also developed through a methodological framework rooted in the real needs of students.

In line with the formulation of the problem, the objectives of this study are: (1) to identify the difficulties and learning needs of students in understanding the material of Multivariable Calculus, especially in the aspects of representation and visualization; (2) to analyze students' perceptions and readiness towards the use of GeoGebra-assisted teaching materials; and (3) to provide an empirical and conceptual basis for the development of the design of GeoGebra-based Multivariable Calculus teaching materials with the Gravemeijer & Cobb approach. Thus, this study is expected to contribute to designing more contextual, interactive instructions, in line with the demands of advanced mathematics learning in higher education.

This research is expected to contribute to three main areas. First, an empirical contribution in the form of data on students' learning needs in Multivariable Calculus highlights explicitly the difficulties of multivariable visualization, mathematical representation, and technology use. This data is important because most studies of multivariable calculus have emphasized procedural aspects rather than exploring students' real needs (Borji et al., 2022). Second, a practical contribution in the form of a conceptual basis for designing GeoGebra-assisted teaching materials that are appropriate to the context of Indonesian students, so that visual media is not only a supplement, but an integral part of the learning strategy (Bedada & Machaba, 2022; Hevardani et al., 2025). Third, a theoretical contribution through the integration of the Gravemeijer & Cobb approach in the context of multivariable calculus learning, which is still relatively rarely studied at the higher education level. This integration is expected to enrich the literature on the application of *design research* in mathematics education, while opening up space for further research in the form of implementation and validation of interactive teaching material designs.

METHOD

This research was conducted using a qualitative approach that focused on analyzing students' learning needs as the basis for developing teaching materials for Multivariable Calculus using GeoGebra. The qualitative approach was chosen because it can reveal the phenomena of students' difficulties, needs, and perceptions in greater depth, which cannot always be measured through statistics alone.

The research subjects were eight Mathematics students at a university in West Java who had taken the Multivariable Calculus course. They comprised six female and two male students, all in their fourth semester. This characteristic is important because all respondents had direct experience studying Multivariable Calculus, so their answers reflected the reality of actual learning needs.

The research instrument was an online questionnaire developed using Google Forms. The questionnaire included four main sections: respondent identity, learning experiences and needs, availability of GeoGebra-based teaching materials, and expectations regarding teaching material design. Each section included closed-ended questions with a rating scale or multiple-choice options and open-ended questions that allowed respondents to express their opinions more freely.

The data collection procedure involved distributing a questionnaire link to students who met the criteria. All respondents completed the questionnaire independently within one week. The collected data was then downloaded and extracted into a response table for easier organization. Data validity was maintained through clear instructions to respondents and by checking the completeness of responses before analysis.

The questionnaire data were analyzed using qualitative descriptive analysis techniques. Quantitative responses, in the form of rating scales, were processed into percentages to illustrate student difficulties or needs trends. Meanwhile, open-ended responses were analyzed using thematic categorization to identify general patterns related to students' learning experiences, obstacles, and expectations regarding GeoGebra-assisted learning materials.

In addition to descriptive analysis, this study also refers to the Gravemeijer & Cobb *design research framework*. This framework interprets the questionnaire findings as the initial stage in the research cycle: *preliminary design*. The results of the student learning needs analysis serve as the basis for formulating the initial design of teaching materials, which will later be tested in *the teaching experiment stage* and evaluated through *retrospective analysis*.

The first year of research was limited to needs analysis and initial design. This limitation was based on time and resource constraints and the fact that the Multivariable Calculus course is only taught once a year. Therefore, the initial phase of this research focused on exploring student difficulties and developing instructional materials responsive to their needs.

To maintain reliability, data analysis was conducted iteratively by reviewing the categories until consistency was achieved. Content validity was strengthened by comparing the questionnaire results with the findings of literature studies on multivariable calculus learning difficulties and the role of visual technology in mathematics education. In this way, empirical data from students could be positioned within a broader research framework.

Overall, this research method describes the students' conditions and provides a conceptual and practical basis for developing GeoGebra-assisted teaching materials for Calculus of Multiple Variables. Thus, it becomes an integral part of the *design research paradigm*, which emphasizes the close relationship between needs analysis, instructional design, and ongoing evaluation.

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RESULTS AND DISCUSSION

Results

Multivariable Calculus is a core course in Mathematics with a high level of complexity, primarily because it covers concepts such as functions of two variables, partial derivatives, multiple integrals, and extreme values. These materials require students to simultaneously master symbolic, numerical, graphical, and verbal representations and possess conceptual understanding that goes beyond procedural skills. However, recent studies, including one by Bedada (2022), indicate that students often struggle to connect mathematical symbols with geometric or spatial interpretations for multivariable concepts, resulting in a lack of in-depth conceptual understanding (Bedada & Machaba, 2022). This research makes it clear that learning needs analysis is not a secondary step but a foundation for designing more effective and targeted learning strategies.

Learning needs analysis is a diagnostic tool that reveals the gap between learning ideals and reality. Ideally, students should be able to visualize three-dimensional graphs, using symbolic, numerical, graphical, and verbal representations in an integrated manner. However, based on the data obtained, most students still excel only in procedural aspects performing calculations and following algorithmic steps while their visualization and representation skills remain weak. Weakness of visualization and representation skills is also supported by a recent study examining students' difficulties in optimizing multivariable functions, which found that poor visualization significantly contributes to misconceptions and obstacles in understanding functional change. (Mkhatshwa, 2023). Thus, needs analysis allows instructors to see which aspects must be realized in teaching materials to make responses to student difficulties more precise.

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In line with global trends in mathematics education, the importance of a needs-based approach is increasingly emphasized. Recent research shows that mathematics instruction tailored to students' real needs can increase their engagement, motivation, and conceptual understanding (Herrera et al., 2024). Therefore, needs analysis in CBT learning is not merely a technical first step, but a fundamental strategy for improving the quality of mathematics education in higher education.

Spatial visualization skills are one of the key aspects revealed in needs analysis. Students often struggle to visualize multivariate function surfaces or read contour curves, even though these skills are crucial for understanding partial derivatives and multiple integrals. Cheong et al. (2023) demonstrated that integrating visual technologies such as VR or GeoGebra 3D can help students develop spatial intuition. However, their effectiveness is only optimal if tailored to their needs (Cheong et al., 2023). Effectiveness reinforces the urgency of needs analysis as a basis for technology utilization.

In addition to the visualization aspect, the needs analysis revealed students' dependence on procedural learning and lectures. This condition is consistent with the results of research by Hevardani et al. (2025), who found that although GeoGebra has been used in calculus courses, its successful use is highly dependent on learning designs tailored to students' needs (Hevardani et al., 2025). Thus, the needs analysis not only serves to identify barriers but also directs relevant pedagogical strategies.

A needs analysis also provides crucial information regarding student perceptions and readiness to use learning technology. Recent qualitative studies confirm that students are more motivated when learning materials align with their learning styles and technological readiness (Schoenherr et al., 2024). Without a needs analysis, technology integration risks becoming merely an add-on activity without significantly impacting student understanding.

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From a methodological perspective, needs analysis aligns with Gravemeijer & Cobb's design research approach. The preliminary design stage of this research cycle emphasizes the importance of understanding student learning phenomena before designing learning interventions (Gravemeijer & Cobb, 2006). Therefore, needs analysis is not merely an administrative step, but an integral part of a research framework based on a cycle of design, experimentation, and retrospective analysis.

The needs analysis contributes to a practical dimension, generating concrete recommendations for developing teaching materials. For example, students in this study emphasized the need for teaching materials equipped with interactive 3D visualizations, GeoGebra-based mini-projects, and retrievable multimedia materials. This aspiration demonstrates that teaching materials relevant to students' needs will be more easily accepted and utilized in learning (Hevardani et al., 2025).

Thus, needs analysis in Calculus multivariable learning plays a dual role: strengthening the theoretical foundation by uncovering students' learning gaps, and providing practical input for direct input to design technology-based teaching materials. These findings reinforce the view that the success of mathematics learning innovations, particularly those supported by GeoGebra, is primarily determined by the extent to which the developed design aligns with students' needs. (Herrera et al., 2024; Schoenherr et al., 2024).

The results of the questionnaire analysis showed that the majority of students considered Multivariable Calculus to be a relatively challenging course. Seventy-five percent of respondents stated that the difficulty level was moderate to high. This finding reinforces the understanding that learning Multivariable Calculus requires a different approach than single-variable calculus.

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The most prominent learning difficulty was partial derivatives, with 50% of respondents stating this was a significant obstacle. This difficulty indicates that students still struggle to understand the concept of partial derivatives in the context of geometry and its application in multivariable calculations. Furthermore, 37.5% of students reported difficulty visualizing multivariable functions. This obstacle reflects students' weak spatial skills in depicting three-dimensional surfaces, contour curves, and gradients. This finding aligns with Cheong et al. (2023), who stated that visualization skills are a key factor in understanding multivariable calculus (Cheong et al., 2023).

Another difficulty identified was understanding limits and continuity in multivariable functions. Twenty-five percent of respondents experienced difficulties in this area, indicating that students still struggle to generalize the concept of limits from one variable to many. Addressing this obstacle is important because it forms the basis for understanding partial derivatives and multiple integrals. As many as 37.5% of students also experienced difficulty applying extreme values. Difficulty applying extreme values indicates that although they understand the calculation procedures, applying the concepts in a multivariable context remains a challenge. Borji (2022) emphasized that students often fall into proceduralism without understanding the conceptual meaning behind the calculations (Borji et al., 2022).

Table 1 provides a visual representation of students' difficulty levels in each Multivariable Calculus topic**.** It displays the percentage of students who encountered difficulties with partial derivatives, multivariable function visualization, limits and continuity, and extreme values. This diagram makes it easy for readers to see the differences in difficulty levels between aspects of the material at a glance.

Based on the findings above, Table 1 below summarizes the percentage of students experiencing difficulties in each aspect of the Multivariable Calculus material. This table provides a clear picture of the areas that most require learning intervention and the development of GeoGebra-based teaching materials.

Table 1. Percentage of Student Difficulties Based on Learning Aspects

Learning Aspects	Percentage of Students Experiencing Difficulties	Information
Partial derivatives	50%	The main obstacle is the difficulty in understanding geometric and applicative concepts.
Visualization of multivariable functions	37.5%	Weak in drawing 3D surfaces, contour curves, and gradients
Limit & continuity	25%	Difficulty generalizing the concept of limit from 1 variable to many variables
Extreme values	37.5%	Understand the procedure, but have difficulty applying the concept

87.5% of respondents cited lecturer explanations as the most helpful primary source for learning media preferences. This data confirms that lecturers remain central to CDE learning. However, this pattern also indicates a high reliance on conventional methods.

In addition to the role of lecturers, 75% of respondents considered learning videos helpful. This preference indicates that students value the flexibility of digital media, which allows for independent material review. According to Medina Herrera et al. (2024), interactive videos can strengthen students' cognitive engagement in learning complex concepts (Herrera et al., 2024).

75% of respondents also recognized the benefit of using visual applications like GeoGebra. This demonstrates that students see great potential in interactive media, although their use remains limited. These findings support the view that technology integration needs to be systematic and tailored to student needs.

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Based on the questionnaire results, Table 2 below summarizes the percentage of students who rated various learning media as the most helpful. This table provides a clear picture of the most effective media according to students' perceptions and serves as a reference in designing GeoGebra-based teaching materials.

Table 2. Percentage of Students Based on Learning Media

Instructional Media	Percentage of Students	Information
Lecturer's explanation	87.5%	Still, the primary source of learning
Learning videos	75%	Supports repetition and independent understanding
GeoGebra	75%	Interactive media, but the student experience is limited
Previous GeoGebra experience	62.5% never, 37.5% limited	Demonstrates the gap between technological potential and real-world experience.
Readiness for using GeoGebra-based teaching materials	100%	Strong signal of acceptance of technological innovation

However, students' experience with GeoGebra remains very low. Data shows that 62.5% of respondents have never used GeoGebra, while 37.5% have only experienced it to a limited extent. The few experiences in GeoGebra indicate a gap between the technology's potential and students'

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experiences. Despite limited experience, students had a positive perception of GeoGebra's effectiveness. Seventy-five percent of respondents agreed that GeoGebra could help them understand CDE material. The more agreement GeoGebra could help them understand CDE material demonstrates a willingness to adopt new technology if it proves beneficial. Student readiness is further strengthened by data showing that all respondents (100%) are willing to use GeoGebra-based teaching materials. Students' willingness indicates that technology-based innovations can be well-received if designed appropriately. Schoenherr (2024) emphasized that perceived usefulness is a greater determinant of technology acceptance than initial user experience (Schoenherr et al., 2024).

Students' expectations for learning materials varied, but most emphasized the need for interactive visualizations. Respondents suggested 3D graphics, GeoGebra-based mini-projects, and exploration activities that allow for active learning. In addition to visualization, students desire a connection between learning materials and real-world contexts. Several respondents emphasized connecting GeoGebra visualizations to everyday life applications or case studies. This aspiration aligns with Bedada (2022), who emphasized the need to contextualize mathematics learning in higher education (Bedada & Machaba, 2022).

Based on these findings, **Table 3** summarizes students' needs and expectations for the Multivariable Calculus teaching materials. This table presents aspects considered important by students, including the need for interactive visualizations, learning media, relevance to real-world contexts, and exploratory activities, thus forming the basis for designing GeoGebra-based teaching materials.

Table 3. Questionnaire Findings

Aspect	Questionnaire Findings	Implications for Teaching Materials
Visualization	37.5% difficulty with 3D visualization	Module with interactive 3D graphics
Interactive media	75% found GeoGebra useful	GeoGebra-based mini project
Learning activities	Students want active classes	Exploration activities, guided reinvention
Real context	Students want everyday life applications	Case studies related to KPB
Lecturer support	87.5% rely on lecturers	GeoGebra structured instructions & guides

Students also expect a variety of learning media, such as a combination of textbooks, instructional videos, and technology-based teaching materials. Using various learning media indicates a preference for a *blended learning approach* that offers flexibility in learning. Several respondents stated that lecturers' explanations must be more detailed and inclusive. They highlighted the differences in educational backgrounds in high schools (SMA/SMK/MA), which impact students' initial understanding. This situation underscores the need for initial assessments to adapt learning strategies.

The questionnaire results also indicated a need for more active learning. Respondents desired hands-on classroom practice to make learning more engaging and easier to understand. Medina Herrera et al. (2024) emphasized that active student engagement is closely linked to increased intrinsic motivation (Herrera et al., 2024).

Regarding learning resources, students emphasized the need for reference books and multimedia materials that can be reviewed. Students' willingness to consider learning resources indicates a need for learning resources that can be accessed independently outside class. The analysis also shows that while students value technology, they still need instructional support from their lecturers. Students' willingness to support from their lecturers indicates the importance of the lecturer's role as a facilitator, guiding technology use.

The questionnaire results revealed a gap between students' procedural and conceptual abilities. They were relatively capable of following calculation procedures, but still had difficulty understanding the underlying conceptual meaning. The affective aspect emerged from students' expectations for enjoyable and interactive learning. Several respondents emphasized that an active classroom atmosphere would make it easier to understand the material. Students' limited experience using GeoGebra presents both challenges and opportunities. If the teaching materials are well-designed, this limitation can be overcome through integrated step-by-step guides.

Student responses also emphasized the importance of a needs-based design approach. These empirical findings demonstrate that teaching materials development must begin with a concrete understanding of student barriers and preferences. Thus, the main results of this study include learning difficulties in representation, preferences for diverse learning media, limited experience but positive perceptions of GeoGebra, high readiness to adopt interactive teaching materials, and expectations for contextual and active learning.

These findings provide a strong foundation for developing GeoGebra-based Multivariable Calculus teaching materials within the Gravemeijer & Cobb framework. The needs analysis was conducted through a questionnaire to identify barriers and open up innovative design directions aligned with student needs. The findings of this questionnaire not only provide an empirical overview of student difficulties and needs but also serve as a starting point for applying Gravemeijer and Cobb's theoretical framework. In the *design research paradigm*, the preliminary design phase focuses on needs analysis, which is then used to design a learning prototype. Data on visualization difficulties, limited technological experience, and student expectations for interactive media directly serve as raw material for this initial design phase.

The Gravemeijer & Cobb framework emphasizes the close relationship between learning theory and practice. By analyzing the empirical gaps emerging from the questionnaire, researchers gained a sharper conceptual basis for developing GeoGebra-based teaching materials. For example, students' difficulties in understanding partial derivatives could be the focus of visual exploration in a prototype teaching material. At the same time, mini-project preferences could be integrated as learning activities that support active engagement. Furthermore, Gravemeijer and Cobb view *design research* as iterative, so each empirical finding is not just a final answer but input for the next development cycle. In the context of this research, the questionnaire results that revealed a gap between procedural and conceptual skills became reflection material to enrich the design of teaching materials that emphasize multiple representations.

The limited student experience with GeoGebra revealed through the questionnaire is also highly relevant within the *teaching experiment framework*. Gravemeijer & Cobb emphasize the importance of classroom experiments to test how students interact with the resulting designs. By recognizing from the outset that students are relatively new to GeoGebra, the design of teaching materials can include step-by-step guidance for more effective technology adoption. Furthermore, the questionnaire results demonstrate students' readiness to embrace technology-based innovation. Gravemeijer and Cobb believe this can be a key asset in developing *didactical phenomenology*, namely, understanding the learning phenomena that emerge when students encounter new mathematical representations. This readiness will be tested and further explored during the design implementation phase.

Students' expectations for interactive 3D visualizations, mini-projects, and multimedia materials align with Gravemeijer's principle of *guided reinvention*. Through designed exploratory activities, students receive information and can rediscover multivariable concepts through interaction with visual media and mathematical discussions. Thus, this study's theoretical contribution lies in strengthening the argument that the Gravemeijer & Cobb framework can be adapted for advanced calculus learning, which has been relatively understudied. Applying this framework in the context of CDE not only enriches the international literature but also broadens the scope of *design research applications* to the realm of multivariable calculus.

From a research perspective, the questionnaire data serve as the basis for the preliminary design phase in the second year. These results will be used to develop a prototype GeoGebra-based teaching material that targets explicitly students' key challenges, namely partial derivatives, extreme values, and visualization of multivariable functions. Thus, the research goes beyond describing needs and continues to design innovative solutions. The initial implementation phase (teaching experiment) will utilize these empirical findings as a reference. For example, the gap between procedural and conceptual skills will be tested through GeoGebra-based exploration activities. At the same time, student preferences for lecturer explanations will be considered when designing a combination of instructional strategies to ensure that the developed design remains contextual and aligned with the students' learning culture.

Next, the results of the initial implementation will be analyzed retrospectively to evaluate the effectiveness of the teaching materials. New findings from this phase will inform the next development cycle. Using an iterative approach, this research aims to produce increasingly mature teaching material designs over the years until they are ready for widespread implementation in the regular curriculum. Ultimately, this research provides empirical contributions in the form of student needs data and practical and theoretical contributions through the application of the Gravemeijer & Cobb framework. Furthermore, this research lays a strong foundation for a long-term research agenda to develop, implement, and validate GeoGebra-based Multivariable Calculus teaching materials, thereby improving the quality of advanced mathematics learning in higher education.

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Discussion

The findings of this study confirm that students still experience significant difficulties in understanding the Multivariable Calculus material, particularly in aspects of partial derivatives, extreme values, and the visualization of multivariable functions. These results align with Borji's (2022) study, which showed that students' primary difficulty lies in their limited ability to connect calculation procedures with the conceptual meaning behind mathematical symbols. (Borji et al., 2022). Thus, this study emphasizes the urgency of pedagogical interventions that strengthen conceptual representations.

The difficulty in three-dimensional visualization experienced by 37.5% of students is also consistent with the findings of Cheong et al. (2023), who emphasized that weak spatial skills can hinder the understanding of the concepts of gradients and surfaces of multivariable functions (Cheong et al., 2023). However, the results of this study add a new perspective that visualization barriers do not stand alone, but are closely related to a weak understanding of partial derivatives. Visualization barriers do not alone broaden the discussion on the interrelationships between concepts in multivariable calculus.

Students' preference for lecturer explanations (87.5%) demonstrates the dominance of traditional methods in KPB learning. However, the data also indicates students' openness to integrating digital media such as instructional videos (75%) and visual applications (75%). This finding is consistent with Hevardani et al. (2025), who found that combining traditional and technological

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Apa target jangka panjangnya?
Apakah akan menghasilkan modul cetak, platform digital, atau integrasi dalam kurikulum?

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strategies was more effective than using either alone. Thus, this study supports the direction of blended learning in the context of advanced mathematics learning.

Students' limited experience with GeoGebra (62.5% had never used it) contrasts with their positive perceptions of its potential. This finding aligns with research by Schoenherr (2024), which found that technology adoption in mathematics learning is determined more by perceived benefits than by prior experience (Schoenherr et al., 2024). In other words, even with minimal experience, students are still ready to embrace GeoGebra if tailored to their needs.

Students' expectations for interactive learning materials, such as 3D visualizations, mini-projects, and multimedia materials, support the findings of a systematic review by Medina Herrera et al. (2024), which emphasized that interactive technology can enhance cognitive engagement and learning motivation (Herrera et al., 2024). This study adds a local dimension, as students desire visualizations and contextualized and independently retrievable learning.

This research strengthens previous studies and makes a new contribution to the literature by integrating the needs analysis results into the Gravemeijer & Cobb framework. Previous research has focused more on student difficulties or media effectiveness separately. In this study, empirical data on student needs serve as the basis for the preliminary design phase, creating a direct bridge between instructional design theory and practice.

Furthermore, this study's findings pave the way for the development of more targeted GeoGebra-based KPB teaching materials. Difficulties in partial derivatives, for example, can be addressed with GeoGebra-based gradient visualization activities. Similarly, difficulties with extreme values can be addressed through interactive simulations of multivariable functions. This approach also tests the validity of Gravemeijer's *guided reinvention principle* in the context of advanced calculus learning, a previously understudied area.

The novelty of this research lies in integrating student needs analysis in learning Multivariable Calculus with the Gravemeijer & Cobb *design research framework*. Previous studies have focused on student learning difficulties (Borji, 2022) or the effectiveness of visual media (Cheong et al., 2023; Medina Herrera et al., 2024), but rarely link empirical data on student needs directly to the *preliminary design stage* of teaching materials (Borji et al., 2022; Cheong et al., 2023; Herrera et al., 2024). Thus, this research offers a new contribution in the form of a bridge between empirical findings and a theoretical framework that can serve as a systematic foundation for developing, implementing, and validating GeoGebra-based teaching materials in the context of multivariable calculus in Indonesian universities.

Implication of Research

The findings of this study have important implications in three main domains. Theoretically, these results extend the application of the Gravemeijer & Cobb framework in learning Multivariable Calculus, confirming that needs analysis can serve as a foundation for *preliminary design* relevant to students' real-world difficulties. Practically, the questionnaire data indicate the need to develop GeoGebra-based teaching materials that provide interactive visualizations and facilitate exploration activities, mini-projects, and links to real-world applications. This study provides an initial foundation for further research cycles in the form of implementation (*teaching experiments*) and retrospective analysis, which are expected to produce valid, effective, and generalizable teaching materials for advanced mathematics learning in higher education.

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Limitation

This study has several limitations that should be noted. First, there were only eight respondents, so the data obtained is not representative of the broader student population. Second, the online questionnaire instrument provided a general overview of students' difficulties, perceptions, and expectations. However, it did not delve deeply into their learning experiences through interviews or direct observation. Third, this study is only at the needs analysis stage, so the effectiveness of the intervention in the form of GeoGebra-based teaching materials cannot yet be verified. These limitations open up opportunities for further research involving larger samples, incorporating qualitative data collection methods, and testing the validity of the learning design through classroom experiments and retrospective analysis.

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CONCLUSION

This study successfully identified students' main difficulties in learning Multivariable Calculus: limitations in understanding partial derivatives, extreme values, and the visualization of multivariable functions. The questionnaire results also showed that although students still rely heavily on traditional methods such as lecturer explanations, they have a positive perception and high readiness for using interactive technologies such as GeoGebra. Students' expectations for 3D visualization, mini-projects, and multimedia materials reinforce the urgency of developing technology-based teaching materials that are contextual and interactive. These findings are then positioned within the Gravemeijer & Cobb framework, emphasizing the importance of needs analysis as a basis for preliminary design. Thus, this study provides empirical contributions in the form of student needs data and practical and theoretical contributions to the development of more meaningful and sustainable Multivariable Calculus instruction.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the students who actively participated in completing the questionnaire, enabling this learning needs analysis to be successfully conducted. Appreciation is also extended to the Mathematics Study Program, Faculty of Mathematics and Natural Sciences, Universitas Bale Bandung, for providing facilities and access to the research. Special acknowledgment is given to the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek) through its Research and Community Service Information Base (BIMA) program, the official platform supporting research proposals and reporting. Access to BIMA has streamlined the administrative process for this research and facilitated systematic data management. The authors thank their colleagues for constructive feedback, methodological suggestions, and encouragement while preparing this manuscript. The support and collaboration of all parties will likely contribute positively to the advancement of calculus education in Indonesia.

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Reviewer2

Visualization of Multivariable Calculus: Learning Needs Analysis for GeoGebra-Assisted Teaching Material Development

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Abstract

Students frequently encounter substantial challenges in studying Multivariable Calculus, especially when visualizing functions of several variables, interpreting partial derivatives, and applying the concept of extrema. This research investigates students' learning needs as the foundation for developing instructional materials supported by GeoGebra. Employing the Gravemeijer and Cobb design research framework within a qualitative descriptive approach, data were obtained from an online questionnaire administered to eight mathematics education students who had completed the Multivariable Calculus course. The analysis revealed that most participants reported moderate to high difficulty levels, particularly in visualization tasks and the comprehension of partial derivatives. In addition, students expressed a strong willingness to engage with GeoGebra-based resources, highlighting the relevance of three-dimensional visualization, interactive projects, and supplementary media such as video materials. Overall, the findings underscore the necessity of carefully designed learning environments that incorporate dynamic visualization tools to strengthen conceptual understanding and application.

Commented [Author1]: Tambahkan 1 kalimat di awal yang menegaskan gap penelitian

Commented [Author2]: Perjelas bagaimana kerangka Gravemeijer & Cobb diadaptasi dalam penelitian ini, terutama tahap yang dilakukan

Commented [Author3]: Lengkapi hasil dengan proporsi atau kecenderungan lebih detail untuk memperkuat klaim, misalnya 6 dari 8 mahasiswa melaporkan kesulitan pada visualisasi.

Commented [Author4]: Kurang diarahkan ke langkah nyata (misalnya hasil ini menjadi dasar rancangan bahan ajar interaktif berbasis GeoGebra untuk topik turunan parsial dan nilai ekstrem)

Keywords: Multivariable calculus; GeoGebra; learning needs; learning design; *design research*

Abstrak

Mahasiswa kerap menghadapi tantangan yang cukup besar dalam mempelajari Kalkulus Peubah Banyak, khususnya pada aspek memvisualisasikan fungsi multivariabel, menafsirkan turunan parsial, serta menerapkan konsep nilai ekstrem. Penelitian ini bertujuan untuk mengkaji kebutuhan belajar mahasiswa sebagai dasar pengembangan bahan ajar yang didukung oleh GeoGebra. Dengan menggunakan kerangka design research Gravemeijer dan Cobb dalam pendekatan deskriptif kualitatif, data dikumpulkan melalui kuesioner daring yang diisi oleh delapan mahasiswa pendidikan matematika yang telah menempuh mata kuliah Kalkulus Peubah Banyak. Hasil analisis menunjukkan bahwa sebagian besar responden melaporkan tingkat kesulitan sedang hingga tinggi, terutama dalam tugas-tugas visualisasi dan pemahaman konsep turunan parsial. Selain itu, mahasiswa menyatakan kesediaan yang kuat untuk menggunakan bahan ajar berbasis GeoGebra, dengan menekankan pentingnya visualisasi tiga dimensi, proyek interaktif, serta media pendukung seperti video pembelajaran. Secara keseluruhan, temuan penelitian ini menegaskan perlunya lingkungan belajar yang dirancang secara cermat dengan mengintegrasikan alat visualisasi dinamis untuk memperkuat pemahaman konseptual dan kemampuan aplikasi mahasiswa.

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Mathematics Clasification: ---- 97D70 ----

Please check Mathematics Clasification here:

https://mathscinet.ams.org/msc/msc2010.html?t=97-XX&s=&btn=Search&ls=s

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INTRODUCTION

Commented [Author6]: Perhatikan! Panjang naskah adalah 6000-7000 kata untuk isi naskah (Judul, abstrak, dan referensi tidak termasuk). Silakan sesuaikan.

In an ideal situation, learning Multivariable Calculus in higher education should not only emphasize students' procedural abilities in performing mathematical calculations, but also foster deep conceptual understanding through mastery of various symbolic, numerical, graphical, and verbal representations as a coherent whole (Andiani, 2016, 2025; Andiani et al., 2020; Bedada & Machaba, 2022; Milenković & Vučićević, 2024). Students should be able to connect multivariable concepts such as functions of two variables, partial derivatives, gradients, multiple integrals, and extreme values, reflecting a meaningful understanding of advanced calculus (Bedada & Machaba, 2022).

Learning should also provide space for the development of three-dimensional visualization skills. Concepts such as contour planes, 3D surfaces, and gradients should be visualized interactively to enhance spatial understanding (Cheong et al., 2023, 2024; Herrera et al., 2024; Jones et al., 2022). Several studies have found that advanced visualization tools such as GeoGebra 3D or virtual reality can intuitively strengthen understanding of partial derivatives and multivariate change-law relationships.(Cheong et al., 2023, 2024; Jones et al., 2022; Sopiany & Rikayanti, 2018)

Furthermore, ideal learning prioritizes active and interactive learning experiences (Doolittle et al., 2023; Dubinsky & Hamid, 2024; Li & Ding, 2023; Martín-Alguacil & Avedillo, 2024; Ribeiro-Silva et al., 2022; Song & Cai, 2024). Students act as active explorers, rediscovering concepts through exploration, modeling, and discussion. *Active learning approaches* have improved conceptual understanding in multivariable calculus beyond traditional learning (Schoenherr et al., 2024).

In addition, the lecturer's role as a facilitator is essential in ideal conditions (Andiani, 2025). The facilitator should guide students to find conceptual understanding through reflection, not just provide procedures (Andiani, 2025). Assessment should also encompass mathematical representation and application skills, not just calculation skills (Andiani et al., 2020; Andiani, Ruhiyat, et al., 2024). However, this practice is often not optimally implemented, necessitating learning and assessment designs that better support higher-level mathematical competencies.

In the practice of teaching Multivariable Calculus, there is a clear gap between the ideal conditions of mastery of inter-representational connections, 3D visualization skills, use of interactive media, and assessments that assess conceptual understanding, and the real conditions experienced by many students (Borji et al., 2022; Chang et al., 2024; Cheong et al., 2023; Herrera et al., 2024; Malone et al., 2023). First, although visual representations are considered crucial for building spatial intuition in multivariable topics, recent empirical studies report that students still experience significant difficulties in visualizing three-dimensional surfaces and relating symbolic changes to geometric changes, resulting in weak conceptual understanding (Borji et al., 2022).

Second, recent research shows that dynamic visualizations such as virtual reality and GeoGebra 3D can significantly improve spatial intuition and understanding of multivariable concepts.

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However, these tools have not been widely adopted in classroom practice, leaving many courses dominated by symbolic teaching and procedural exercises (Andiani, Nurlaelah, et al., 2024; Cheong et al., 2023; Herrera et al., 2024; Jones et al., 2022; Schoenherr et al., 2024). Dominating by symbolic teaching and procedural exercises creates a gap between the pedagogical potential of visual technologies and their implementation in the classroom (Cheong et al., 2023).

Third, recent meta-analyses and comparative studies indicate that learning with well-designed visual representations improves concept transfer and mathematical reasoning. However, its effectiveness depends heavily on the instructional design and accompanying scaffolding—aspects that are often overlooked when technology is introduced as a "demo" without a structured learning strategy (Malone et al., 2023; Nickl et al., 2024; Rexigel et al., 2024; Schoenherr et al., 2024; Wang et al., 2025).

Fourth, surveys and qualitative studies show that assessment aspects in many calculus courses are still oriented toward procedural skills (calculation), resulting in under-stimulation of learning outcomes that measure the representation, modeling, and application of multivariable concepts. This situation widens the gap between ideal learning outcomes and actual student outcomes (Cheong et al., 2023; Herrera et al., 2024; Schoenherr et al., 2024; Spencer-Tyree et al., 2024).

Fifth, the empirical findings are in line with the results of the preliminary questionnaire in this study which showed students' readiness to use GeoGebra-based teaching materials as well as a real need for 3D visualization, interactive projects, and multimedia supporting materials, empirical evidence that confirms the need for planned and iterative learning design (see the questionnaire results in the Methods & Results Chapter) (Abuhassna & Alnawajha, 2023; Andiani, 2025; Andiani, Nurlaelah, et al., 2024; Jong, 2023; Leung et al., 2024; Peters-Burton et al., 2024; Tinoca et al., 2022).

Commented [Author7]: Bangun jembatan narasi yang lebih mulus antara hasil studi terdahulu dan temuan awal penelitian (preliminary questionnaire)

In bridging the gap between the ideal and the reality of learning Multivariable Calculus, educational technologies such as GeoGebra are highly relevant. GeoGebra provides an interactive visual environment that allows students to explore multivariable functions through dynamic graphs, parameter manipulation, and three-dimensional visualization. Recent research has shown that using GeoGebra can improve students' conceptual understanding and facilitate the integration of mathematical representations (Bedada & Machaba, 2022; Hevardani et al., 2025). In fact, integrating GeoGebra with active learning strategies has been shown to improve spatial representation skills and increase student learning engagement (Bedada & Machaba, 2022; Cheong et al., 2023; Herrera et al., 2024).

In addition to the technological aspect, Gravemeijer & Cobb's approach within the *design research framework* also makes an important contribution (Cela-Ranilla et al., 2025; Komatsu et al., 2024; Mackey et al., 2023; Prediger et al., 2015). This approach emphasizes the instructional development cycle through three stages: *preliminary design*, *teaching experiment*, and *retrospective analysis*. By placing the student's learning experience as the center of attention, this approach allows researchers and lecturers to design, implement, and revise teaching materials iteratively based on empirical data (Andiani, Nurlaelah, et al., 2024; Gravemeijer & Cobb, 2006). In the context of Multivariable Calculus, this framework encourages the creation of teaching materials that are not only technologically innovative but also rooted in the real needs of students, so that learning is more meaningful and sustainable (Schoenherr et al., 2024).

Previous research has highlighted the importance of representation and visualization in calculus learning, including using computer-based media to support understanding multivariable concepts (Herrera et al., 2024; Schoenherr et al., 2024; Wong et al., 2024). Bedada's (2022) study demonstrated that the use of GeoGebra can improve students' understanding of basic calculus concepts, while Cheong et al. (2023) demonstrated that the integration of virtual reality technology can strengthen the understanding of partial derivatives through dynamic visualization (Bedada & Machaba, 2022; Cheong et al., 2023). Furthermore, Schoenherr's (2024) meta-analysis confirmed that using pedagogically designed visualizations has significantly impacted mathematical learning outcomes. However, most of these studies focused on applying specific technologies or media without integrating a systematic theoretical framework in developing learning designs (Schoenherr et al., 2024).

On the other hand, the *design research approach* introduced by Gravemeijer & Cobb (2006) offers a methodological framework that focuses on an empirically data-driven instructional development cycle (Gravemeijer et al., 2006; Gravemeijer & Cobb, 2006). Although it has been widely applied in mathematics education research, its application in Multivariable Calculus with GeoGebra support is still relatively rare, especially in higher education in Indonesia. Thus, this study occupies an important position as an effort to fill the gap in previous research by integrating GeoGebra technology and the Gravemeijer & Cobb approach within a needs analysis framework. Giving an important position as an effort to fill the gap in previous research by integrating GeoGebra technology and the Gravemeijer & Cobb approach within a *needs analysis framework* makes this study not only a replication of previous studies, but also an innovative step in designing a Multivariable Calculus learning design that is rooted in the real needs of students.

Commented [Author8]: Tegaskan, penelitian terdahulu hanya fokus pada media (GeoGebra/VR) atau hanya design research, penelitian ini menggabungkan keduanya

Based on the description of ideal conditions, empirical gaps found through questionnaires, and previous research studies, it can be formulated that the main problems in learning Multivariable Calculus lie in students' limitations in visualizing multivariable concepts, minimal experience using interactive technologies such as GeoGebra, and the dominance of procedural learning that does not support conceptual understanding. This condition indicates the need for an innovative approach that not only presents visual media but is also developed through a methodological framework rooted in the real needs of students.

In line with the formulation of the problem, the objectives of this study are: (1) to identify the difficulties and learning needs of students in understanding the material of Multivariable Calculus, especially in the aspects of representation and visualization; (2) to analyze students' perceptions and readiness towards the use of GeoGebra-assisted teaching materials; and (3) to provide an empirical and conceptual basis for the development of the design of GeoGebra-based Multivariable Calculus teaching materials with the Gravemeijer & Cobb approach. Thus, this study is expected to contribute to designing more contextual, interactive instructions, in line with the demands of advanced mathematics learning in higher education.

Commented [Author9]: Hubungkan tujuan dengan gap lebih eksplisit, misalnya tambahkan pengantar: 'Berdasarkan gap dan rumusan masalah yang telah dijelaskan, penelitian ini bertujuan ...'

This research is expected to contribute to three main areas. First, an empirical contribution in the form of data on students' learning needs in Multivariable Calculus highlights explicitly the difficulties of multivariable visualization, mathematical representation, and technology use. This data is important because most studies of multivariable calculus have emphasized procedural aspects rather than exploring students' real needs (Borji et al., 2022). Second, a practical contribution in the form of a conceptual basis for designing GeoGebra-assisted teaching materials that are appropriate to the context of Indonesian students, so that visual media is not only a supplement, but an integral part of the learning strategy (Bedada & Machaba, 2022; Hevardani et al., 2025). Third, a theoretical contribution through the integration of the Gravemeijer & Cobb approach in the context of multivariable calculus learning, which is still relatively rarely studied at the higher education level. This integration is expected to enrich the literature on the application of *design research* in mathematics education, while opening up space for further research in the form of implementation and validation of interactive teaching material designs.

Commented [Author10]: Buatlah uraian kontribusi agar lebih ringkas, fokus pada inti (empiris, praktis, teoretis)

METHOD

This research was conducted using a qualitative approach that focused on analyzing students' learning needs as the basis for developing teaching materials for Multivariable Calculus using GeoGebra. The qualitative approach was chosen because it can reveal the phenomena of students' difficulties, needs, and perceptions in greater depth, which cannot always be measured through statistics alone.

Commented [Author11]: Perjelas hubungan antara pendekatan kualitatif dengan design research. Apakah penelitian ini murni studi kebutuhan (preliminary design) dalam kerangka design research, atau kualitatif deskriptif yang memakai design research sebagai acuan teoretis?

The research subjects were eight Mathematics students at a university in West Java who had taken the Multivariable Calculus course. They comprised six female and two male students, all in their fourth semester. This characteristic is important because all respondents had direct experience studying Multivariable Calculus, so their answers reflected the reality of actual learning needs.

Commented [Author12]: Jelaskan teknik pemilihan subyek. Mengapa hanya 8 dari seluruh mahasiswa semester 4?

The research instrument was an online questionnaire developed using Google Forms. The questionnaire included four main sections: respondent identity, learning experiences and needs, availability of GeoGebra-based teaching materials, and expectations regarding teaching material design. Each section included closed-ended questions with a rating scale or multiple-choice options and open-ended questions that allowed respondents to express their opinions more freely.

Commented [Author13]: Apakah kuesioner diuji coba? apakah ada expert judgment untuk memastikan butir pertanyaan sesuai indikator? Silakan tambahkan informasi validasi instrumen.

The data collection procedure involved distributing a questionnaire link to students who met the criteria. All respondents completed the questionnaire independently within one week. The collected data was then downloaded and extracted into a response table for easier organization. Data validity was maintained through clear instructions to respondents and by checking the completeness of responses before analysis.

The questionnaire data were analyzed using qualitative descriptive analysis techniques. Quantitative responses, in the form of rating scales, were processed into percentages to illustrate student difficulties or needs trends. Meanwhile, open-ended responses were analyzed using thematic categorization to identify general patterns related to students' learning experiences, obstacles, and expectations regarding GeoGebra-assisted learning materials.

Commented [Author14]: Sebutkan contoh kategori tematik yang muncul dari open-ended responses

In addition to descriptive analysis, this study also refers to the Gravemeijer & Cobb *design research framework*. This framework interprets the questionnaire findings as the initial stage in the research cycle: *preliminary design*. The results of the student learning needs analysis serve as the basis for formulating the initial design of teaching materials, which will later be tested in *the teaching experiment stage* and evaluated through *retrospective analysis*.

The first year of research was limited to needs analysis and initial design. This limitation was based on time and resource constraints and the fact that the Multivariable Calculus course is only taught once a year. Therefore, the initial phase of this research focused on exploring student difficulties and developing instructional materials responsive to their needs.

Commented [Author15]: Tegaskan bahwa hasil analisis kebutuhan ini diposisikan sebagai preliminary design dalam Gravemeijer & Cobb, bukan sekadar deskriptif

To maintain reliability, data analysis was conducted iteratively by reviewing the categories until consistency was achieved. Content validity was strengthened by comparing the questionnaire results with the findings of literature studies on multivariable calculus learning difficulties and the role of visual technology in mathematics education. In this way, empirical data from students could be positioned within a broader research framework.

Overall, this research method describes the students' conditions and provides a conceptual and practical basis for developing GeoGebra-assisted teaching materials for Calculus of Multiple Variables. Thus, it becomes an integral part of the *design research paradigm*, which emphasizes the close relationship between needs analysis, instructional design, and ongoing evaluation.

RESULTS AND DISCUSSION

Results

Multivariable Calculus is a core course in Mathematics with a high level of complexity, primarily because it covers concepts such as functions of two variables, partial derivatives, multiple integrals, and extreme values. These materials require students to simultaneously master symbolic, numerical, graphical, and verbal representations and possess conceptual understanding that goes beyond procedural skills. However, recent studies, including one by Bedada (2022), indicate that students often struggle to connect mathematical symbols with geometric or spatial interpretations for multivariable concepts, resulting in a lack of in-depth conceptual understanding (Bedada & Machaba, 2022). This research makes it clear that learning needs analysis is not a secondary step but a foundation for designing more effective and targeted learning strategies.

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Learning needs analysis is a diagnostic tool that reveals the gap between learning ideals and reality. Ideally, students should be able to visualize three-dimensional graphs, using symbolic, numerical, graphical, and verbal representations in an integrated manner. However, based on the data obtained, most students still excel only in procedural aspects performing calculations and following algorithmic steps while their visualization and representation skills remain weak. Weakness of visualization and representation skills is also supported by a recent study examining students' difficulties in optimizing multivariable functions, which found that poor visualization significantly contributes to misconceptions and obstacles in understanding functional change. (Mkhatshwa, 2023). Thus, needs analysis allows instructors to see which aspects must be realized in teaching materials to make responses to student difficulties more precise.

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In line with global trends in mathematics education, the importance of a needs-based approach is increasingly emphasized. Recent research shows that mathematics instruction tailored to students' real needs can increase their engagement, motivation, and conceptual understanding (Herrera et al., 2024). Therefore, needs analysis in CBT learning is not merely a technical first step, but a fundamental strategy for improving the quality of mathematics education in higher education.

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Spatial visualization skills are one of the key aspects revealed in needs analysis. Students often struggle to visualize multivariate function surfaces or read contour curves, even though these skills are crucial for understanding partial derivatives and multiple integrals. Cheong et al. (2023) demonstrated that integrating visual technologies such as VR or GeoGebra 3D can help students develop spatial intuition. However, their effectiveness is only optimal if tailored to their needs (Cheong et al., 2023). Effectiveness reinforces the urgency of needs analysis as a basis for technology utilization.

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In addition to the visualization aspect, the needs analysis revealed students' dependence on procedural learning and lectures. This condition is consistent with the results of research by Hevardani et al. (2025), who found that although GeoGebra has been used in calculus courses, its successful use is highly dependent on learning designs tailored to students' needs (Hevardani et al., 2025). Thus, the needs analysis not only serves to identify barriers but also directs relevant pedagogical strategies.

A needs analysis also provides crucial information regarding student perceptions and readiness to use learning technology. Recent qualitative studies confirm that students are more motivated when learning materials align with their learning styles and technological readiness (Schoenherr et al., 2024). Without a needs analysis, technology integration risks becoming merely an add-on activity without significantly impacting student understanding.

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From a methodological perspective, needs analysis aligns with Gravemeijer & Cobb's design research approach. The preliminary design stage of this research cycle emphasizes the importance of understanding student learning phenomena before designing learning interventions (Gravemeijer & Cobb, 2006). Therefore, needs analysis is not merely an administrative step, but an integral part of a research framework based on a cycle of design, experimentation, and retrospective analysis.

The needs analysis contributes to a practical dimension, generating concrete recommendations for developing teaching materials. For example, students in this study emphasized the need for teaching materials equipped with interactive 3D visualizations, GeoGebra-based mini-projects, and retrievable multimedia materials. This aspiration demonstrates that teaching materials relevant to students' needs will be more easily accepted and utilized in learning (Hevardani et al., 2025).

Thus, needs analysis in Calculus multivariable learning plays a dual role: strengthening the theoretical foundation by uncovering students' learning gaps, and providing practical input for direct input to design technology-based teaching materials. These findings reinforce the view that the success of mathematics learning innovations, particularly those supported by GeoGebra, is primarily determined by the extent to which the developed design aligns with students' needs. (Herrera et al., 2024; Schoenherr et al., 2024).

The results of the questionnaire analysis showed that the majority of students considered Multivariable Calculus to be a relatively challenging course. Seventy-five percent of respondents stated that the difficulty level was moderate to high. This finding reinforces the understanding that learning Multivariable Calculus requires a different approach than single-variable calculus.

The most prominent learning difficulty was partial derivatives, with 50% of respondents stating this was a significant obstacle. This difficulty indicates that students still struggle to understand the concept of partial derivatives in the context of geometry and its application in multivariable calculations. Furthermore, 37.5% of students reported difficulty visualizing multivariable functions. This obstacle reflects students' weak spatial skills in depicting three-dimensional surfaces, contour curves, and gradients. This finding aligns with Cheong et al. (2023), who stated that visualization skills are a key factor in understanding multivariable calculus (Cheong et al., 2023).

Another difficulty identified was understanding limits and continuity in multivariable functions. Twenty-five percent of respondents experienced difficulties in this area, indicating that students still struggle to generalize the concept of limits from one variable to many. Addressing this obstacle is important because it forms the basis for understanding partial derivatives and multiple integrals. As many as 37.5% of students also experienced difficulty applying extreme values. Difficulty applying extreme values indicates that although they understand the calculation procedures, applying the concepts in a multivariable context remains a challenge. Borji (2022) emphasized that students often fall into proceduralism without understanding the conceptual meaning behind the calculations (Borji et al., 2022).

Table 1 provides a visual representation of students' difficulty levels in each Multivariable Calculus topic**.** It displays the percentage of students who encountered difficulties with partial derivatives, multivariable function visualization, limits and continuity, and extreme values. This diagram makes it easy for readers to see the differences in difficulty levels between aspects of the material at a glance.

Based on the findings above, Table 1 below summarizes the percentage of students experiencing difficulties in each aspect of the Multivariable Calculus material. This table provides a clear picture of the areas that most require learning intervention and the development of GeoGebra-based teaching materials.

Table 1. Percentage of Student Difficulties Based on Learning Aspects

Learning Aspects	Percentage of Students Experiencing Difficulties	Information
Partial derivatives	50%	The main obstacle is the difficulty in understanding geometric and applicative concepts.
Visualization of multivariable functions	37.5%	Weak in drawing 3D surfaces, contour curves, and gradients
Limit & continuity	25%	Difficulty generalizing the concept of limit from 1 variable to many variables
Extreme values	37.5%	Understand the procedure, but have difficulty applying the concept

87.5% of respondents cited lecturer explanations as the most helpful primary source for learning media preferences. This data confirms that lecturers remain central to CDE learning. However, this pattern also indicates a high reliance on conventional methods.

In addition to the role of lecturers, 75% of respondents considered learning videos helpful. This preference indicates that students value the flexibility of digital media, which allows for independent material review. According to Medina Herrera et al. (2024), interactive videos can strengthen students' cognitive engagement in learning complex concepts (Herrera et al., 2024).

75% of respondents also recognized the benefit of using visual applications like GeoGebra. This demonstrates that students see great potential in interactive media, although their use remains limited. These findings support the view that technology integration needs to be systematic and tailored to student needs.

Based on the questionnaire results, Table 2 below summarizes the percentage of students who rated various learning media as the most helpful. This table provides a clear picture of the most effective media according to students' perceptions and serves as a reference in designing GeoGebra-based teaching materials.

Table 2. Percentage of Students Based on Learning Media

Instructional Media	Percentage of Students	Information
Lecturer's explanation	87.5%	Still, the primary source of learning
Learning videos	75%	Supports repetition and independent understanding
GeoGebra	75%	Interactive media, but the student experience is limited
Previous GeoGebra experience	62.5% never, 37.5% limited	Demonstrates the gap between technological potential and real-world experience.
Readiness for using GeoGebra-based teaching materials	100%	Strong signal of acceptance of technological innovation

However, students' experience with GeoGebra remains very low. Data shows that 62.5% of respondents have never used GeoGebra, while 37.5% have only experienced it to a limited extent. The few experiences in GeoGebra indicate a gap between the technology's potential and students' experiences. Despite limited experience, students had a positive perception of GeoGebra's effectiveness. Seventy-five percent of respondents agreed that GeoGebra could help them understand CDE material. The more agreement GeoGebra could help them understand CDE material demonstrates a willingness to adopt new technology if it proves beneficial. Student readiness is further strengthened by data showing that all respondents (100%) are willing to use GeoGebra-based teaching materials. Students' willingness indicates that technology-based innovations can be well-received if designed appropriately. Schoenherr (2024) emphasized that perceived usefulness is a greater determinant of technology acceptance than initial user experience (Schoenherr et al., 2024).

Students' expectations for learning materials varied, but most emphasized the need for interactive visualizations. Respondents suggested 3D graphics, GeoGebra-based mini-projects, and exploration activities that allow for active learning. In addition to visualization, students desire a connection between learning materials and real-world contexts. Several respondents emphasized connecting GeoGebra visualizations to everyday life applications or case studies. This aspiration aligns with Bedada (2022), who emphasized the need to contextualize mathematics learning in higher education (Bedada & Machaba, 2022).

Based on these findings, **Table 3** summarizes students' needs and expectations for the Multivariable Calculus teaching materials. This table presents aspects considered important by students, including the need for interactive visualizations, learning media, relevance to real-world contexts, and exploratory activities, thus forming the basis for designing GeoGebra-based teaching materials.

Table 3. Questionnaire Findings

Aspect	Questionnaire Findings	Implications for Teaching Materials
Visualization	37.5% difficulty with 3D visualization	Module with interactive 3D graphics
Interactive media	75% found GeoGebra useful	GeoGebra-based mini project
Learning activities	Students want active classes	Exploration activities, guided reinvention
Real context	Students want everyday life applications	Case studies related to KPB
Lecturer support	87.5% rely on lecturers	GeoGebra structured instructions & guides

Students also expect a variety of learning media, such as a combination of textbooks, instructional videos, and technology-based teaching materials. Using various learning media indicates a preference for a *blended learning approach* that offers flexibility in learning. Several respondents stated that lecturers' explanations must be more detailed and inclusive. They highlighted the differences in educational backgrounds in high schools (SMA/SMK/MA), which impact students' initial understanding. This situation underscores the need for initial assessments to adapt learning strategies.

The questionnaire results also indicated a need for more active learning. Respondents desired hands-on classroom practice to make learning more engaging and easier to understand. Medina Herrera et al. (2024) emphasized that active student engagement is closely linked to increased intrinsic motivation (Herrera et al., 2024).

Regarding learning resources, students emphasized the need for reference books and multimedia materials that can be reviewed. Students' willingness to consider learning resources indicates a need for learning resources that can be accessed independently outside class. The analysis also shows that while students value technology, they still need instructional support from their lecturers. Students' willingness to support from their lecturers indicates the importance of the lecturer's role as a facilitator, guiding technology use.

The questionnaire results revealed a gap between students' procedural and conceptual abilities. They were relatively capable of following calculation procedures, but still had difficulty understanding the underlying conceptual meaning. The affective aspect emerged from students' expectations for enjoyable and interactive learning. Several respondents emphasized that an active classroom atmosphere would make it easier to understand the material. Students' limited experience using GeoGebra presents both challenges and opportunities. If the teaching materials are well-designed, this limitation can be overcome through integrated step-by-step guides.

Student responses also emphasized the importance of a needs-based design approach. These empirical findings demonstrate that teaching materials development must begin with a concrete understanding of student barriers and preferences. Thus, the main results of this study include learning difficulties in representation, preferences for diverse learning media, limited experience but positive perceptions of GeoGebra, high readiness to adopt interactive teaching materials, and expectations for contextual and active learning.

These findings provide a strong foundation for developing GeoGebra-based Multivariable Calculus teaching materials within the Gravemeijer & Cobb framework. The needs analysis was conducted through a questionnaire to identify barriers and open up innovative design directions aligned with student needs. The findings of this questionnaire not only provide an empirical overview of student difficulties and needs but also serve as a starting point for applying Gravemeijer and Cobb's theoretical framework. In the *design research paradigm*, the preliminary design phase focuses on needs analysis, which is then used to design a learning prototype. Data on visualization difficulties, limited technological experience, and student expectations for interactive media directly serve as raw material for this initial design phase.

The Gravemeijer & Cobb framework emphasizes the close relationship between learning theory and practice. By analyzing the empirical gaps emerging from the questionnaire, researchers gained a sharper conceptual basis for developing GeoGebra-based teaching materials. For example, students' difficulties in understanding partial derivatives could be the focus of visual exploration in a prototype teaching material. At the same time, mini-project preferences could be integrated as learning activities that support active engagement. Furthermore, Gravemeijer and Cobb view *design research* as iterative, so each empirical finding is not just a final answer but input for the next development cycle. In the context of this research, the questionnaire results that revealed a gap between procedural and conceptual skills became reflection material to enrich the design of teaching materials that emphasize multiple representations.

The limited student experience with GeoGebra revealed through the questionnaire is also highly relevant within the *teaching experiment framework*. Gravemeijer & Cobb emphasize the importance of classroom experiments to test how students interact with the resulting designs. By recognizing from the outset that students are relatively new to GeoGebra, the design of teaching materials can include step-by-step guidance for more effective technology adoption. Furthermore, the questionnaire results demonstrate students' readiness to embrace technology-based innovation. Gravemeijer and Cobb believe this can be a key asset in developing *didactical phenomenology*, namely, understanding the learning phenomena that emerge when students encounter new mathematical representations. This readiness will be tested and further explored during the design implementation phase.

Students' expectations for interactive 3D visualizations, mini-projects, and multimedia materials align with Gravemeijer's principle of *guided reinvention*. Through designed exploratory activities, students receive information and can rediscover multivariable concepts through interaction with visual media and mathematical discussions. Thus, this study's theoretical contribution lies in strengthening the argument that the Gravemeijer & Cobb framework can be adapted for advanced calculus learning, which has been relatively understudied. Applying this framework in the context of CDE not only enriches the international literature but also broadens the scope of *design research applications* to the realm of multivariable calculus.

From a research perspective, the questionnaire data serve as the basis for the preliminary design phase in the second year. These results will be used to develop a prototype GeoGebra-based teaching material that targets explicitly students' key challenges, namely partial derivatives, extreme values, and visualization of multivariable functions. Thus, the research goes beyond describing needs and continues to design innovative solutions. The initial implementation phase (teaching experiment) will utilize these empirical findings as a reference. For example, the gap between procedural and conceptual skills will be tested through GeoGebra-based exploration activities. At the same time, student preferences for lecturer explanations will be considered when designing a combination of instructional strategies to ensure that the developed design remains contextual and aligned with the students' learning culture.

Next, the results of the initial implementation will be analyzed retrospectively to evaluate the effectiveness of the teaching materials. New findings from this phase will inform the next development cycle. Using an iterative approach, this research aims to produce increasingly mature teaching material designs over the years until they are ready for widespread implementation in the regular curriculum. Ultimately, this research provides empirical contributions in the form of student needs data and practical and theoretical contributions through the application of the Gravemeijer & Cobb framework. Furthermore, this research lays a strong foundation for a long-term research agenda to develop, implement, and validate GeoGebra-based Multivariable Calculus teaching materials, thereby improving the quality of advanced mathematics learning in higher education.

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Discussion

The findings of this study confirm that students still experience significant difficulties in understanding the Multivariable Calculus material, particularly in aspects of partial derivatives, extreme values, and the visualization of multivariable functions. These results align with Borji's (2022) study, which showed that students' primary difficulty lies in their limited ability to connect calculation procedures with the conceptual meaning behind mathematical symbols. (Borji et al., 2022). Thus, this study emphasizes the urgency of pedagogical interventions that strengthen conceptual representations.

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The difficulty in three-dimensional visualization experienced by 37.5% of students is also consistent with the findings of Cheong et al. (2023), who emphasized that weak spatial skills can hinder the understanding of the concepts of gradients and surfaces of multivariable functions (Cheong et al., 2023). However, the results of this study add a new perspective that visualization barriers do not stand alone, but are closely related to a weak understanding of partial derivatives. Visualization barriers do not alone broaden the discussion on the interrelationships between concepts in multivariable calculus.

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Students' preference for lecturer explanations (87.5%) demonstrates the dominance of traditional methods in KPB learning. However, the data also indicates students' openness to integrating digital media such as instructional videos (75%) and visual applications (75%). This finding is consistent with Hevardani et al. (2025), who found that combining traditional and technological strategies was more effective than using either alone. Thus, this study supports the direction of blended learning in the context of advanced mathematics learning.

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Students' limited experience with GeoGebra (62.5% had never used it) contrasts with their positive perceptions of its potential. This finding aligns with research by Schoenherr (2024), which found that technology adoption in mathematics learning is determined more by perceived benefits than by prior experience (Schoenherr et al., 2024). In other words, even with minimal experience, students are still ready to embrace GeoGebra if tailored to their needs.

Students' expectations for interactive learning materials, such as 3D visualizations, mini-projects, and multimedia materials, support the findings of a systematic review by Medina Herrera et al. (2024), which emphasized that interactive technology can enhance cognitive engagement and learning motivation (Herrera et al., 2024). This study adds a local dimension, as students desire visualizations and contextualized and independently retrievable learning.

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This research strengthens previous studies and makes a new contribution to the literature by integrating the needs analysis results into the Gravemeijer & Cobb framework. Previous research has focused more on student difficulties or media effectiveness separately. In this study, empirical data on student needs serve as the basis for the preliminary design phase, creating a direct bridge between instructional design theory and practice.

Furthermore, this study's findings pave the way for the development of more targeted GeoGebra-based KPB teaching materials. Difficulties in partial derivatives, for example, can be addressed with GeoGebra-based gradient visualization activities. Similarly, difficulties with extreme values can be addressed through interactive simulations of multivariable functions. This approach also tests the validity of Gravemeijer's *guided reinvention principle* in the context of advanced calculus learning, a previously understudied area.

The novelty of this research lies in integrating student needs analysis in learning Multivariable Calculus with the Gravemeijer & Cobb *design research framework*. Previous studies have focused on student learning difficulties (Borji, 2022) or the effectiveness of visual media (Cheong et al., 2023; Medina Herrera et al., 2024), but rarely link empirical data on student needs directly to the *preliminary design stage* of teaching materials (Borji et al., 2022; Cheong et al., 2023; Herrera et al., 2024). Thus, this research offers a new contribution in the form of a bridge between empirical findings and a theoretical framework that can serve as a systematic foundation for developing, implementing, and validating GeoGebra-based teaching materials in the context of multivariable calculus in Indonesian universities.

Implication of Research

The findings of this study have important implications in three main domains. Theoretically, these results extend the application of the Gravemeijer & Cobb framework in learning Multivariable Calculus, confirming that needs analysis can serve as a foundation for *preliminary design* relevant to students' real-world difficulties. Practically, the questionnaire data indicate the need to develop GeoGebra-based teaching materials that provide interactive visualizations and facilitate exploration activities, mini-projects, and links to real-world applications. This study provides an initial foundation for further research cycles in the form of implementation (*teaching experiments*) and retrospective analysis, which are expected to produce valid, effective, and generalizable teaching materials for advanced mathematics learning in higher education.

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Limitation

This study has several limitations that should be noted. First, there were only eight respondents, so the data obtained is not representative of the broader student population. Second, the online questionnaire instrument provided a general overview of students' difficulties, perceptions, and expectations. However, it did not delve deeply into their learning experiences through interviews or direct observation. Third, this study is only at the needs analysis stage, so the effectiveness of the intervention in the form of GeoGebra-based teaching materials cannot yet be verified. These limitations open up opportunities for further research involving larger samples, incorporating qualitative data collection methods, and testing the validity of the learning design through classroom experiments and retrospective analysis.

CONCLUSION

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This study successfully identified students' main difficulties in learning Multivariable Calculus: limitations in understanding partial derivatives, extreme values, and the visualization of multivariable functions. The questionnaire results also showed that although students still rely heavily on traditional methods such as lecturer explanations, they have a positive perception and high readiness for using interactive technologies such as GeoGebra. Students' expectations for 3D visualization, mini-projects, and multimedia materials reinforce the urgency of developing technology-based teaching materials that are contextual and interactive. These findings are then positioned within the Gravemeijer & Cobb framework, emphasizing the importance of needs analysis as a basis for preliminary design. Thus, this study provides empirical contributions in the form of student needs data and practical and theoretical contributions to the development of more meaningful and sustainable Multivariable Calculus instruction.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the students who actively participated in completing the questionnaire, enabling this learning needs analysis to be successfully conducted. Appreciation is also extended to the Mathematics Study Program, Faculty of Mathematics and Natural Sciences, Universitas Bale Bandung, for providing facilities and access to the research. Special acknowledgment is given to the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek) through its Research and Community Service Information Base (BIMA) program, the official platform supporting research proposals and reporting. Access to BIMA has streamlined the administrative process for this research and facilitated systematic data management. The authors thank their colleagues for constructive feedback, methodological suggestions, and encouragement while preparing this manuscript. The support and collaboration of all parties will likely contribute positively to the advancement of calculus education in Indonesia.

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2. Setiap kata kunci dalam judul (Multivariable calculus; GeoGebra; learning needs; learning design; *design research*) harus terkait dengan minimal 6 referensi yang judulnya memuat kata kunci tersebut

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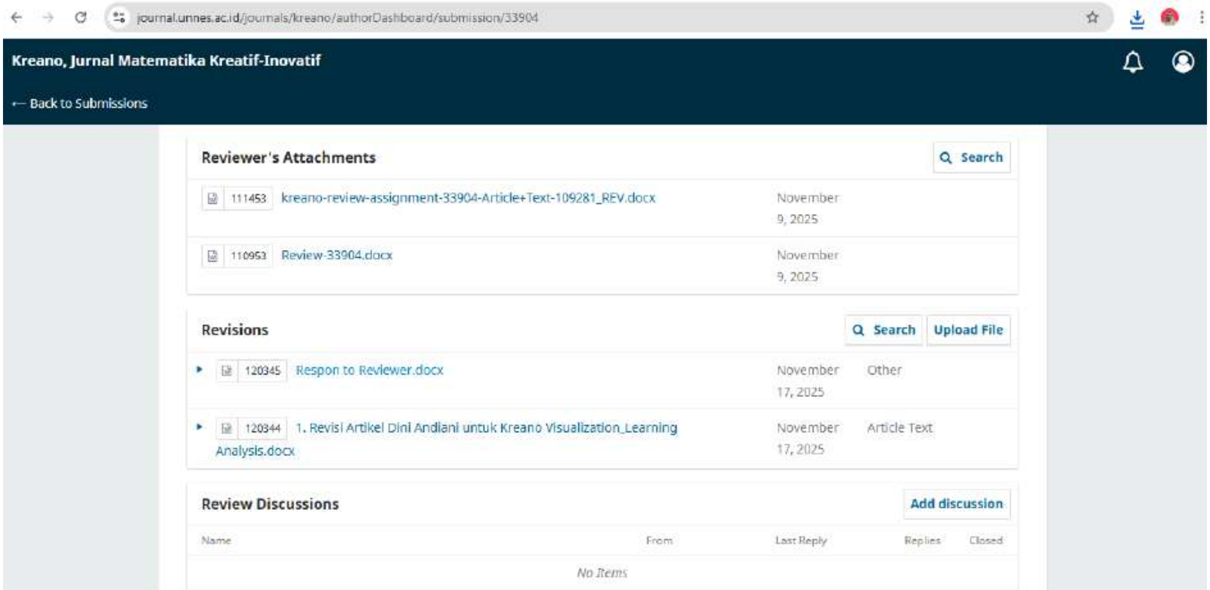
3. Bukti Konfirmasi Submit Revisi Pertama, Respon Kepada Reviewer, dan Artikel Yang Diresubmit

(17 November 2025)



Bukti Konfirmasi Submit Revisi Pertama pada 17 November 2025 melalui OJS
https://journal.unnes.ac.id/journals/kreano/authorDashboard/submission/33904

Reviewer1		
Reviewer's Comment	**Author's Response**	**Location in Manuscript**
Panjang artikel 6000-7000 kata	Sudah disesuaikan	
ABSTRACT – Perlu penjelasan teknik penentuan 8 subjek, instrumen apa saja yang digunakan	Sudah ditambahkan penjelasan bahwa subjek dipilih dengan **purposive sampling** (8 mahasiswa yang telah menyelesaikan mata kuliah) dan instrumen yang digunakan adalah **angket analisis kebutuhan**. Penjelasan ini tercantum pada bagian Metode dan diringkas dalam abstrak revisi.	Abstract-Method
ABSTRACT– Tambahkan satu kalimat penjelasan implikasi dari penelitian ini atau penelitian berikutnya	Penulis telah menambahkan satu kalimat yang menjelaskan implikasi penelitian pada bagian akhir abstrak. Kalimat tersebut menegaskan bahwa temuan studi ini menjadi dasar bagi pengembangan desain bahan ajar berbantuan GeoGebra pada tahap penelitian berikutnya	Abstract
INTRODUCTION – Introduction maksimal 35% dari keseluruhan artikel. Introduction cukup panjang dan padat. Dapat dipadatkan pada bagian tertentu agar fokus pada poin inti.	Penulis telah memadatkan bagian "Introduction" sesuai arahan reviewer dan tetap mengakomodir arahan dari reviewer	Introduction
INTRODUCTION – Tulisan banyak dalam paragraf pendek, perlu disesuiakn penulisan minimal kalimat dalam satu paragraf	Paragraf sudah disesuaikan sehingga tidak muncul paragraf pendek.	Introduction
INTRODUCTION – Di bagian akhir, disebutkan kontribusi penelitian: **empiris**, **praktis**, dan **teoritis**. Tegaskan keterkaitan antara ketiganya. Buat satu paragraf penutup yang **membingkai kembali urgensi penelitian**,	Kami telah merevisi bagian akhir *Introduction* dengan memperjelas keterkaitan antara kontribusi empiris, praktis, dan teoretis. Kami juga menambahkan satu paragraf sintesis yang menegaskan bagaimana ketiga kontribusi tersebut secara bersama-sama menunjukkan urgensi penelitian ini. Teks baru tersebut kini menghubungkan kebutuhan belajar mahasiswa, kerangka teoretis, serta implikasi praktis bagi desain pembelajaran secara lebih eksplisit.	Paragraf akhir bagian Introduction
METHOD – Pembagian metode adalah 1) participants 2)	Kami telah merevisi bagian *Method* agar sesuai dengan struktur yang direkomendasikan. Secara khusus, metode kini disajikan dalam empat subbagian utama—**Participants, Instruments,**	Method

Reviewer1		
Reviewer's Comment	**Author's Response**	**Location in Manuscript**
instruments; 3) data collection; 4) data analysis.	**Data Collection**, dan **Data Analysis**—sehingga pembaca dapat mengikuti alur penelitian dengan lebih jelas dan sistematis. Isi setiap subbagian disusun berdasarkan teks asli yang telah dipertahankan substansinya, kemudian ditata ulang agar memenuhi standar pelaporan metodologi yang umum digunakan pada penelitian kualitatif dan design research. Selain itu, kami mempertahankan penjelasan mengenai integrasi kerangka Gravemeijer & Cobb dengan menempatkannya sebagai bagian pemantik yang menghubungkan temuan hasil analisis data dengan perencanaan siklus penelitian tahun berikutnya. Dengan demikian, struktur metode kini tidak hanya sesuai saran reviewer, tetapi juga lebih koheren dan mudah dipahami.	
METHOD – Pada penelitian kualitatif perlu adanya penjelasan peran peneliti dalam penelitian ini.	Sudah ditambahkan pada bagian akhir Method	Method-Paragraf akhir.
RESULT AND DISCUSSION – Belum menunjukkan hasil penelitian, masih bersifat deskriptif dan belum memberikan hasil secara rinci	Bagian Hasil telah direvisi secara substansial dengan penyajian temuan yang lebih rinci, analitis, dan disertai contoh konkret sehingga tidak lagi bersifat deskriptif. Kami berharap revisi ini telah memenuhi rekomendasi penelaah.	Results
RESULT AND DISCUSSION – Tambahkan contoh konkret dari kebutuhan siswa, misalnya hasil kutipan wawancara atau tanggapan langsung dari mahasiswa terkait kesulitan mereka dalam memahami kontur atau gradien.	Penambahan contoh konkret telah dilakukan dengan menyisipkan kutipan langsung dari pernyataan mahasiswa pada bagian *Results*. Kutipan tersebut menunjukkan secara eksplisit kebutuhan dan kesulitan yang mereka alami, khususnya terkait pemahaman kontur, gradien, dan representasi tiga dimensi. Penyesuaian ini kami tempatkan pada paragraf yang membahas kesulitan visualisasi agar tetap konsisten dengan alur penyajian hasil penelitian.	Results
RESULT AND DISCUSSION – Perlu adanya pejelasan lebih rinci dan	Bagian terkait telah direvisi dengan menambahkan kalimat pengantar sebelum	Results

Reviewer1		
Reviewer's Comment	**Author's Response**	**Location in Manuscript**
awal kalimat atau paragraf bukan langsung angka	penyebutan angka persentase, sehingga paragraf tidak lagi dimulai langsung dengan angka. Penjelasan awal juga diperluas untuk memberikan konteks yang lebih jelas mengenai data yang disajikan. Dengan demikian, penyajian hasil kini menjadi lebih runtut, informatif, dan sesuai dengan kaidah penulisan ilmiah.	
RESULT AND DISCUSSION – Disebutkan bahwa penelitian ini menjadi bagian dari agenda jangka panjang. Akan lebih baik jika disampaikan dengan lebih spesifik: Apa target jangka panjangnya? Apakah akan menghasilkan modul cetak, platform digital, atau integrasi dalam kurikulum?	Kami telah menambahkan penjelasan yang lebih spesifik mengenai agenda jangka panjang penelitian. Pada bagian akhir Results, kami menjelaskan secara eksplisit target akhir penelitian, yaitu pengembangan modul cetak, versi digital interaktif berbantuan GeoGebra, serta rencana integrasi ke dalam kurikulum. Selain itu, tahapan multitahun telah dijelaskan untuk menunjukkan arah dan keluaran penelitian pada fase berikutnya.	Results
DISCUSSION – Perlu memperjelas klaim novelty dengan perbandingan langsung terhadap penelitian sebelumnya.	Kami telah merevisi bagian Pembahasan dengan memperjelas kontribusi kebaruan penelitian melalui perbandingan langsung dengan penelitian sebelumnya (Borji et al., 2022; Cheong et al., 2023; Medina Herrera et al., 2024). Paragraf tambahan yang menegaskan posisi kebaruan penelitian telah disisipkan pada bagian discussion	Discussion
REFERENCES – Referensi minimal 60% dari jurnal internasional bereputasi (terindeks scopus), perlu ditambahkan	Kami telah menambahkan referensi dari jurnal internasional bereputasi yang terindeks di Scopus, sehingga kini minimal 60% referensi telah memenuhi kriteria tersebut."	Referensi

Reviewer 2		
Reviewer's Comment	**Author's Response**	**Changes Made in Manuscript**
ABSTRACT – Tambahkan 1 kalimat di awal yang menegaskan gap penelitian**.**	Kami telah menambahkan satu kalimat pada bagian Pendahuluan yang menegaskan gap penelitian, khususnya terkait kurangnya studi yang secara sistematis mengeksplorasi kebutuhan belajar mahasiswa sebagai dasar pengembangan pembelajaran Kalkulus Multivariabel.	(halaman 1, paragraf 1)
ABSTRACT – Perjelas bagaimana kerangka Gravemeijer & Cobb diadaptasi dalam penelitian ini, terutama tahap yang dilakukan	Kami telah memperjelas bagaimana kerangka Gravemeijer & Cobb diadaptasi dalam penelitian ini dengan menjelaskan tiga tahap yang digunakan, yaitu *Preliminary Design*, *Teaching Experiment* yang diadaptasi menjadi proses pengumpulan data kebutuhan belajar, serta *Retrospective Analysis* sebagai dasar perumusan prinsip desain awal. Penjelasan ini telah dimasukkan pada bagian *Method* sesuai arahan reviewer.	Added 8 new references and refined arguments (lines 25–75).
ABSTRACT – Lengkapi hasil dengan proporsi atau kecenderungan lebih detail untuk memperkuat klaim, misalnya 6 dari 8 mahasiswa melaporkan kesulitan pada visualisasi.	Penulis telah menambahkan proporsi dan jumlah responden secara lebih rinci pada bagian *Results*. Informasi mengenai kecenderungan data kini dituliskan secara eksplisit, misalnya: *"50% (4 dari 8 mahasiswa) mengalami kesulitan pada turunan parsial, 37.5% (3 dari 8) mengalami kesulitan visualisasi fungsi multivariat, serta 87.5% (7 dari 8) menyatakan penjelasan dosen sangat membantu."*	Results
ABSTRACT – Kurang diarahkan ke langkah nyata (misalnya hasil ini menjadi dasar rancangan bahan ajar interaktif berbasis GeoGebra untuk topik turunan parsial dan nilai ekstrem)	Penulis telah menambahkan penjelasan pada bagian **ABSTRACT** dan kesimpulan bahwa temuan ini menjadi dasar pengembangan materi pembelajaran berbantuan GeoGebra yang secara khusus menyasar kesulitan mahasiswa pada turunan parsial dan nilai ekstrem pada fase desain selanjutnya.	Akhir abstract; Conclusion
ABSTRACT – Sesuaikan dengan perbaikan abstrak English version	Abstrak versi bahasa Inggris telah diperbaiki sesuai saran reviewer	ABSTRACT

Reviewer 2		
Reviewer's Comment	**Author's Response**	**Changes Made in Manuscript**
INTRODUCTION – Perhatikan! Panjang naskah adalah 6000-7000 kata untuk isi naskah (Judul, abstrak, dan referensi tidak termasuk). Silakan sesuaikan.	Sudah disesuaikan	
INTRODUCTION – Bangun jembatan narasi yang lebih mulus antara hasil studi terdahulu dan temuan awal penelitian (preliminary questionnaire)	Keterkaitan antara hasil-hasil penelitian sebelumnya dan temuan dari kuesioner pendahuluan telah diperjelas untuk memastikan alur narasi yang lebih koheren.	Halaman 3 paragraf 4
INTRODUCTION – Tegaskan, penelitian terdahulu hanya fokus pada media (GeoGebra/VR) atau hanya design research, penelitian ini menggabungkan keduanya	Bagian ini telah direvisi untuk menegaskan bahwa penelitian-penelitian terdahulu umumnya hanya berfokus pada penggunaan media teknologi (seperti GeoGebra atau VR) atau penerapan pendekatan design research secara terpisah. Paragraf hasil revisi kini secara eksplisit menyatakan bahwa penelitian ini mengintegrasikan kedua aspek tersebut—teknologi GeoGebra dan kerangka design research Gravemeijer & Cobb—dalam konteks analisis kebutuhan untuk menjembatani kesenjangan penelitian sebelumnya.	Halaman 4 paragraf 2
INTRODUCTION – Hubungkan tujuan dengan gap lebih eksplisit, misalnya tambahkan pengantar: 'Berdasarkan gap dan rumusan masalah yang telah dijelaskan, penelitian ini bertujuan …'	Sebuah kalimat pengantar telah ditambahkan untuk secara eksplisit mengaitkan tujuan penelitian dengan kesenjangan penelitian dan perumusan masalah yang telah diidentifikasi sebelumnya. Revisi ini memastikan keterhubungan narasi yang lebih jelas antara dasar pemikiran dan tujuan penelitian.	Halaman 4 paragraf 4
METHOD – Perjelas hubungan antara pendekatan kualitatif dengan design research. Apakah penelitian ini murni studi kebutuhan (preliminary design) dalam kerangka design research, atau kualitatif deskriptif yang memakai design research sebagai acuan teoretis?	Bagian metode telah direvisi untuk memperjelas hubungan antara pendekatan kualitatif dan kerangka *design research*. Paragraf hasil revisi menegaskan bahwa penelitian ini berada dalam kerangka *design research* dan merepresentasikan tahap *preliminary design* yang berfokus pada identifikasi dasar empiris untuk	Bagian METHOD

Reviewer 2		
Reviewer's Comment	**Author's Response**	**Changes Made in Manuscript**
	pengembangan desain pembelajaran berbantuan GeoGebra.	
METHOD – Jelaskan teknik pemilihan subyek. Mengapa hanya 8 dari seluruh mahasiswa semester 4?	Penjelasan tentang teknik pemilihan subjek telah ditambahkan pada bagian *Method*. Penelitian ini menggunakan teknik *purposive sampling* untuk memilih delapan mahasiswa semester empat program studi matematika yang telah menyelesaikan mata kuliah Kalkulus Peubah Banyak. Jumlah partisipan ditentukan berdasarkan pendekatan deskriptif kualitatif yang menekankan kedalaman dan kekayaan konteks dibandingkan ukuran sampel. Mahasiswa yang dipilih mewakili tingkat kemampuan dan pengalaman yang beragam, sehingga data yang diperoleh memadai untuk menggambarkan kebutuhan belajar nyata pada tahap *preliminary design*.	METHOD
METHOD – Apakah kuesioner diuji coba? apakah ada expert judgment untuk memastikan butir pertanyaan sesuai indikator? Silakan tambahkan informasi validasi instrumen.	Informasi mengenai validasi instrumen telah ditambahkan pada bagian *Method (Instrument)*. Kuesioner telah melalui proses *expert judgment* oleh dua ahli, satu di bidang matematika dan satu di bidang teknologi informasi, untuk menilai relevansi, kejelasan, dan keterwakilan butir pertanyaan terhadap indikator yang diukur. Selain itu, instrumen juga diuji coba kepada dua mahasiswa di luar sampel utama untuk memastikan kejelasan dan fungsi teknis kuesioner daring.	METHOD
METHOD –Sebutkan contoh kategori tematik yang muncul dari open-ended responses	Kami telah menambahkan penjelasan mengenai contoh kategori tematik yang diidentifikasi dari hasil analisis *open-ended responses*. Informasi ini kini terdapat pada bagian *Method (Data Analysis)*, yang menyebutkan tiga kategori utama, yaitu kesulitan dalam memvisualisasikan fungsi multivariabel, keterbatasan pemahaman terhadap turunan parsial dan ekstrem, serta	METHOD

Reviewer 2		
Reviewer's Comment	**Author's Response**	**Changes Made in Manuscript**
	kebutuhan akan alat bantu visual interaktif untuk mendukung pemahaman konseptual.	
METHOD –Tegaskan bahwa hasil analisis kebutuhan ini diposisikan sebagai *preliminary design* dalam Gravemeijer & Cobb, bukan sekadar deskriptif	Sudah direvisi. Bagian Metode kini secara eksplisit menegaskan bahwa hasil analisis kebutuhan siswa diposisikan sebagai **Preliminary Design** dalam kerangka Design Research Gravemeijer & Cobb. Dijelaskan bahwa temuan analisis kebutuhan ini menjadi dasar empiris untuk merancang desain awal bahan ajar berbasis GeoGebra, bukan hanya sekadar temuan deskriptif.	METHOD
RESULTS –Sebaiknya kalimat interpretasi dipindahkan ke bagian *Discussion*, karena di *Results* sebaiknya hanya menyajikan data.	Kalimat interpretatif pada paragraf pertama bagian *Results* ("This research makes it clear that learning needs analysis is not a secondary step but a foundation for designing more effective and targeted learning strategies.") telah dipindahkan ke bagian *Discussion* (paragraf keenam), tepat setelah kalimat yang diakhiri dengan "...between instructional design theory and practice." Dengan demikian, bagian *Results* kini hanya menyajikan data secara deskriptif, sedangkan penafsiran dan implikasi konsep disajikan secara tepat pada bagian *Discussion* sesuai arahan reviewer.	Results-Discussion
RESULTS –Ini juga bentuk implikasi/interpretasi. Lebih tepat ditempatkan di *Discussion*.	alimat interpretatif tersebut telah dipindahkan dari bagian *Results* ke bagian *Discussion*, tepat setelah kalimat *"Previous research has focused more on student difficulties or media effectiveness separately."* (paragraf keenam). Dengan pemindahan ini, bagian *Results* kini hanya memuat deskripsi data secara faktual, sedangkan interpretasi dan implikasi konseptual ditempatkan secara tepat di bagian *Discussion* sesuai dengan arahan reviewer.	Results-Discussion

Reviewer 2		
Reviewer's Comment	**Author's Response**	**Changes Made in Manuscript**
RESULTS –Bagian ini lebih cocok sebagai pembahasan teoritis, bukan laporan hasil.	Paragraf yang dimaksud telah dipindahkan dari bagian *Results* ke bagian *Discussion*, agar sesuai dengan fungsinya sebagai pembahasan teoretis yang mengaitkan hasil penelitian dengan tren global dalam pendidikan matematika. Perubahan ini diharapkan memperjelas batas antara penyajian data dan interpretasi hasil penelitian.	Results-Discussion
RESULTS –Ini seharusnya berada di *Discussion* karena berupa argumentasi, bukan hasil kuesioner.	Kalimat **"Effectiveness reinforces the urgency of needs analysis as a basis for technology utilization."** telah dihapus dari bagian *Results* dan dipindahkan ke bagian *Discussion* pada paragraf setelah pembahasan mengenai persepsi mahasiswa terhadap penggunaan GeoGebra. Penempatan ini dipilih karena kalimat tersebut merupakan bentuk interpretasi dan argumentasi teoretis terkait efektivitas teknologi, sehingga lebih sesuai ditempatkan dalam *Discussion*. Perubahan ini dilakukan untuk memastikan bahwa bagian *Results* tetap berisi penyajian data empiris tanpa interpretasi.	Results-Discussion
DISCUSSION-Sudah membandingkan, tetapi hanya menunjukkan kesamaan (*align with*). Perlu ditambahkan perbedaan atau kontribusi baru dari penelitian ini.	Pada bagian *Discussion*, setelah kalimat yang menyatakan kesesuaian temuan dengan Borji (2022), telah ditambahkan penjelasan mengenai kontribusi baru penelitian ini. Revisi tersebut menegaskan bahwa meskipun terdapat kesamaan, penelitian ini menemukan bahwa kesulitan simbolik–konseptual juga berkaitan erat dengan lemahnya kemampuan visualisasi tiga dimensi, sehingga memberikan perspektif baru yang tidak dibahas dalam studi Borji. Dengan demikian, perbedaan dan kontribusi penelitian ini kini telah diperjelas sesuai arahan reviewer.	Discussion
DISCUSSION-Sama seperti di atas, masih sebatas konfirmasi. Jelaskan apa yang lebih mendalam atau berbeda dari	Paragraf telah direvisi dengan menambahkan penjelasan mengenai kontribusi baru, yaitu	Discussion

Reviewer 2		
Reviewer's Comment	**Author's Response**	**Changes Made in Manuscript**
penelitian Anda (misalnya keterkaitan dengan turunan parsial)	keterkaitan antara kesulitan visualisasi tiga dimensi dengan kesalahan konsep pada limit dua variabel dan turunan parsial. Perbaikan telah ditempatkan pada bagian Discussion.	
DISCUSSION-Sudah membandingkan, tapi sifatnya mendukung. Bisa diperjelas apa kontribusi tambahan dari penelitian ini	Kami telah merevisi bagian *Discussion* dengan menambahkan penjelasan yang lebih eksplisit mengenai kontribusi baru penelitian ini. Pada paragraf yang membahas temuan Borji (2022) dan Cheong et al. (2023), kami tidak hanya menunjukkan kesesuaian hasil, tetapi juga menegaskan kontribusi tambahan penelitian kami, yaitu mengungkap keterkaitan antara kelemahan visualisasi tiga dimensi dan pemahaman turunan parsial hubungan yang belum dibahas secara mendalam dalam penelitian sebelumnya. Revisi ini telah ditambahkan pada paragraf kedua dan ketiga bagian *Discussion* untuk memperjelas diferensiasi dan nilai tambah penelitian kami.	Discussion
DISCUSSION- Sama, ini mendukung. Perlu penegasan.	Pernyataan pada bagian tersebut telah direvisi agar tidak hanya menunjukkan kesesuaian dengan penelitian sebelumnya, tetapi juga menegaskan kontribusi tambahan dari penelitian ini. Kami telah menambahkan penjelasan bahwa penelitian ini tidak sekadar mendukung temuan Medina Herrera et al. (2024), tetapi juga mengidentifikasi secara spesifik komponen media pembelajaran yang paling dibutuhkan mahasiswa, yaitu *visualisasi 3D* dan *mini-project berbasis konteks*. Penegasan ini telah dimasukkan pada kalimat: *"However, this study goes further by identifying which specific components students find most essential …"*	Discussion
CONCLUSION- Kesimpulan masih cenderung mengulang hasil penelitian; sebaiknya difokuskan pada makna	Sudah disesuaikan dengan saran dari reviewer	Conclusion

Reviewer 2		
Reviewer's Comment	**Author's Response**	**Changes Made in Manuscript**
temuan, kontribusi, dan arah penelitian selanjutnya.		

Visualization of Multivariable Calculus: Learning Needs Analysis for GeoGebra-Assisted Teaching Material Development

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Abstract

Students often struggle to visualize multivariable functions, interpret partial derivatives, and apply extrema, yet systematic needs analyses for designing meaningful Multivariable Calculus learning environments remain limited. This study aims to identify students' learning needs as a foundation for developing GeoGebra-assisted materials. Using a qualitative descriptive approach within the Gravemeijer and Cobb design research framework, data were collected through a needs-analysis questionnaire administered to eight purposively selected university students who had completed the course. Results show that six of the eight students experienced moderate to high levels of difficulty, especially in visualizing multivariable functions and understanding partial derivatives. Students also reported that videos and lecturer explanations were helpful, and all expressed readiness to use GeoGebra-based materials. The findings indicate the importance of designing structured learning environments that integrate dynamic visualizations. This study provides the groundwork for subsequent teaching experiment and retrospective analysis cycles in developing valid and generalizable instructional designs.

Keywords: Multivariable Calculus; GeoGebra; learning needs; learning design; *design research*

Abstrak

Mahasiswa sering mengalami kesulitan dalam memvisualisasikan fungsi multivariabel, menafsirkan turunan parsial, dan menerapkan konsep nilai ekstrem, namun analisis kebutuhan yang sistematis untuk merancang lingkungan belajar Kalkulus Peubah Banyak masih terbatas. Penelitian ini bertujuan mengidentifikasi kebutuhan belajar mahasiswa sebagai dasar pengembangan bahan ajar berbantuan GeoGebra. Dengan pendekatan deskriptif kualitatif dalam kerangka penelitian desain Gravemeijer dan Cobb, data dikumpulkan melalui angket analisis kebutuhan yang diberikan kepada delapan mahasiswa terpilih yang telah menyelesaikan mata kuliah tersebut. Hasil menunjukkan bahwa enam dari delapan mahasiswa mengalami tingkat kesulitan sedang hingga tinggi, terutama dalam visualisasi fungsi multivariabel dan pemahaman turunan parsial. Mahasiswa juga menyatakan bahwa video dan penjelasan dosen membantu pemahaman, dan seluruhnya siap menggunakan bahan ajar berbasis GeoGebra. Temuan ini menjadi dasar bagi pelaksanaan teaching experiment dan analisis retrospektif untuk menghasilkan desain pembelajaran yang valid dan tergeneralisasi.

Mathematics Clasification: ---- 97D70 ----

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INTRODUCTION

In ideal conditions, learning Multivariable Calculus should foster not only procedural fluency but also deep conceptual understanding supported by coherent symbolic, graphical, numerical, and verbal representations (Al Dehaybes et al., 2025; Altindis et al., 2024; Andiani, 2016; Andiani et al., 2020, 2025; Bedada & Machaba, 2022; Hahn & Klein, 2025; Milenković & Vučićević, 2024). Students are expected to connect key multivariable concepts such as functions of two variables, gradients, partial derivatives, and multiple integrals through strong representational and spatial reasoning, particularly supported by 3D visualization tools (Cheong et al., 2023, 2024; Herrera et al., 2024; Jones et al., 2022). Ideal learning also emphasizes active engagement, where students rediscover concepts through exploration and modeling while lecturers act as facilitators who guide reflection rather than transmit procedures (Andiani et al., 2025; Biehler et al., 2024; Johnson et al., 2025; Ribeiro-Silva et al., 2022; Song & Cai, 2024; Weinhandl et al., 2025). Assessment, accordingly, should measure conceptual, representational, and application skills rather than calculations alone (Andiani et al., 2020, 2024; Vízek et al., 2024).

However, gaps persist between these ideals and classroom realities. Research reports that many students struggle to visualize 3D surfaces and interpret symbolic changes geometrically, leading to weak conceptual understanding (Borji et al., 2022; Herrera et al., 2024). Although virtual reality, GeoGebra 3D, and other dynamic visualization tools have proven effective, they remain underused in practice, leaving instruction dominated by symbolic procedures (Cheong et al., 2023; Herrera et al., 2024; Schoenherr et al., 2024). Furthermore, visual tools are often implemented without adequate scaffolding, limiting their pedagogical impact (Abraham & Prediger, 2025; Huang et al., 2024; Malone et al., 2023; Nickl et al., 2024a, 2024b; Wang et al., 2025). Assessments in many calculus courses also still emphasize procedural skills, widening the gap between intended and actual learning outcomes (Ballon et al., 2024; Castillo et al., 2025; Spencer-Tyree et al., 2024). Consistent with previous studies, preliminary questionnaire results in this study confirm that students experience difficulties in visualizing multivariable concepts and express readiness to engage with GeoGebra-based materials (Abuhassna & Alnawajha, 2023; Andiani et al., 2025; Leung et al., 2024).

To reduce these disparities, the integration of technological visualization particularly GeoGebra with well designed instructional strategies becomes essential. GeoGebra enables dynamic exploration of multivariable functions and has been shown to improve conceptual understanding and representation skills (Bedada & Machaba, 2022; Hevardani et al., 2025). Combining this technology with active learning approaches further enhances students' spatial reasoning and engagement (Cheong et al., 2023; Herrera et al., 2024). Additionally, the design research approach by Gravemeijer and Cobb (2006) offers a systematic framework for developing instructional materials through iterative cycles of design, teaching experiments, and retrospective analysis, ensuring that innovations align with students' real learning needs (Komatsu et al., 2024; Mackey et al., 2023; Prediger et al., 2015). Although prior studies have examined visualization tools or design research separately, research that integrates both in the context of Multivariable Calculus especially in Indonesian higher education remains limited.

Based on the ideal conditions, empirical gaps, and students' expressed needs, the main problems identified in Multivariable Calculus learning include limited visualization skills, minimal experience with interactive technologies such as GeoGebra, and the dominance of procedural instruction that undermines conceptual understanding. Therefore, this study aims to develop a theoretically grounded and technology-assisted instructional design that addresses these issues. Specifically, the objectives are: (1) to identify students' difficulties and learning needs related to representation and visualization; (2) to analyze students' perceptions and readiness toward GeoGebra-assisted materials; and (3) to provide an empirical and conceptual foundation for designing a GeoGebra-based Multivariable Calculus learning model using the Gravemeijer and Cobb approach.

This study contributes empirically by documenting students' learning needs; practically by offering a conceptual basis for technology-supported instructional design relevant to Indonesian higher education; and theoretically by integrating visualization tools with the Gravemeijer and Cobb design research framework, thereby advancing the literature and laying groundwork for future validation studies. Taken together, these contributions highlight the urgency of developing an instructional design that is both empirically grounded and theoretically informed. The persistent gap between ideal conceptual understanding and current learning practices in Multivariable Calculus, combined with students' demonstrated need for visualization-based support, underscores the necessity of a systematic and integrated approach. By merging the strengths of technological visualization and design research, this study aims to provide a sustainable foundation for improving learning outcomes and informing future instructional development.

METHOD

This study employed a qualitative descriptive approach to identify students' learning needs as the basis for developing GeoGebra-assisted teaching materials for Multivariable Calculus. Eight fourth-semester mathematics education students from a university in West Java were selected through purposive sampling, as their prior completion of the Multivariable Calculus course provided relevant and context-rich insights for a needs analysis study. Data were collected using an online questionnaire developed in Google Forms, consisting of sections on participant identity, learning experiences and needs, availability of GeoGebra-based resources, and expectations for teaching material design. The instrument included closed ended rating scale items and open ended prompts and was validated by two experts one in mathematics and one in information technology who reviewed the items for clarity, relevance, and representativeness; minor revisions were made accordingly, and the final version was pilot tested with two students outside the main sample to ensure clarity and technical usability.

Data collection was conducted asynchronously, allowing students to respond reflectively and ensuring complete and manageable digital records. The analysis used qualitative descriptive techniques in which numerical ratings were converted into percentages to illustrate general trends, while open ended responses were coded thematically to identify recurring issues such as difficulties in visualizing multivariable functions, limited understanding of partial derivatives and extrema, and the need for interactive visual tools to support conceptual comprehension. Trustworthiness was strengthened through iterative comparison of codes, repeated category checking, and alignment with prior literature on technology-supported calculus learning. The researcher acted as the primary instrument of the study, designing the questionnaire, coordinating expert validation, managing data collection, and conducting the thematic coding and interpretation, while taking measures to minimize bias through iterative reflection and expert consultation.

The methodological procedure was also positioned within the Gravemeijer and Cobb design research framework by aligning the needs analysis with the three interconnected stages of preliminary design, teaching experiment, and retrospective analysis. In this first year cycle, preliminary design involved identifying learning difficulties from existing studies and constructing the questionnaire to investigate initial conjectures; the teaching experiment was adapted into a systematic needs assessment activity in which students' responses were used to refine those conjectures; and retrospective analysis consisted of examining and interpreting the questionnaire data to generate thematic findings and form early design principles for developing GeoGebra-assisted instructional materials. Altogether, this methodological design provides a systematic and empirically grounded foundation for understanding students' learning needs and informing the initial stage of a broader instructional design developed through the design research paradigm.

In this qualitative descriptive study, the researcher served as the primary instrument responsible for designing the questionnaire, validating its content with experts, administering the data collection process, and conducting the thematic analysis. The researcher interpreted students' responses through iterative coding, continuously comparing emerging categories with existing literature to minimize subjective bias. To enhance trustworthiness, the researcher engaged in repeated checks of the coding scheme, consulted experts during validation, and ensured that interpretations remained aligned with the empirical focus of the needs-analysis phase within the design research framework.

RESULTS AND DISCUSSION

Results

The analysis of the questionnaire responses provides a detailed overview of students' learning challenges in Multivariable Calculus and clarifies the specific conceptual and procedural aspects that require strengthened instructional support. A majority of students (75%) categorized the course as moderately to highly difficult across core topics involving limits of two variables, visualization of surfaces, partial derivatives, and extreme values. The area reported as most challenging was partial derivatives, with 50% of students stating that they experienced persistent difficulties not only in carrying out the symbolic computations but also in interpreting what the derivatives represent in a multivariable context. Visualization of multivariable functions emerged as another major source of difficulty for 37.5% of respondents, who indicated that they struggled to interpret three-dimensional surfaces, understand the meaning of contour curves, and recognize how directional changes relate to gradients. Students' written comments further illuminate the depth of these difficulties. For example, one student noted, "*I can compute the partial derivatives, but I still cannot picture the shape of the surface,"* while another remarked, "*Contour lines are confusing because I cannot see how they represent the height or slope of the graph*." These statements describe the specific difficulties students encountered when working with geometric representations.

Additionally, 25% of students reported difficulties with limits and continuity of functions of two variables, often citing uncertainty about how a function behaves when approaching a point from infinitely many directions. Meanwhile, 37.5% struggled with extreme values, particularly in understanding the relationship between critical points, gradients, and the geometric structure of the surface. The proportions of these reported difficulties indicate that partial derivatives had the highest percentage of students experiencing challenges compared with the other topics. Table 1 presents a detailed overview of the proportion of students who reported experiencing difficulties across four key conceptual areas in Multivariable Calculus. Partial derivatives emerged as the most challenging topic, with 50% of students indicating that they struggle to understand both the geometric interpretations and the practical applications of these concepts. Visualization of multivariable functions was also a notable difficulty, reported by 37.5% of respondents, who specifically mentioned problems in accurately representing three dimensional surfaces, interpreting contour curves, and understanding gradients. Difficulties with limits and continuity in two variables were reported by 25% of students. In addition, 37.5% of students reported difficulties in applying extreme value concepts.

Table 1. Percentage of Student Difficulties Based on Learning Aspects

Learning Aspects	Percentage of Students Experiencing Difficulties	Information
Partial derivatives	50%	The main obstacle is the difficulty in understanding geometric and applicative concepts.
Visualization of multivariable functions	37.5%	Weak in drawing 3D surfaces, contour curves, and gradients
Limit & continuity	25%	Difficulty generalizing the concept of limit from 1 variable to many variables
Extreme values	37.5%	Understand the procedure, but have difficulty applying the concept

In terms of learning resources used by students in studying Multivariable Calculus, 87.5% of students identified lecturer explanations as their primary source of support. Students reported that explanations delivered during lectures were the resource they relied on most frequently when attempting to understand course concepts and solve related problems. Additionally, 75% of students indicated that learning videos were helpful in supporting their study of Multivariable Calculus. Students noted that they used these videos to review examples, revisit explanations, and follow procedural steps demonstrated in the materials. A similar proportion, 75%, reported that visual tools such as GeoGebra were beneficial for their learning. These students mentioned that the tools assisted them when working with graphical representations, examining surfaces, or checking the structure of multivariable functions. However, several students stated that they used these tools only occasionally and primarily when such tools were introduced or demonstrated during classroom sessions.

Based on the questionnaire responses, Table 2 summarizes the percentage of students who identified each type of learning medium as helpful. The table includes data on lecturer explanations, learning videos, visual tools such as GeoGebra, textbooks, online tutorials, and other supplementary resources. The distribution shows the frequency with which each medium was selected by students as supportive for their understanding of the material. The table also indicates whether students used these resources independently, during lessons, or both. The results further show the range of resources students accessed: some relied solely on lecturer explanations, some combined videos with visualization tools, while others used multiple resources including textbooks and online materials. The data also record variations in usage patterns, such as students who reported regular use of visual tools compared to those who used them only when assigned. Additionally, a portion of students indicated that they supplemented primary resources with external materials such as YouTube tutorials or online mathematics forums. These patterns are further detailed in Table 2, which presents a summary of the learning media used by students and the corresponding proportions of students who reported each medium as helpful.

Table 2. Percentage of Students Based on Learning Media

Instructional Media	Percentage of Students	Information
Lecturer's explanation	87.5%	Still, the primary source of learning
Learning videos	75%	Supports repetition and independent understanding
GeoGebra	75%	Interactive media, but the student experience is limited
Previous GeoGebra experience	62.5% never, 37.5% limited	Demonstrates the gap between technological potential and real-world experience.
Readiness for using GeoGebra-based teaching materials	100%	Strong signal of acceptance of technological innovation

Students report limited prior experience with GeoGebra. The data show that 62.5% of respondents have never used GeoGebra in any mathematics course, while 37.5% have used the software only to a limited extent. Several participants provided comments regarding their experience. One student states, "*I know GeoGebra exists, but I have never used it in class*." Another student reports, "*I tried using GeoGebra before, but I did not understand how to manipulate the 3D view*." In terms of perceived usefulness, 75% of respondents indicate that GeoGebra could help them learn material related to Multivariable Calculus. Furthermore, all respondents (100%) report that they are willing to use GeoGebra-based teaching materials in future learning activities. The responses were recorded consistently across all participants, and prior studies by Schoenherr et al. (2024) are cited to provide contextual reference for patterns of technology acceptance (Schoenherr et al., 2024).

Students' expectations for learning materials varied, but most emphasized the need for interactive visualizations. Respondents suggested 3D graphics, GeoGebra-based mini-projects, and exploration activities that allow for active learning. Some respondents requested more dynamic representations, noting, for instance, *"It would help if I could rotate the surface and see the contour lines at the same time."* In addition to visualization, students desire a connection between learning materials and real world contexts. Several respondents stated that they preferred GeoGebra visualizations to be connected to everyday life applications or case studies.

Based on the findings from the questionnaire, Table 3 summarizes students' expressed needs and expectations regarding Multivariable Calculus teaching materials. The table lists specific features and components identified by students as relevant to their learning. These features include the use of interactive visualizations to represent three-dimensional concepts, the inclusion of diverse types of learning media, the presence of problems and examples connected to practical or real world contexts, and the availability of exploratory and inquiry-based activities that require students' active participation. The responses recorded in Table 3 indicate the number and proportion of students who mentioned each type of resource or activity. For instance, the table shows how many students requested interactive visualizations, the frequency with which students mentioned the need for multiple learning media, and the number of students highlighting the importance of problem examples from real-world contexts. The table also presents the proportion of students who indicated a preference for exploratory or inquiry-based activities as part of their learning process.

Table 3. Questionnaire Findings

Aspect	Questionnaire Findings	Implications for Teaching Materials

Visualization	37.5% difficulty with 3D visualization	Module with interactive 3D graphics
Interactive media	75% found GeoGebra useful	GeoGebra-based mini project
Learning activities	Students want active classes	Exploration activities, guided reinvention
Real context	Students want everyday life applications	Case studies related to KPB
Lecturer support	87.5% rely on lecturers	GeoGebra structured instructions & guides

Students reported expectations regarding the availability of diverse learning media for studying Multivariable Calculus. The responses show that students considered multiple types of media as relevant to their learning. Specifically, students mentioned traditional textbooks, instructional videos, and technology based resources such as interactive simulations or software tools. The questionnaire recorded how many students referred to each type of media, including cases where students preferred a combination of several resources. Several participants provided comments about lecturer explanations. Students reported expectations regarding the availability of diverse learning media for studying Multivariable Calculus. The responses show that students mentioned multiple types of media, including traditional textbooks, instructional videos, and technology-based resources such as interactive simulations or software tools. The questionnaire recorded how many students referred to each type of media, including cases where students preferred a combination of several resources.

Several students provided comments about lecturer explanations. Some students noted that detailed and inclusive explanations were important, particularly in relation to differences in prior educational experiences. Students also reported variations in their foundational understanding of Multivariable Calculus, referring to varied types of prior secondary education. In addition, students identified a need for more active learning activities. The responses included references to hands-on classroom exercises, exploratory problem-solving activities, and collaborative tasks. The questionnaire data recorded the proportion of students mentioning each type of activity and whether they expressed a preference for multiple types of active learning approaches simultaneously.

Regarding students' experiences and needs in studying Multivariable Calculus, the questionnaire collected information on demographic and educational backgrounds. The respondents included both male and female students, all of whom had previously taken a Multivariable Calculus course. Students reported varying levels of difficulty in understanding the material, with some describing it as moderately difficult and others as very challenging. In terms of specific learning challenges, several students mentioned difficulties in visualizing multivariable functions, understanding limits and continuity, performing partial derivatives, and applying extreme values.

Students described the types of learning resources they found most helpful. Many referred to lecturer explanations and learning videos, while others mentioned textbooks, interactive applications such as GeoGebra, and group discussions. Regarding prior experience with GeoGebra, some students indicated they had never used it, while others had only limited exposure. One student commented, "I know GeoGebra exists, but I have never used it in class," and another added, "I tried using GeoGebra before, but I did not understand how to manipulate the 3D view." Most students agreed that instructional materials should include interactive GeoGebra visualizations, and all respondents expressed willingness to use GeoGebra-based teaching materials developed with the Gravemeijer & Cobb approach. Students also reported preferences for learning activities and features in instructional materials. These included interactive 3D visualizations, mini-projects using GeoGebra, videos for repeated individual study, contextual exploration with real-life case studies, and detailed lecturer explanations, highlighting the variety of approaches students considered supportive of their learning.

Student responses were collected through a questionnaire to document learning difficulties, prior experience, and preferences related to Multivariable Calculus. The responses identified specific challenges in visualizing multivariable functions, understanding limits and continuity, performing partial derivatives, and applying extreme values. Students reported preferences for learning media, including lecturer explanations, instructional videos, textbooks, GeoGebra, and group discussions. Prior experience with GeoGebra varied, with 62.5% of students reporting that they had never used it and 37.5% indicating limited experience. All students expressed willingness to use GeoGebra-based teaching materials. Students also mentioned desired features for instructional materials, including interactive 3D visualizations, mini-projects using GeoGebra, videos for repeated individual study, contextual exploration with real-life case studies, and detailed lecturer explanations. Additionally, hands-on classroom exercises, exploratory problem-solving activities, and collaborative tasks were cited. These responses provide the empirical basis for the preliminary design phase in which instructional materials are developed.

The questionnaire collected information on students' experiences, difficulties, and preferences in studying Multivariable Calculus. Several students reported difficulties in visualizing multivariable functions, understanding limits and continuity, performing partial derivatives, and applying extreme values. One student noted, "*I can compute the partial derivatives, but I still cannot picture the shape of the surface*," while another commented, "Contour lines are confusing because I cannot see how they represent the height or slope of the graph." Regarding learning activities, a few students mentioned a preference for hands-on classroom exercises, exploratory problem-solving activities, and collaborative tasks. One respondent stated, "*I understand better when I can try things myself rather than only listening*," highlighting the importance of active engagement. Some students suggested mini-projects using GeoGebra, and several expressed interest in interactive 3D visualizations, with comments such as, "*Seeing the graph in 3D helps me connect the formulas to the shape of the surface*."

In terms of learning media, most students identified lecturer explanations and learning videos as helpful, while others mentioned textbooks, GeoGebra, or group discussions. Regarding prior experience with GeoGebra, some students had never used it, while others reported limited experience. One student shared, "*I know GeoGebra exists, but I have never used it in class*," while another added, "*I tried using GeoGebra before, but I did not understand how to manipulate the 3D view*." When asked about the inclusion of GeoGebra visualizations in teaching materials, the majority of students agreed that such visualizations would be useful. All respondents indicated willingness to use GeoGebra-based teaching materials developed using the Gravemeijer & Cobb approach.

Students' expectations for interactive 3D visualizations, mini projects, and multimedia materials align with Gravemeijer's principle of *guided reinvention*. Through designed exploratory activities, students receive information and can rediscover multivariable concepts through interaction with visual media and mathematical discussions. Thus, this study's theoretical contribution lies in strengthening the argument that the Gravemeijer & Cobb framework can be adapted for advanced calculus learning, which has been relatively understudied. Applying this framework in the context of CDE not only enriches the international literature but also broadens the scope of *design research applications* to the realm of Multivariable Calculus.

From a research perspective, the questionnaire data serve as the basis for the preliminary design phase in the second year. These results will be used to develop a prototype GeoGebra-based teaching material that targets explicitly students' key challenges, namely partial derivatives, extreme values, and visualization of multivariable functions. Thus, the research goes beyond describing needs and continues to design innovative solutions. The initial implementation phase (teaching experiment) will utilize these empirical findings as a reference. For example, the gap between procedural and conceptual skills will be tested through GeoGebra-based exploration activities. At the same time, student preferences for lecturer explanations will be considered when designing a combination of instructional strategies to ensure that the developed design remains contextual and aligned with the students' learning culture.

Next, the results of the initial implementation will be analyzed retrospectively to evaluate the appropriateness of the teaching materials. New findings from this phase will inform the next development cycle. Using an iterative approach, this research aims to produce increasingly mature teaching material designs over the years until they are ready for widespread implementation in the regular curriculum. Ultimately, this study provides empirical contributions through detailed data on student learning needs and offers both practical and theoretical value through the application of a design based research approach. Building on these empirical results, this study also delineates the long term research agenda within the Gravemeijer and Cobb (2006) design research framework. The needs analysis presented here constitutes the starting point for a multi-year trajectory aimed at developing a comprehensive set of Multivariable Calculus learning materials. The planned outputs include a printed instructional module, an interactive digital module supported by GeoGebra-based 3D visualizations, and a sequence of guided reinvention activities aligned with departmental curriculum standards. In the second year, a preliminary prototype of these materials will be constructed and refined through iterative teaching experiments, followed by successive cycles of revision and classroom implementation in subsequent years. The long term goal of this research agenda is to produce a validated, scalable, and curriculum integrated learning resource that systematically addresses the conceptual difficulties identified in this study.

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Discussion

The findings of this study confirm that students experience persistent difficulties in Multivariable Calculus, particularly regarding partial derivatives, extreme values, and the visualization of multivariable functions. These results are consistent with Borji et al. (2022), who reported that students often fail to connect procedural manipulation with the conceptual meaning of mathematical symbols. While Borji's work emphasizes symbolic–conceptual gaps, the present study extends this understanding by showing that such difficulties are intertwined with weaknesses in three-dimensional visualization. This indicates that conceptual errors identified in symbolic tasks cannot be separated from students' limited capacity to mentally represent surfaces, contours, and directional changes.

An important implication emerging from these findings concerns the role of needs-based instruction. The trend highlighted by Herrera et al. (2024) shows that mathematics learning aligned with students' actual needs tends to increase engagement and conceptual depth (Herrera et al., 2024). In this study, needs analysis plays a central role in interpreting student difficulties, especially in the context of technology based learning. Rather than serving as a preliminary administrative step, needs analysis becomes a strategic foundation for determining which aspects of the Multivariable Calculus curriculum require reinforcement, particularly in visual conceptual domains.

The difficulty in three-dimensional visualization experienced by 37.5% of students also aligns with Cheong et al. (2023), who found that weak spatial reasoning hinders understanding of gradients and the behavior of multivariable functions (Cheong et al., 2023). The present study, however, contributes a more specific insight: students' inability to visualize surfaces directly influences their conceptual misunderstanding of two-variable limits and partial derivatives. For example, several students misinterpreted the behavior of functions approaching a point from multiple directions—an error tied closely to how gradients and directional derivatives are conceptualized. This suggests that visualization difficulties form a chain of interconnected conceptual weaknesses that collectively obstruct students' understanding of multivariable ideas.

Students' preference for lecturer explanations (87.5%) demonstrates the continued dominance of traditional teaching methods in KPB learning. Nevertheless, their strong interest in adopting instructional videos and visual applications (75%) indicates readiness for blended learning. These findings reinforce Hevardani et al. (2025), who emphasized that the combination of traditional and digital strategies is more effective than either approach alone (Hevardani et al., 2025). The present study adds nuance by revealing *why* students prefer blended learning: their conceptual challenges especially those involving spatial visualization demand dynamic technological tools that cannot be addressed through conventional lectures.

Students' limited experience with GeoGebra (62.5% had never used it) contrasts with their positive perceptions of its potential benefits. Consistent with Schoenherr (2024), technology adoption in mathematics learning appears driven more by perceived usefulness than prior exposure (Schoenherr et al., 2024). This finding underscores the importance of designing learning materials that directly respond to student needs, particularly interactive modules such as 3D visualizations, context-based mini projects, and multimedia explanations. These preferences echo the conclusions of Medina Herrera et al. (2024), who reported that interactive technology enhances cognitive engagement and motivation (Herrera et al., 2024). The present study extends these insights by identifying specific components that students find most essential particularly 3D visualization and contextual tasks elements that directly support key concepts in Multivariable Calculus.

Integrating needs analysis into the Gravemeijer & Cobb design research framework further strengthens the contribution of this study. Previous research tends to focus either on student difficulties or on the benefits of learning media, without connecting empirical student needs to the *preliminary design* stage of instructional development. This study provides such a bridge by using students' expressed needs to inform the early phases of design, thereby reinforcing the theoretical coherence of the framework and ensuring that pedagogical choices are empirically grounded. Consequently, needs analysis should be regarded not as a secondary diagnostic step but as a core component of designing effective teaching materials for advanced mathematics.

Finally, the findings of this study open opportunities for developing more targeted GeoGebra-based learning materials for Multivariable Calculus. Unlike previous research which examined student difficulties (Borji et al., 2022) or explored the benefits of visual media separately (Cheong et al., 2023; Herrera et al., 2024) this study directly connects empirical needs analysis with the Gravemeijer & Cobb design research framework. This explicit linkage has not been addressed in earlier studies and therefore represents the main novelty of the present work. By integrating students' conceptual difficulties, their technological needs, and the principles of guided reinvention, this study provides a systematic foundation for designing, implementing, and validating GeoGebra-supported Multivariable Calculus materials in the Indonesian higher education context.

Implication of Research

The findings of this study have important implications in three main domains. Theoretically, these results extend the application of the Gravemeijer & Cobb framework in learning Multivariable Calculus, confirming that needs analysis can serve as a foundation for *preliminary design* relevant to students' real-world difficulties. Practically, the questionnaire data indicate the need to develop

GeoGebra-based teaching materials that provide interactive visualizations and facilitate exploration activities, mini-projects, and links to real-world applications. This study provides an initial foundation for further research cycles in the form of implementation (*teaching experiments*) and retrospective analysis, which are expected to produce valid, instructionally meaningful, and generalizable teaching materials for advanced mathematics learning in higher education.

Limitation

This study has several limitations that should be noted. First, there were only eight respondents, so the data obtained is not representative of the broader student population. Second, the online questionnaire instrument provided a general overview of students' difficulties, perceptions, and expectations. However, it did not delve deeply into their learning experiences through interviews or direct observation. Third, this study is only at the needs analysis stage, so the instructional impact of the intervention in the form of GeoGebra-based teaching materials cannot yet be verified. These limitations open up opportunities for further research involving larger samples, incorporating qualitative data collection methods, and testing the validity of the learning design through classroom experiments and retrospective analysis.

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CONCLUSION

This study highlights that students' primary challenges in Multivariable Calculus lie in visualizing multivariable functions, interpreting partial derivatives, and integrating multiple mathematical representations. These findings indicate that traditional instructional approaches, which often emphasize procedural fluency over conceptual understanding, may not fully address students' cognitive needs. The positive perceptions toward GeoGebra suggest that technology mediated tools, when thoughtfully integrated, can enhance conceptual comprehension and support active, exploratory learning. The main contribution of this research is the demonstration that a needs-based analysis, combined with the Gravemeijer & Cobb design research framework, provides a systematic foundation for developing instructional materials tailored to students' conceptual and representational challenges. Building on these results, future research should focus on iterative teaching experiments using GeoGebra-based materials, assess their meaningful in improving spatial reasoning and conceptual understanding, and refine blended learning strategies to optimize engagement and learning outcomes in Multivariable Calculus.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the students who actively participated in completing the questionnaire, enabling this learning needs analysis to be successfully conducted. Appreciation is also extended to the Mathematics Study Program, Faculty of Mathematics and Natural Sciences, Universitas Bale Bandung, for providing facilities and access to the research. Special acknowledgment is given to the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek) through its Research and Community Service Information Base (BIMA) program, the official platform supporting research proposals and reporting. Access to BIMA has streamlined the administrative process for this research and facilitated systematic data management. The authors thank their colleagues for constructive feedback, methodological suggestions, and encouragement while preparing this manuscript. The support and collaboration of all parties will likely contribute positively to the advancement of calculus education in Indonesia.

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4. Bukti Konfirmasi Artikel Accepted (24 Desember 2025)

[Kreano] Your submission has been accepted to Kreano, Jurnal Matematika Kreatif-Inovatif

From Amidi, S.Si., M.Pd. on 2025-12-24 14:56

Details Headers Plain text

The following email was sent to Dini Andiani from Kreano, Jurnal Matematika Kreatif-Inovatif regarding Visualization of Multivariable Calculus: Learning Needs Analysis for GeoGebra-Assisted Teaching Material Development.

You are receiving a copy of this notification because you are identified as an author of the submission. Any instructions in the message below are intended for the submitting author, Dini Andiani, and no action is required of you at this time.

Dear Dini Andiani,

I am pleased to inform you that we have decided to accept your submission. After careful review, we found your submission, Visualization of Multivariable Calculus: Learning Needs Analysis for GeoGebra-Assisted Teaching Material Development, to meet or exceed our expectations. We are excited to publish your piece in Kreano, Jurnal Matematika Kreatif-Inovatif and we thank you for choosing our journal as a venue for your work.

As an open access journal, publication of articles in Kreano, Jurnal Matematika Kreatif-Inovatif are associated with Article Processing Charges (APC). With respect to the business, we convey that the APC is charged to the author of the article for **IDR 2.000.000,-** (for any additional fee, such as translate, etc please see Services and Fees).

APC can be transferred to the account number below:

Bank name: Bank BNI'46
Account number: 1184481447
Name: Detalia Noriza Munahefi

Proof of payment can be sent via discussion menu at the copy-editing stage within 3 days.

Your submission is now forthcoming in a future issue of Kreano, Jurnal Matematika Kreatif-Inovatif and you are welcome to include it in your list of publications. We recognize the hard work that goes into every successful submission and we want to congratulate you on reaching this stage.

Your submission will now undergo copy editing and formatting to prepare it for publication.

You will shortly receive further instructions.

If you have any questions, please contact me from your submission dashboard.

Kind regards,
Editorial Team
KREANO

5. Bukti Konfirmasi Artikel Published Online

(30 Desember 2025)

Next steps for publishing your submission

From Amidi, S.Si., M.Pd. on 2025-12-30 10:18

Details Headers Plain text

The following email was sent to Dini Andiani from Kreano, Jurnal Matematika Kreatif-Inovatif regarding Visualization of Multivariable Calculus: Learning Needs Analysis for GeoGebra-Assisted Teaching Material Development.

You are receiving a copy of this notification because you are identified as an author of the submission. Any instructions in the message below are intended for the submitting author, Dini Andiani, and no action is required of you at this time.

Dear Dini Andiani,

I am writing from Kreano, Jurnal Matematika Kreatif-Inovatif to let you know that the editing of your submission, Visualization of Multivariable Calculus: Learning Needs Analysis for GeoGebra-Assisted Teaching Material Development, is complete. Your submission will now advance to the production stage, where the final galleys will be prepared for publication. We will contact you if we need any further assistance.

If you have any questions, please contact me from your submission dashboard.

Kind regards,

Amidi, S.Si., M.Pd.