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Evaluation of the Implementation of GeoGebra-assisted Advanced Calculus Courses Using the CIPP Model

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Abstract- This study aims to evaluate the implementation of advanced calculus courses assisted by GeoGebra using the CIPP model. This evaluation assessed the relevance, effectiveness, and results of applying GeoGebra as an interactive learning medium. The research approach was descriptive quantitative, with data collection through questionnaires and observations. The research subjects were 36 students who attended advanced calculus courses at FMIPA Universitas Negeri Padang in the July–December 2024 semester. The evaluation results show that in the context aspect, the use of GeoGebra is aligned with the curriculum objectives that support the mastery of advanced mathematical concepts and visualization skills. Regarding input, lecturers have basic competence in using GeoGebra, but not all students are familiar with this software. In terms of process, GeoGebra-assisted learning is interactive, although it is constrained by students' adaptation time to the software. In terms of product, the evaluation results showed increased students' analytical skills and conceptual understanding, although the increase in exam results was not significant overall. The findings recommend the need for intensive training for lecturers and students related to the use of GeoGebra, the provision of technology-based learning guides, and adjustments to lecture strategies to maximize the effectiveness of GeoGebra in supporting advanced calculus lectures.

1. Introduction

Advanced calculus is a core course in mathematics education and science and technology-related programmes of study (Ayebo et al., 2017; Hurdle & Mogilski, 2022). This course is designed to build high-level mathematical thinking skills that include analysis, abstraction, and complex problem solving. Understanding the material of multivariable functions, partial derivatives, double integrals, and vector fields is

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Essential as a foundation in physics, engineering, economics, and computer science (Mahadewsing et al., 2024; Stewart, 2016). Students who can master this material will have the skills to solve real-world problems that require mathematical modelling with a high level of precision.

In the development of science and technology, advanced mathematical thinking skills are one of the core competencies that must be possessed by higher education graduates (Attipoe, 2024; Çelik & Özdemir, 2020; Tashtoush et al., 2024). Advanced calculus hones arithmetic and analytical skills and trains critical and logical thinking skills useful in making data and information-based decisions. In addition, advanced calculus material is an important basis for mastering advanced topics, such as numerical analysis, optimization methods, and mathematical modelling used in science and engineering research (Cargnin-Stieler et al., 2019; Haciomeroglu & Haciomeroglu, 2020; Z. Yang et al., 2020).

Despite its important role, advanced calculus learning in higher education often faces various obstacles (Alp & Sungur, 2017; Ozaltun-Celik, 2021). Difficulties in understanding abstract material, limited visualization of concepts, and low student involvement in learning are challenges that must be overcome (Milenković & Vučićević, 2024). These difficulties are caused by various factors, both internal and external (Ferguson, 2020). One of the main factors is the high level of abstraction of the material. The concepts of multivariable functions, partial derivatives, and double integrals require advanced mathematical thinking skills that not all students have. Students have difficulty understanding the relationship between theory and its application, especially when faced with contextual problems that require mathematical modeling (McCunn & Cilli-Turner, 2020; Ramadoni & Mustofa, 2022).

In addition, students' limited visualization ability is also an obstacle in understanding advanced calculus material (Díaz, 2024; Karakuş & Aydin, 2017). Graphs of three-dimensional functions, vector fields, and double integrals require strong visual imagination. Unfortunately, classroom learning focuses on theoretical and algebraic approaches without adequate visualization support. When students cannot visualize these concepts, their understanding of the material will be superficial.

The next factor is the low readiness of basic mathematics owned by students (Haciomeroglu & Haciomeroglu, 2020). Most students who take advanced calculus courses have a weaker understanding of prerequisite materials, such as basic calculus, linear algebra, and trigonometry (Bakri et al., 2020; Li et al., 2017). This deficiency becomes an obstacle to understanding more complex, advanced material. As a result, students need more time to understand new concepts, which affects their motivation and confidence to learn advanced calculus.

In addition to internal factors from students, lecturers' teaching methods also affect learning effectiveness (Ramadoni & Mustofa, 2022). Conventional learning cannot accommodate students' diverse learning styles (Manurung et al., 2019; Roop et al., 2018). This method tends to make students passive and only focuses on solving routine problems without an in-depth understanding of basic concepts. Therefore, innovation is needed in teaching methods that are more interactive so that advanced calculus learning can run effectively and help students achieve optimal understanding.

GeoGebra is an open-source software that combines geometry, algebra, calculus, and statistics in one interactive platform (Jelatu et al., 2018; Kusumah et al., 2020). With dynamic visualization features, GeoGebra allows students to explore mathematical concepts more in-depth and contextually (Birgin & Acar, 2020; Hussin et al., 2018; Jusufi & Kitanov, 2019). Although GeoGebra has great potential in supporting mathematics learning, implementing this tool in advanced calculus lectures is still not optimal in several universities. Several factors, such as the readiness of lecturers and students in using technology, limited supporting facilities, and limited lecture time, are the main obstacles (Açıkgül, 2021; Dockendorff & Solar, 2017; Horzum & Ünlü, 2017). Therefore, implementing GeoGebra-assisted advanced calculus lectures must be evaluated to identify strengths, weaknesses, and the impact of using this tool on student learning processes and outcomes.

The CIPP (Context, Input, Process, Product) evaluation model developed by Stufflebeam (2014) is a comprehensive approach to evaluating educational programmes. Context evaluation focuses on analyzing the situation behind the need for a programme. This stage aims to identify problems, needs, and opportunities relevant to the programme to be evaluated. A context evaluation may include an analysis of student needs, the relevance of learning objectives to the curriculum, and the program's suitability to the demands of 21st-century competencies. This evaluation provides initial information useful in formulating clear and targeted programme objectives.

The input evaluation stage focuses on the resources, strategies, and plans to implement the programme. This evaluation includes analyzing human resources, facilities, infrastructure readiness, learning methods, and the available budget. Input evaluation aims to provide information on the program's planning quality and feasibility before implementation (Fitzpatrick et al., 2011; Mertens & Wilson, 2019; Stufflebeam & Coryn, 2014). This evaluation can map the readiness of teaching staff and the availability of supporting technology.

Process evaluation aims to monitor programme implementation and identify obstacles that arise during the implementation process. At this stage, evaluators observe the extent to which the programme is implemented according to plan and measure the effectiveness of the strategies used. Process evaluation involves observation of activities, interviews with participants, and analysis of the involvement of all parties involved (Fitzpatrick et al., 2011; Mertens & Wilson, 2019; Stufflebeam & Coryn, 2014). This evaluation assesses the quality of interaction between lecturers and students, the utilization of technology, and the effectiveness of the learning methods applied.

Product evaluation aims to measure the results or impact of the programme that has been implemented. This stage assesses the extent to which the programme objectives have been achieved and the resulting benefits, both in the short and long term. Product evaluation may include improvements in student learning outcomes, concept understanding, problem-solving skills, and learner satisfaction with the programme (Fitzpatrick et al., 2011; Mertens & Wilson, 2019; Stufflebeam & Coryn, 2014). This evaluation not only assesses the program's success, but also provides recommendations for future improvements.

The CIPP model is comprehensive and flexible in evaluating various types of programmes (Keskİn & Yazar, 2020; Ratnaya et al., 2022; Thurab-Nkhosi, 2019). The CIPP evaluation model has been widely used to evaluate learning programmes, curriculum, and technological innovations (Aziz et al., 2018; Zainudin et al., 2023). The results of evaluation through this approach can be the basis for formulating education policies that are more effective, efficient, and sustainable. This model is a sustainable decision-making tool because each evaluation stage provides useful input for programme improvement (Aziz et al., 2018; Stufflebeam & Coryn, 2014). Using the CIPP model, it is hoped that this evaluation can provide a clear picture of the effectiveness of implementing GeoGebra-assisted advanced calculus lectures and provide constructive recommendations for future improvements.

Evaluating the implementation of GeoGebra-assisted advanced calculus courses using the CIPP model is essential to ensure that this technology integration positively impacts learning. Holistic evaluation allows educational institutions to identify learning programs' needs, readiness, implementation, and outcomes. Thus, the CIPP model can effectively improve the quality of mathematics education in the digital era. This research evaluates the implementation of advanced calculus lectures assisted by GeoGebra using the CIPP model.

2. Methods

The research approach is descriptive quantitative, with data collection through questionnaires and observations. Quantitative descriptive research aims to systematically, objectively, and accurately describe certain phenomena using quantitative data (Creswell & Creswell, 2018). Quantitative data obtained in the form of numbers are processed and analyzed by statistical methods. This research focuses on a phenomenon without intervening (Sugiyono, 2013).

The research subjects were 36 students who attended advanced calculus lectures at FMIPA Universitas Negeri Padang in the July–December 2024 semester. This research is expected to be the basis for improving the quality of advanced calculus learning by utilizing technology to improve students' concept understanding and mathematical thinking skills. The questionnaire lattice for evaluating the implementation of advanced calculus lectures using GeoGebra is described in Table 1.

Table 1. Evaluation Questionnaire Grid for the Implementation of Advanced Calculus Lectures Assisted by GeoGebra

Aspects of Evaluation	Indicator	No. Item
Context	The suitability of lecture objectives with student needs.	1, 2
	Relevance of advanced calculus material to competency demands.	3, 4
Input	Availability of GeoGebra supporting facilities and infrastructure.	5, 6
	Lecturers' readiness to teach using GeoGebra.	7, 8
	Students' initial understanding of the use of GeoGebra.	9, 10
Process	Clarity of material delivery using GeoGebra.	11, 12
	Active interaction between lecturers and students during lectures.	13, 14

Aspects of	Indicator	No.

Evaluation		Item
Product	Utilization of GeoGebra in visualizing abstract concepts.	15, 16
	Improved student understanding of advanced calculus material.	17, 18
	Student satisfaction with GeoGebra-assisted learning.	19, 20

The data obtained was then processed using descriptive statistical techniques, such as frequency, percentage, average, and standard deviation. This technique aims to provide a clear picture of the characteristics of the data collected. Descriptive statistics assist researchers in summarizing large data into simpler and easier-to-understand information, such as through tables, graphs, or diagrams (Creswell & Creswell, 2018).

3. Results and Discussion

Evaluating the implementation of GeoGebra-assisted advanced calculus lectures using the CIPP model provides a comprehensive picture of the learning program's effectiveness. Each evaluation dimension provides different but complementary information to assess the success of this course. Tables 2 to 5 outline the results of evaluating the implementation of advanced calculus lectures using GeoGebra.

(a) Context Evaluation Results

The evaluation was conducted to ensure the relevance of the learning programme's objectives and background to the students' needs and competency demands in the digital era. Table 2 outlines the results of the context evaluation.

Table 2. Context Evaluation Results

No	Statements	Strongly Disagree (SD)	Disagree (D)	Agree (A)	Strongly Agree (SA)
1	The GeoGebra-assisted advanced calculus lecture aims to meet my needs as a student.			27.8%	72.2%
2	The material presented in the lectures aligns with the needs of the world of work and my academics.			33.3%	66.7%
3	The advanced calculus material is relevant to the competencies needed in my field.			38.9%	61.1%
4	The advanced calculus material taught can be applied to solving real problems.		2.8%	33.3%	63.9%

These results indicate that the objectives of GeoGebra-assisted advanced calculus lectures are relevant to student needs, especially in improving understanding of coordinate systems, partial derivatives, double integrals, and their applications. This has been relevant to the demands of competence in the technological era. GeoGebra, as a learning tool, provides ease of visualization and interactivity, an important demand in modern mathematics learning.

However, there is a gap between the programme's theoretical relevance and students' perceptions of their needs. Some students felt that the program did not fully accommodate their basic skills in using technology. As Starkey (2011) argues, although students are often regarded as the digital generation, not all have high digital literacy. This indicates the need for an initial assessment of students' abilities before implementing the program. With this assessment, lecturers can adjust learning strategies to be more inclusive (Sugiyono, 2013).

Students' digital literacy skills determine their success in using technology, such as GeoGebra, to solve problems or visualize concepts. For example, students with high digital literacy tend to adapt more quickly to mathematics software and can explore various features to understand integral or differential concepts. In contrast, students with low digital literacy often find it difficult, hindering their learning process (Hohenwarter et al., 2008). This poses a major challenge in ensuring equitable access and successful learning (X. Yang, 2023).

Educational institutions must support students' digital literacy skills, including providing digital literacy training, access to technology tools, and systematic technology integration in the curriculum. These programmes can help students understand how mathematics software and other technologies work so that they can use them effectively in their learning. Lecturers need to adopt pedagogical approaches that support the development of digital literacy, such as providing technology-based assignments and encouraging students' independent exploration of digital tools (Ng, 2012).

(b) Input Evaluation Results

In the input aspect, the evaluation focused on resource readiness, including the lecturer's competence, the availability of facilities and infrastructure, and students' readiness to use GeoGebra. The results of this evaluation can be seen in Table 3 below.

Table 3. Input Evaluation Results

No	Statements	Strongly Disagree (SD)	Disagree (D)	Agree (A)	Strongly Agree (SA)
5	Supporting facilities and infrastructure, such as smartphones, laptops, and the internet, are adequate for GeoGebra-assisted learning.			19.4%	80.6%
6	I am confident in using GeoGebra during lectures.		2.8%	58.3%	38.9%
7	Lecturers have a good ability to use GeoGebra during lectures.			27.8%	72.2%
8	Lecturers provide effective guidance in using GeoGebra to understand advanced calculus concepts.			25%	75%
9	I learnt to use GeoGebra independently from the internet.		5.6%	69.4%	25%
10	I used GeoGebra to check the answers to the problems I did.			50%	50%

Lecturers have adequate competence in using GeoGebra, both from a technical and pedagogical perspective. This competence is important considering that lecturers play a central role in successfully implementing technology in learning (Henderson et al., 2015). Without adequate competence, GeoGebra's potential in improving the quality of mathematics learning is difficult to realize (Arbain & Shukor, 2015). Lecturers can integrate GeoGebra into the learning process so that it helps students understand difficult concepts. However, the main obstacle lies in students' access to hardware and software.

Students' level of technological literacy varied, so some needed additional time to adjust to the use of GeoGebra in learning. This is relevant to the findings of Çakıroğlu (2023) that technology integration in learning requires adequate infrastructure support and training for users. Technology provides tools to visualize complex mathematical concepts (Bilgiç, 2022; Kaşçı & Selçuk, 2021). For example, GeoGebra allows students to draw function graphs, explore the relationship between integrals and differentials, and understand dynamic changes in mathematical equations (Khalil et al., 2019).

Students can more intuitively understand the interrelationships between concepts through these visualizations than through conventional learning methods. In addition, technology supports discovery-based learning, where students conduct mathematical experiments independently by modelling real problems and analyzing their mathematical solutions. This is in line with the constructivist learning approach, which emphasizes the role of students in building their understanding through active exploration (Jirasatjanukul et al., 2023).

(c) Process Evaluation Results

The evaluation on the process aspect assessed the extent to which the lecture took place according to the planning and the effectiveness of using GeoGebra in learning activities. Table 4 shows the results of evaluating the implementation process of advanced calculus lectures using GeoGebra.

Table 4. Process Evaluation Results

No	Statements	Strongly Disagree (SD)	Disagree (D)	Agree (A)	Strongly Agree (SA)
11	The material presented with the help of GeoGebra is easy to understand.			50%	50%
12	GeoGebra makes it easier to understand abstract concepts in advanced calculus.		2.8%	36.1%	61.1%
13	Lecturers provide opportunities for students to ask questions or discuss during lectures.		2.8%	13.9%	83.3%
14	GeoGebra facilitates active interaction between lecturers and students in understanding advanced calculus material.			41.7%	58.3%
15	The visualizations produced by GeoGebra increased my interest and motivation to learn.			47.2%	52.8%
16	I believe GeoGebra is easy for mathematics students to understand.			55.6%	44.4%

math.ppj.unp.ac.id Rangkiang Mathematics Journal Vol 4, No.1 , 2025

This indicates that the learning process went well through interactive and participatory methods. In its implementation, students are given worksheets to discuss in their groups. Then, students solve the problems given using GeoGebra. They can access GeoGebra via mobile phones or laptops. GeoGebra allows students to interact directly with mathematical concepts through simulations and dynamic graphics, which have been proven to improve their understanding of the material (Hohenwarter et al., 2008).

However, there are obstacles related to the time allocation, which is deemed inadequate for exploring GeoGebra's more complex features. The time limitation allows students to utilize only the basic features of GeoGebra without understanding the full potential of this software. As a result, their ability to utilize GeoGebra to understand mathematical concepts in depth is limited. Birgin (2020) asserted that students with more time to explore GeoGebra better understand concepts than those with limited learning time. Some students have no previous experience in using GeoGebra. Without adequate initial training, lecture time is often consumed by introducing basic features, reducing time for students' independent exploration of more complex features (Arbain & Shukor, 2015). Therefore, effective strategies, such as initial training, integration in independent assignments, and study guides, are needed to overcome this obstacle. With the right approach, GeoGebra can significantly positively impact mathematics learning.

Effective interaction between lecturers and students is crucial in technology-based learning because it helps students feel more involved and motivated (Ayuwanti et al., 2021). In modern education, technology becomes a connecting tool that can expand opportunities for interaction between lecturers and students in synchronous and asynchronous forms (Mohammad et al., 2024). This interaction plays a role in delivering material and providing academic support, motivation, and personalized guidance. Lecturers who are responsive and adaptive to student needs can create an inclusive learning atmosphere where students feel supported and valued (Rose, 2024).

(d) Product Evaluation Results

In the product aspect, the evaluation assesses the final result of the lecture. This can be seen from improving students' understanding of advanced calculus material and their satisfaction with GeoGebra-assisted learning. The results of this evaluation are outlined in Table 5 below.

Table 5. Product Evaluation Results

No	Statements	Strongly Disagree (SD)	Disagree (D)	Agree (A)	Strongly Agree (SA)
17	Using GeoGebra improved my understanding of advanced calculus material.			47.2%	52.8%

18	I understand graphs in three-dimensional space better by using GeoGebra.	2.8%	36.1%	61.1%
19	Advanced calculus lectures become interesting and fun with GeoGebra.		41.7%	58.3%
20	I used GeoGebra for several courses.		50%	50%

Most students experienced significant improvement in their understanding of advanced calculus concepts. They stated that GeoGebra helped visualize previously difficult concepts that could only be understood through conventional methods. De Las Peñas (2024) revealed that using GeoGebra in learning improved students' conceptual and analytical understanding skills. However, some students feel that the increased understanding is not very significant. This is due to limitations in access to technology and digital literacy that impact the effectiveness of their learning.

In addition, students' satisfaction with GeoGebra-assisted learning varies. Student satisfaction reflects how GeoGebra successfully meets their learning needs regarding concept understanding, engagement, and learning motivation (De Las Peñas et al., 2024; Jusufi & Kitanov, 2019). GeoGebra allows students to interact directly with the subject matter. They can change parameters in equations or graphs to see the impact in real-time, making learning more engaging. This interactivity promotes discovery-based learning where students actively explore and understand mathematical concepts. Student satisfaction increases when they feel they are part of the learning process, not just recipients of information (Hohenwarter et al., 2008).

Although students are satisfied with GeoGebra-assisted learning, several challenges may affect their satisfaction levels. One is the lack of initial training on how to use the software. Students unfamiliar with GeoGebra may feel frustrated, especially if they have low digital literacy (Ng, 2012). Support from lecturers in effectively integrating GeoGebra into learning is also very important. Lecturers who do not utilize GeoGebra's features to their full potential may reduce the potential benefits of this tool (Kim & Md-Ali, 2017).

4. Conclusion

The results of the context evaluation show that advanced calculus lectures assisted by GeoGebra have good relevance to students' learning needs. Regarding input, lecturers' readiness is quite good, but there are constraints on the availability of facilities and students' technological literacy. The process evaluation shows that the interactive learning method was successfully implemented despite time and communication constraints. Meanwhile, the product evaluation indicates increased students' understanding of the material, although there is room for improvement regarding technical support and more inclusive learning. These results indicate the importance of synergy between learning objectives, resource availability, and implementation processes to produce optimal products. To improve the success of the program, several recommendations that can be given include providing initial training to students on the use of GeoGebra to ensure adequate technological literacy, increasing the accessibility of supporting devices, adopting a more interactive learning approach to improve communication between lecturers and students, and conducting periodic evaluations to ensure that the program continues to be relevant and adaptive to students' needs.

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math.ppj.unp.ac.id Rangkiang Mathematics Journal Vol 4, No.1 , 2025