Development and Application of a Chatbot for University-level Calculus Learning

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Abstract

This paper introduces an AI-powered calculus chatbot, 'Solgit', designed to support college-level math education through both in-class and self-directed learning. Using Retrieval Augmented Generation (RAG) technique, the 'Solgit' chatbot provides accurate responses by linking subject-specific materials. The chatbot offers diagnostic tests, tailored precalculus reviews, and generates diverse calculus problems with solutions. It supports student-led learning by allowing instructors to assign weekly keywords for exploration. Students can study, organize concepts, and collaborate with classmates anytime. Practical examples show that this calculus chatbot enhances engagement and learning efficiency, demonstrating the potential of subject-specific generative AI as an effective, affordable tool in higher education. In this paper, we share the contents and experiences that we have tried. The chatbot was developed first in Korean, but has the potential to adapt to other languages.

Keywords: Artificial Intelligence (AI), Chatbot, Calculus, College Mathematics Education

1 Introduction

The rapid development of generative AI, led by ChatGPT, has significantly influenced various academic disciplines, including education. In mathematics education, such applications have been explored to assist students in understanding concepts and solving problems. For example, Pepin et al. (2025) presented a scoping survey examining the integration of ChatGPT in school and university mathematics education, highlighting its benefits, challenges, and implications for teaching and learning. Two recent studies illustrate the application of AI in educational settings. Gouia-Zarrad and Gunn (2024) found that ChatGPT could generate personalized codes for solving differential equations, significantly improving student engagement. Similarly, Lee and Yeo (2022) developed an AI chatbot to foster better responsive teaching skills in future elementary mathematics teachers. Furthermore, Gurl et al. (2025) explored the role of ChatGPT as a lesson-planning assistant for preservice secondary mathematics teachers (PSTs). These prior studies highlight both the potential and limitations of generative AI in education, suggesting the need for more subject-specific, structured applications such as the one proposed in this paper.

However, there are currently few generative AI tools specifically designed for university-level mathematics. Existing AI chatbots are primarily based on natural language models, which can produce inaccurate answers due to insufficient training data (Jancarik & Dušek, 2024). Most existing AI tools provide procedural support through step-by-step solutions that solve the problem at hand but does not foster conceptual understanding. Therefore, it is necessary to develop an AI chatbot that serves as a supplementary tool for conceptual learning.

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An AI-driven pre-learning chatbot for university-level calculus education may help with learning difficulties and foster more personalized support for students. This work builds upon previous research by the authors on the use of ChatGPT in college mathematics education (Lee et al., 2024). This study introduces an AI chatbot[1] designed for university-level calculus education. The chatbot utilizes Retrieval Augmented Generation (RAG[2]) technology (Gao et al., 2023), leveraging textbooks, codes, and practice problems to enhance response accuracy. That is, we developed a customized chatbot by integrating ChatGPT with materials related to calculus. Hence, the chatbot is ChatGPT specific. Additionally, it assesses students' mathematical proficiency, providing targeted reviews of fundamental concepts from precalculus. The chatbot also organizes keywords to facilitate structured queries, presents practice problems alongside explanations, and offers step-by-step solutions. Moreover, it includes an algorithm for problem generation, ensuring varied and dynamic problem sets alongside providing links to educational videos that supports students in self-directed study.

Building on these features, the study is guided by the following research questions:

1. How can a domain-specific generative AI chatbot be designed to support conceptual and procedural learning in university-level calculus?
2. In what ways does the chatbot enhance student engagement and self-directed learning in a flipped classroom model?

Additionally, our work is grounded in the TPACK (Technological Pedagogical Content Knowledge) framework, which highlights the integration of content, pedagogy, and technology in effective instructional design. By applying TPACK principles, we aim to ensure that the chatbot does not merely provide procedural support but fosters conceptual understanding in line with sound pedagogical practices.

In sum, this research presents practical applications of the calculus chatbot and discusses how it enhances student engagement and learning efficiency. The paper also outlines key implementation details, user interaction flows, and design considerations so that educators may understand how to integrate or adapt similar AI tools for their own instructional contexts. Accordingly, the paper outlines practical design principles and usage scenarios to inform the development or adaptation of similar chatbots for university-level calculus instruction. Thus, future users of the chatbots can expect to greatly improve the quality of university-level calculus education. This study primarily focuses on college-level calculus education, though the chatbot design allows for adaptation to other educational levels as well.

2 Background

Mathematics education relies heavily on conceptual learning and problem-solving. In university settings, large class sizes often prevent instructors from providing individualized feedback to students, resulting in difficulties in comprehension and retention. Consequently, there is growing demand for supplementary learning tools that support independent studying for students. Our previous research, Lee et al. (2024), is one example of a response to the increasing need for individualized and supplementary learning support in mathematics education. This paper is a consequence of Lee et al. (2024) and expands upon more details.

The emergence of generative AI has introduced AI-powered learning assistants that enhance education. Among these, chatbots—a kind of AI agent that will incorporate RAG technology, extend beyond simple question-answer interactions by integrating extensive domain-specific data. This includes textbooks

[1] Readers interested in testing Solgit can access a demonstration version at https://precalc.solgitmath.com using the login ID dev30@procyan.com and password Dev123$%^. [2] RAG refers to an AI framework for retrieving facts from external knowledge, providing the most accurate and up-to-date information to large-scale language models (LLMs), and providing users with insight into the generation process of LLMs.

and practice problems to provide accurate and contextually relevant responses. This advancement opens new possibilities for enhancing university-level mathematics education. Below are a few examples of developments related to mathematical AI in Korea that were analyzed in this study.

On January 8, 2024, Upstage announced the development of SAAS[3], a large language model specialized in the mathematical domain. This model is reported to outperform those of Microsoft and OpenAI's GPT-4 on two key benchmarks: the MATH benchmark and GSM8K (Kim et al., 2024). However, rather than supporting the overall learning process, it primarily focuses on solving individual problems, which may lead to a high level of learner dependence on the AI model. MathFlat[4] (commonly used in South Korea) developed an AI-powered mathematics education platform on April 25, 2024. It offers learning support functions integrated with an AI chatbot and incorporates LaTeX-based mathematical input along with a math voice TTS feature. However, because it is primarily designed for elementary to high school students, its application at the university level is limited. MataEdu AI[5] (commonly used in South Korea) remembers students' submitted responses to the AI, identifies their weak concepts, and provides practice problems to reinforce those areas. Notably, it includes university-level as well as K-12 level mathematics education content and is optimized for progress management based on learner data. However, since it is primarily focused on progress management, its real-time interaction capabilities are limited.

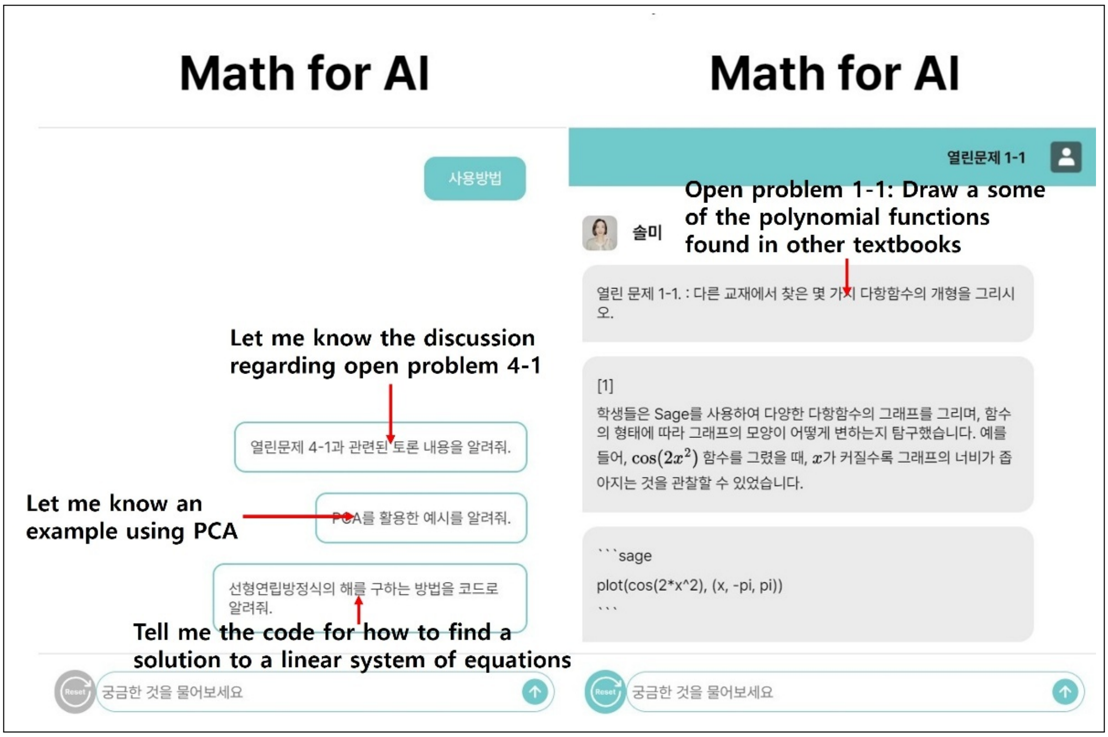
Procyan[6] offers Solgit, a mathematics learning service powered by generative AI. It provides an integrated learning experience encompassing diagnosis, learning, and assessment by automatically generating answers and solutions through its proprietary technology. Procyan also developed a university-level chatbot[7] for Mathematics for AI, which was applied in actual classroom settings. According to their reports, students understood most of the core concepts and open-ended problems presented in the course by sharing and discussing the responses generated by the chatbot. Figure 1 shows screenshots and examples of its use. For more details, refer to Lee et al. (2024).

Our current research builds on the 'Solgit' project and offers preliminary evidence that supports its reported educational effects.

[3] https://www.upstage.ai/ [4] https://www.mathflat.com/ [5] https://mataedu.com/ [6] https://www.procyan.co.kr/
[7] https://math4ai.solgitmath.com/

Figure 1

The chatbot for mathematics for AI (Lee et al., 2024)



We have previously undertaken various efforts to enhance university-level mathematics education. In particular, we have developed textbooks and other content that allow students to review precalculus[8] while learning university-level calculus[9] efficiently with coding. By utilizing these resources, students have been able to reduce the burden of complex calculations, instead using the extra time to engage in discussions with peers and instructors, leading to a deeper understanding of calculus. Consequently, the process of deriving complex mathematical expressions can be handled with AI, allowing for a more focused and concept-driven learning experience. For further details, refer to Lee et al. (2022). The calculus chatbot introduced in this paper is the result of applying the technological expertise gained from these research experiences. In addition, the chatbot addresses the limitations of conventional generative AI models by employing RAG-based retrieval techniques and personalized learning pathways. By analyzing individual learning progress, the chatbot offers customized problem sets and study materials, facilitating a more adaptive learning experience.

Furthermore, the chatbot's design is grounded in constructivist learning theory, which emphasizes learner autonomy, scaffolding, and formative assessment. Its use of diagnostic tools and adaptive feedback aligns with key principles from learning sciences (e.g., Bransford et al., 2000), supporting students' self-regulated learning and conceptual development.

This study examines the chatbot's development, application in real classroom settings, and potential role in AI-driven education. It will be introduced in detail in the next chapter.

3 Development of an AI-Based Chatbot for University Level Calculus Education

The use of AI chatbots in university-level calculus courses offers multiple benefits for both students and instructors. First, students can engage with the chatbot at any time to review concepts, ask questions, and solve practice problems. The chatbot provides not only step-by-step explanations but

[8] http://matrix.skku.ac.kr/9th-Grade/, http://matrix.skku.ac.kr/10th-Grade/, http://matrix.skku.ac.kr/11th-Grade-1/, http://matrix.skku.ac.kr/11th-Grade-2/, http://matrix.skku.ac.kr/12th-Grade-1/, http://matrix.skku.ac.kr/12th-Grade-2/

[9] http://matrix.skku.ac.kr/S-calculus/

also generates practice questions tailored to individual learning needs. This approach enables students to reinforce their understanding through iterative learning.

Second, the chatbot serves as a supplementary instructional tool for instructors. By predefining key learning concepts for each lecture, instructors can guide students toward structured inquiries and encourage independent exploration of course materials. The chatbot also categorizes students' queries based on key topics, allowing for a more systematic review process.

Third, the chatbot facilitates collaborative learning among students. By organizing their learning materials, sharing explanations provided by the chatbot, and engaging in discussions, students can deepen their understanding of calculus concepts. The chatbot-generated practice problems can furthermore be used in study groups, enabling peer-led problem-solving sessions that enhance comprehension.

The chatbot[10] developed in this study, Solmi, is designed to support university-level calculus learning with a primary focus on Calculus I—a component of a one-year introductory calculus course that covers functions, limits, derivatives, differentiation, indefinite and definite integrals, sequences, and infinite series. When a user submits a query, the system interacts with GPT through internal backend logic in conjunction with a structured database of calculus content. The system retrieves learning materials that are highly relevant to the user's question and generates optimized responses through GPT, which are then delivered to the learner. This process is designed to provide a more structured and in-depth learning experience.

To effectively apply AI-based chatbots in university-level calculus education, the structuring of knowledge into the data and design of internal backend logic play a critical role. This study outlines three key approaches to delivering high-quality learning outcomes to users and proposes specific strategies for data construction and system design for the chatbot.

Learning data[11] for university-level calculus education was collected from various sources including textbooks, web-based practice environments[12], and previous lecture recordings[13]. Textbooks in PDF format were converted into text using OCR and categorized based on their table of contents, while web resources and lecture logs were transformed through text extraction. The collected data was converted into n-dimensional vectors using embedding techniques[14] and stored in a vector database to enable fast retrieval of relevant content. Web-based resources are continuously updated through batch processing to reflect ongoing learning progress.

The core learning support function of the chatbot is built on a RAG pipeline and follows the steps below:

1. The user's question is converted into a vector embedding, which is then used to retrieve relevant learning information from a vector database.
2. The retrieved content and the user's original query are programmatically combined and submitted to the GPT model through our backend system. The system internally reformulates the question's logic to enable GPT to generate a more accurate response.
3. The chatbot system provides GPT-generated responses through a web-based interface. It also analyzes user interactions to recommend related problems that align with the learner's current level and topic.
4. To incorporate up-to-date learning materials, an iterative process is implemented to regularly update the database by the chatbot.

[10] https://precalc.solgitmath.com/ [11] https://buk.io/@kc7894 [12] http://matrix.skku.ac.kr/S-Calculus/ [13] http://matrix.skku.ac.kr/2022-S-Final-PBL/ [14] Vector embeddings are numerical representations that capture the relationships and meaning of words, phrases and other data types.

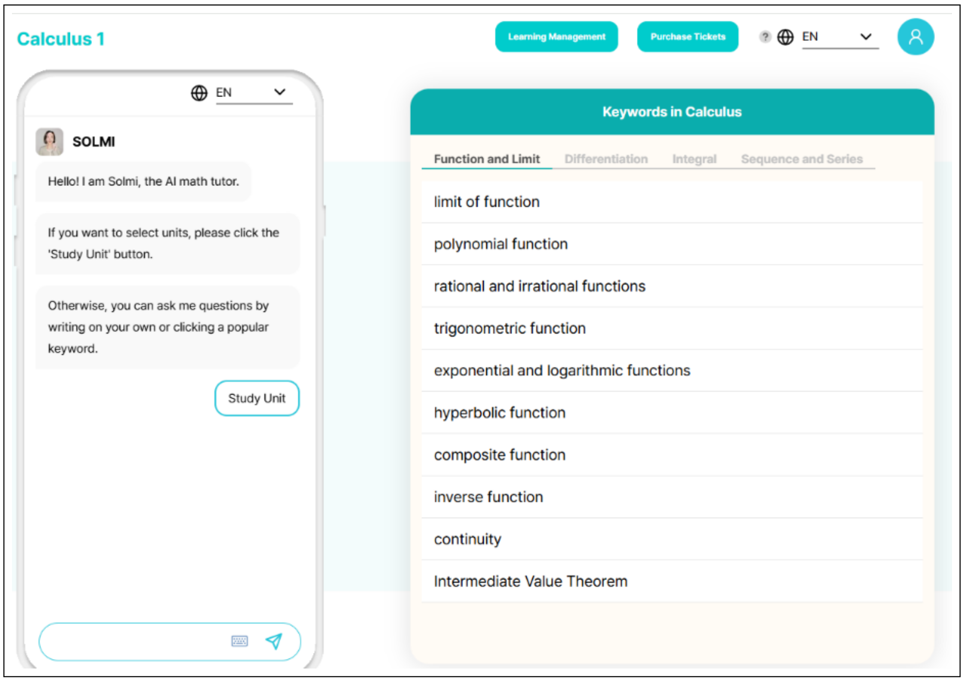
To ensure mathematical precision and support conceptual understanding, the chatbot employs predefined tagging and structured prompts, particularly for multi-step problems. For example, when a student submits a question involving the derivative of a composite function, the system not only performs symbolic differentiation but also explains the chain rule using formal notation and guided reasoning.

Beyond the core RAG-based interaction pipeline, our AI chatbot system includes additional learning support features to enhance the effectiveness of the learning experience. For example, the "Solmi (meaning 'solve me')'s Step-by-Step Explanation" function, which is built into the system, allows users to input a problem and its solution process into the GPT model. The system then internally analyzes the input, logically organizes each step of the solution, and provides detailed explanations alongside relevant conceptual information to support learners' understanding. It is designed to present definitions, theorems, and examples related to the problem, enabling GPT to generate more accurate mathematical explanations.

Additionally, the AI calculus chatbot developed in this study offers several distinctive features. It diagnoses learners' prior knowledge to recommend personalized learning pathways and supports structured learning by sequentially delivering conceptual explanations and practice problems. When users ask open-ended questions, the AI responds based on related concepts and also suggests supplementary materials linked to textbooks and lecture content.

For example, as shown in Figure 2, the calculus AI chatbot presents the topics of Calculus I in four categories: limits of functions, differentiation, integration, and sequences and series.

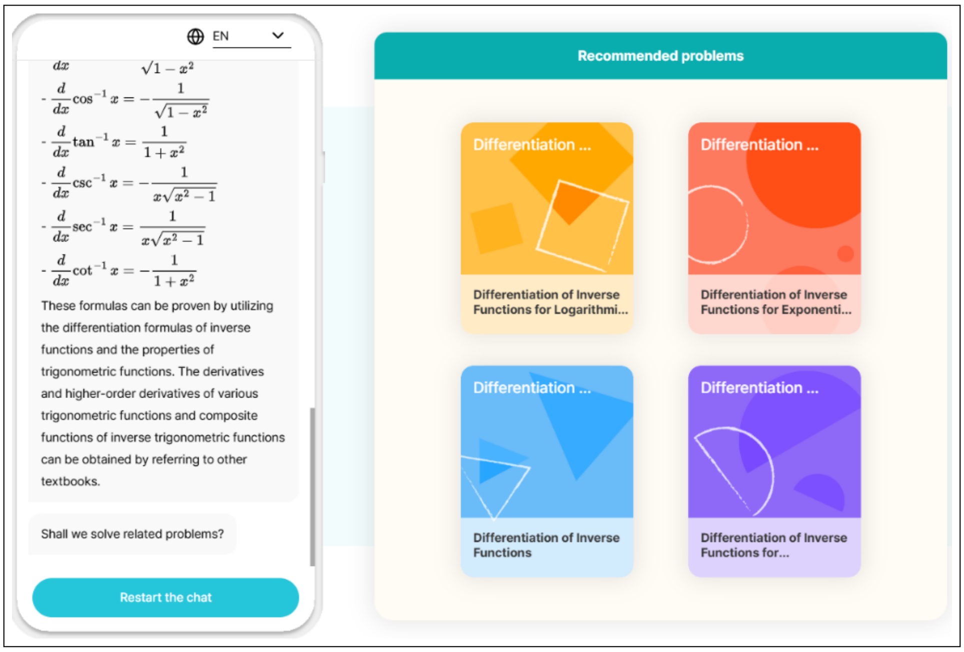
Figure 2
Main interface of the calculus AI chatbot showing four topic categories



When a question keyword is selected, our AI chatbot tutor, Solmi, provides an answer related to the concept along with an example, as shown in the left of Figure 3. It also suggests recommended problems, as shown in the right of Figure 3.

Figure 3

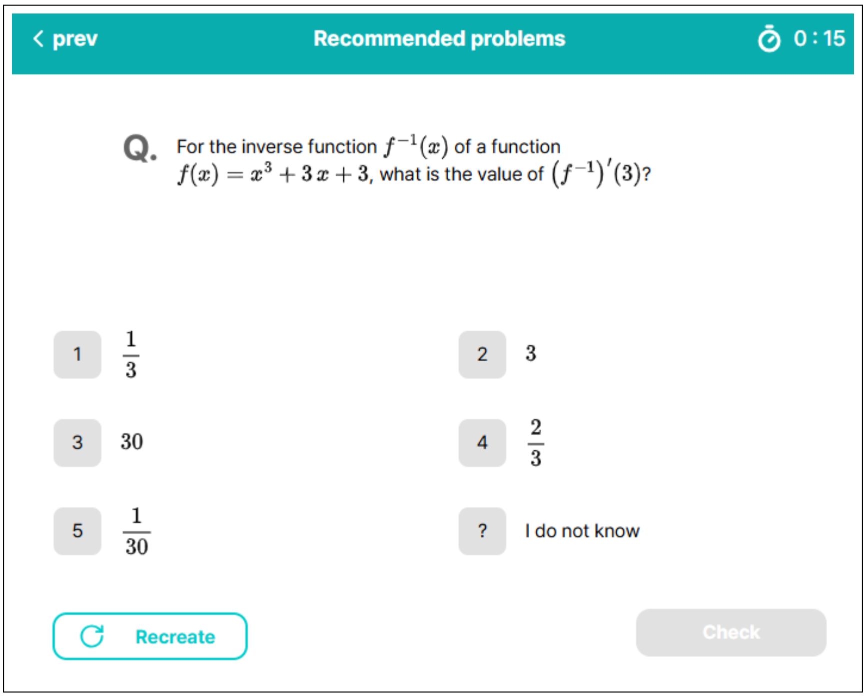
Chatbot response showing concept explanation (left) and recommended problems (right)



When a recommended problem is selected, the tutor system provides an example problem in a multiple-choice format as shown in Figure 4.

Figure 4

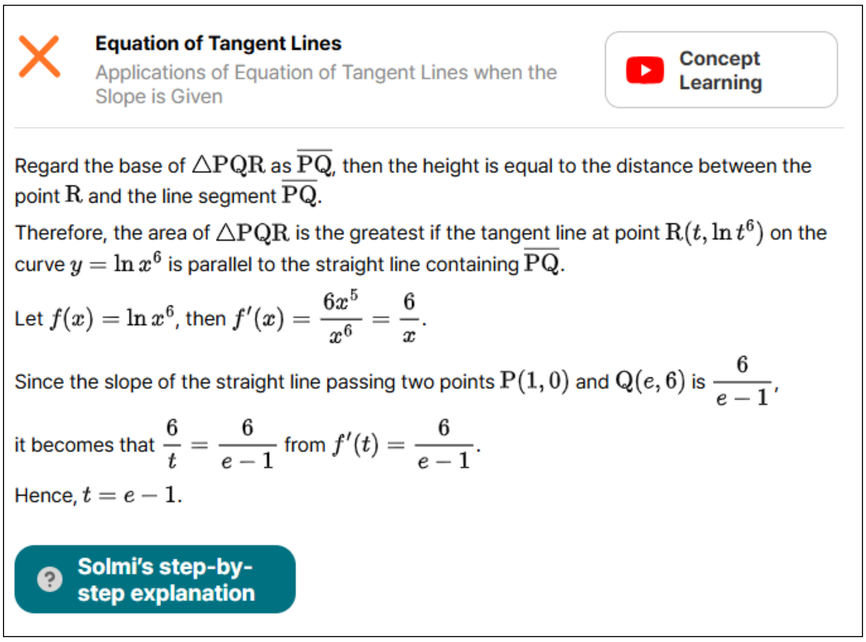
Example of a recommended problem in multiple-choice format



When a student selects an answer and presses the "Submit" button, the system, Solmi, provides feedback indicating whether the answer is correct or incorrect, along with a detailed solution, as shown in Figure 5. Additionally, when generating adaptive math problems for the student using its proprietary algorithm, the system simultaneously creates the correct answer and corresponding solution. Each time a new problem is generated, the answer and solution are automatically updated, enabling the delivery of personalized and differentiated problems for each learner—that is, depending on the learner's level of understanding. Thus, during the learning process, the system evaluates the student's understanding of a specific mathematical concept and adaptively adjusts the learning path to improve their comprehension. It then provides adaptive problems along with corresponding solutions.

Figure 5

Detailed solution with step-by-step explanation provided by the chatbot



This step-by-step breakdown (described earlier in Section 3) can be especially helpful when students revisit problems independently. The 'Concept Learning' section (Figure 6) complements this by offering concise explanations and links to YouTube lectures for further review. The learning content suggested by the system is adjusted throughout the learning process based on the student's improvement in understanding.

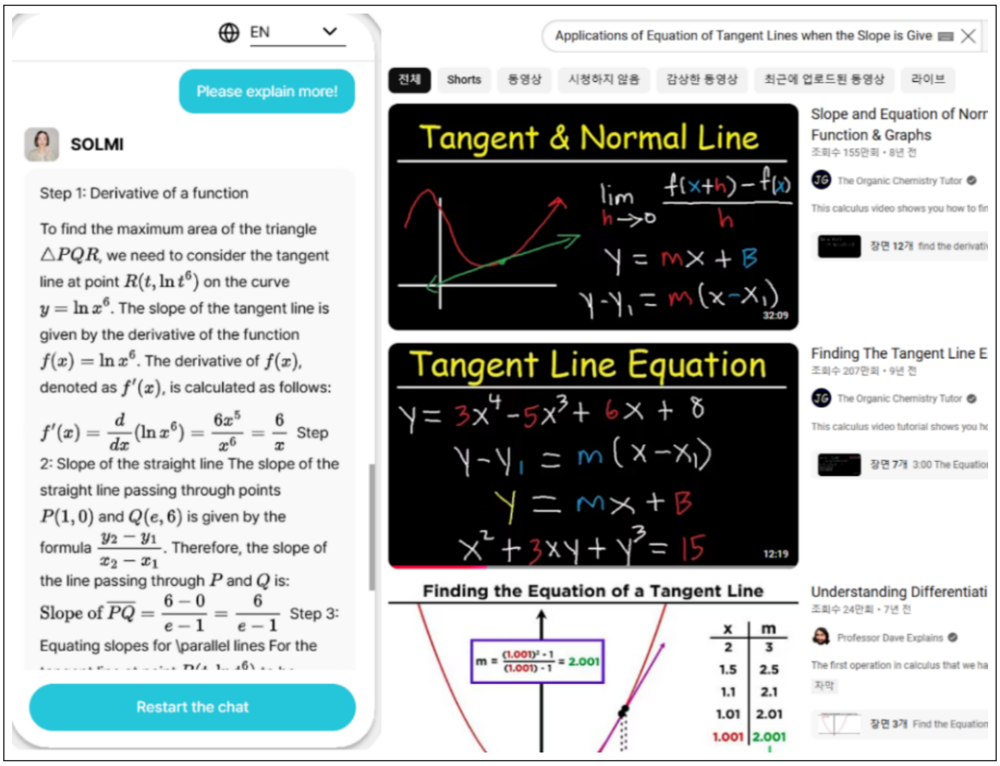
Furthermore, students who lack a solid understanding of precalculus concepts while preparing for university-level math can use the "Study Unit" feature in the chat window to review topics as shown in Figure 7. This function helps learners solidify their understanding of prerequisite knowledge and better prepare for learning calculus at the university level. By engaging learners with structured review materials, the system encourages them to revisit foundational concepts that they might otherwise neglect.

This calculus chatbot also features a mechanism for automatic translation into 104 languages, providing learning support for non-native English students and international learners. For 12 major languages, the system has demonstrated an accuracy rate of over 95%. Figure 8 shows a screenshot translated into Spanish.

To ensure ethical use and data privacy, the chatbot is designed to operate with anonymized logs of student interactions. No personally identifiable information is stored unless explicitly consented to. When integrated with institutional LMS platforms, user data remains within closed systems under institutional data policies. Moreover, we implemented prompt filtering mechanisms to reduce hallucination risks and ensure mathematical factuality. All generated content is tagged with source metadata when available (e.g., textbook sections). Further testing is underway to refine output monitoring and mitigate risks of misinformation or student overreliance.

Figure 6

Concept learning section with explanations and links to YouTube lecture videos



4 Use of the Chatbot in the Course

The calculus AI chatbot developed in this study can be utilized in various ways in university-level courses. First, instructors can use it as a real-time Q&A tool during lectures to immediately address students' questions. In problem-solving sessions, the chatbot can present multiple solution methods, thereby broadening the scope of learning. It can also be effectively used to provide individualized guidance during assignments and exam preparation. Furthermore, it enables the collection of data for process-oriented assessments, such as discussion logs recorded within the learning management system (LMS).

Students can use the AI chatbot as a review tool before and after lectures to engage in self-directed learning. They can also design personalized learning pathways through concept-based learning modules. In group study sessions involving the AI chatbot, students receive automated feedback that could facilitate both discussion and learning. The following are some students comments from after the semester ended.

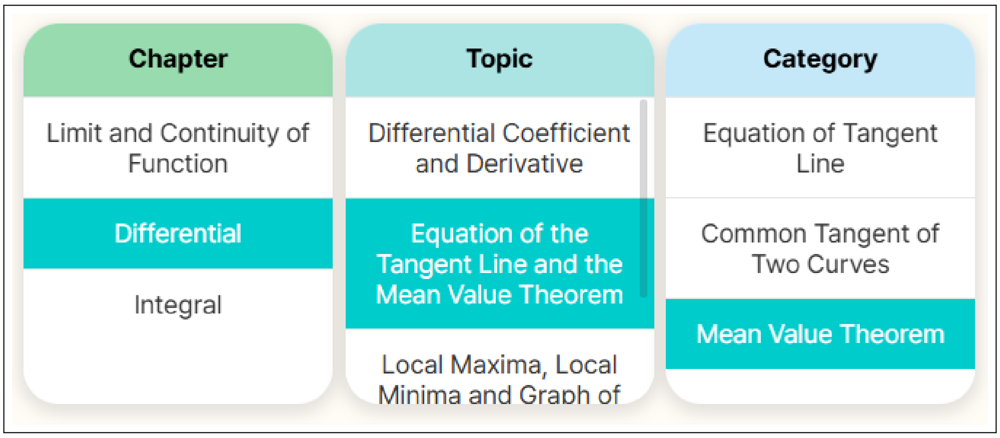
> "When solving problems, Solmi allowed me to rethink the concepts I had learned in the past, such as those learned in high school. If I didn't know how to approach problems conceptually, Solmi helped me by teaching me the concepts."

> "After solving a problem, I was able to quickly check whether or not I was correct. At the same time, Solmi also provided brief commentary to ensure my understanding of any parts of the problem that I did not thoroughly understand."

> "By using Solmi's problem recommendation feature, I was able to solve various types of problems. It was very useful to be able to work on multiple problems focused on a desired concept determined by simply entering a couple keywords."

Figure 7

Precalculus chapters, topics, and categories



> "When I couldn't understand Solmi's solution, the concept could be learned by video through the concept learning YouTube link. This made it easier to understand the content than with the text alone."

In addition, the AI chatbot can be actively utilized in the assessment and feedback processes by analyzing each student's level of understanding based on their learning history and providing this information to instructors. It also analyzes students' incorrect answer patterns and suggests remedial learning strategies.

Evidence from post-course surveys and interviews indicated that students experienced increased confidence in solving calculus problems and greater autonomy in managing their learning. One student remarked, "Solmi helped me realize what I didn't understand before class. I could try multiple problems and get explanations until it made sense—it felt like having a tutor on standby." Others noted that the chatbot helped reduce anxiety about asking questions in large classes. Overall, student feedback highlighted the benefits of instant feedback, conceptual scaffolding, and language support features.

The flipped learning model for calculus using this chatbot was designed with reference to previous research on university mathematics education (Go et al., 2024; Lee et al., 2024; Lee et al., 2020). This model aims to complement traditional lecture-based instruction and maximize students' learning outcomes through chatbot-based learning. To implement this model, the flipped learning course using the chatbot was created as following. The steps below describe the detailed procedures from the pre-class preparation phase to the weekly activities and assessment methods.

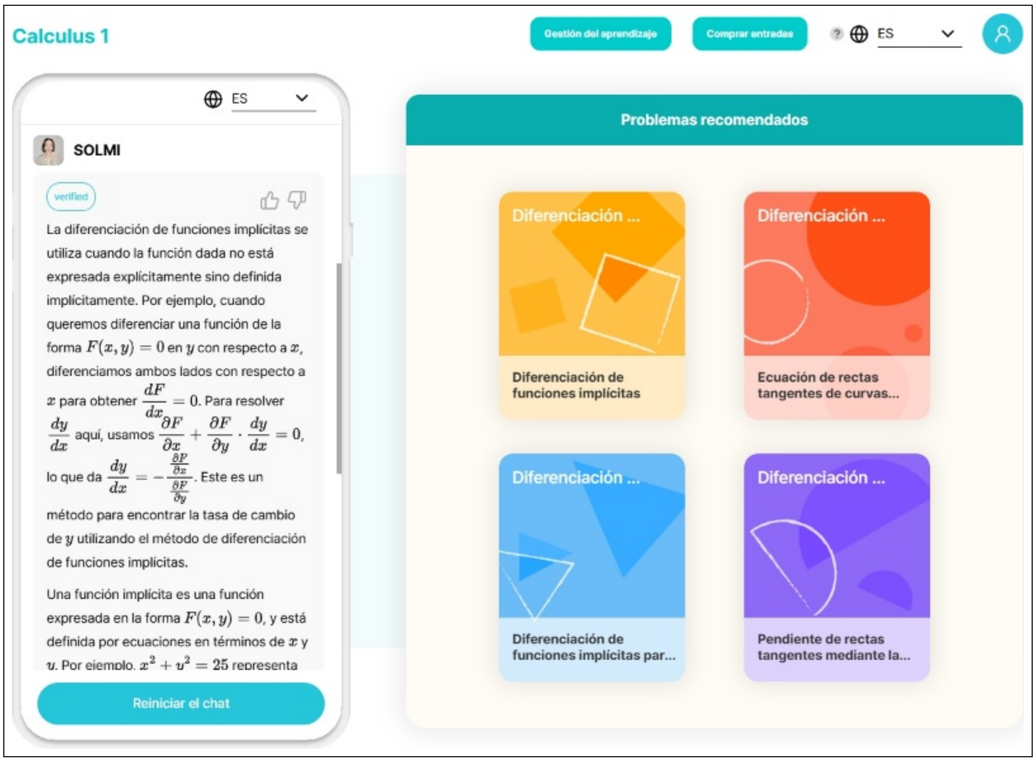
1. **Approximately 1–3 weeks of class shopping period:** Students are encouraged to watch the pre-recorded lecture videos and review the lecture materials provided by the instructor to understand the objectives of the course through the website link for the AI chatbot. Students may choose to take diagnostic or level tests to assess their mathematical proficiency and receive support before the semester begins.

2. **Week 1:** Students are asked to submit a self-introduction and a brief statement of their motivation for taking this problem/project-based learning (PBL) course.

3. **Weekly Activities:** Each week, students are expected to summarize the parts of the lecture content they have understood or engage in question-and-answer, discussion, and reflection activities via the LMS regarding concepts they find unclear.

4. **Feedback and Reflection:** Students engage in mutual feedback with the instructor/peers to deepen their understanding of the core concepts. Through these learning activities, they review newly acquired key concepts and track their participation in Q&A sessions using online quizzes.

Figure 8
Chatbot interface translated into Spanish



Students are asked to submit a structured PBL Report by filling in the provided template with a summary of their calculus-related learning activities, reviewing their progress, and adding a final comment.

5 Conclusion and Recommendations

The chatbot developed in this study is a promising learning tool for effectively supporting students' self-directed learning in university-level mathematics education. Analysis of user feedback revealed that the systematic organization of learning materials and the difficulty adjustment function enabled personalized learning tailored to each student's level. Additionally, the approach of offering immediate problem-solving exercises after concept explanations helps students improve in applying concepts and develop problem-solving skills.

One limitation of the chatbot is that the chatbot's search algorithm needs further refinement and that terminality needs to be used more consistently. Additionally, the sequence of recommended problems needs to be adjusted to align with the hierarchy of learning. Future research can focus on improving the chatbot's problem recommendation algorithm and implementing more effective strategies to enhance learning motivation.

The findings and methodology of this study can be applied to other university-level mathematics courses as well, including calculus, linear algebra, discrete mathematics, engineering mathematics, and introductory statistics. Our approach can support the design of mathematics courses in disciplines that require mathematical proficiency, such as natural sciences, engineering, and social sciences. Additionally, it helps students understand proofs through reasoning-based functions and enhances their logical thinking. Finally, when students study various mathematics courses independently alongside textbooks, they receive optimal real-time guidance on textbook problems without the need for additional human resources or costs.

The chatbot can reduce instructors' workload and helps to address the challenges posed by a shortage of qualified teaching assistants (e.g., for office hours) without incurring additional costs. Furthermore, it supports course design, including the integration of various process-oriented assessments.

Conclusively, AI chatbots specialized in university-level mathematics courses enable personalized, real-time learning. Students can reinforce their understanding of concepts by interacting with peers or instructors based on the chatbot's responses. Furthermore, because AI chatbots simultaneously promotes active peer and student-instructor discussions, students are less prone to blindly trusting or overly depend on chatbot-generated results.

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