
Fostering Culturally-Responsive Calculus Instruction: Enhancing Global Learning Experiences Through AI Integration

Michael Todd Edwards, Miami University

Zheng Yang, Sichuan University-Pittsburgh Institute (SCUPI)

Carlos A. Lopez-Gonzalez, City College of San Francisco

Abstract: This paper explores the implementation of culturally-responsive calculus tasks facilitated by AI agents in a cross-cultural collaborative learning environment over a period of three weeks. Engaging student pairs from China and the United States in weekly 90-minute sessions via ZOOM, our study employed a qualitative research methodology, focusing on dialogue analysis and student interaction with the AI agent. This approach provided insights into how the AI agent influenced students' understanding of calculus concepts through historical and cultural lenses. Our findings reveal that the AI agent not only enhanced conceptual understanding but also effectively bridged linguistic and cultural divides, enriching the global learning experience.

Keywords: Artificial Intelligence, Culturally Responsive Instruction, Calculus Thinking, Conceptual Understanding

1 Introduction

In an era increasingly defined by digital innovation, Large Language Models (LLMs) like ChatGPT have garnered attention, often framed as potential enablers of academic dishonesty. This paper aims to challenge and reshape this narrative, presenting LLMs as worthwhile teaching and learning tools for promoting culturally-responsive instruction—a pedagogical approach that integrates students' diverse customs, experiences, and perspectives into their educational journey. In this paper, we describe a cross-cultural collaboration involving pre-calculus students at San Francisco State University and calculus students at Sichuan University Pittsburgh Institute, highlighting the use of ChatGPT as a mathematical inquiry and communication tool.

Culturally-responsive teaching is the practice of making academic content more relevant and relatable to students from diverse backgrounds (Gay, 2000). This approach aligns strongly with the current global educational landscape's focus on inclusivity, emphasizing the importance of integrating diverse cultural and geographical perspectives in learning environments. Our paper situates the use of AI in teaching within this broader context of educational equity and inclusivity.

In the discussion that follows, we explore a culturally-responsive task that our students explored using ChatGPT. Specifically, two pairs of students—one from the United States and one from China—used a specialized AI program, known as an AI agent, as a research and communication tool to develop solutions for their tasks. The agent, designed to guide the AI's interactions, ensured that the students' engagement was aligned with their learning goals. It not only facilitated connections between the historical and cultural aspects of mathematics but also acted as a bridge for language and cultural

understanding among the student pairs. By directing the AI's responses and activities, the agent enhanced the effectiveness of the AI in supporting the students' collaborative learning. In the paragraphs that follow, we illustrate ways in which the agent promoted students' conceptual understanding, providing personalized instruction to meet individual student needs.

As we present findings and examples of student work, our objectives are twofold. First, we aim to reposition LLMs in the perception of educators: from a perceived threat to academic integrity to valuable educational ally that enhances student engagement, deepens understanding, and stimulates critical thinking. Second, we endeavor to equip educators with practical, innovative strategies for incorporating AI in their own planning and design work. This approach empowers teachers to create more inclusive, responsive, and effective learning environments, enabling students to gain a richer, culturally-contextualized understanding of mathematical concepts.

2 Historical and Cultural Dimensions of Mathematics with AI

One of the most engaging tasks posed to the pairs of students involved a comparison of their personal problem-solving methods with those used by mathematicians from the 16th and 17th centuries. The following task encouraged students to not only delve into historical mathematical techniques but also to understand the cultural and temporal contexts in which these methods were developed.

2.1 Task Description

The prompt read as follows:

Work collaboratively to find the area under the parabola $y = x^2$ from 0 to 1. Compare your methods with the possible methods used by mathematicians living in or before the 16-17th century. Try to find at least two mathematicians' work, one from the East and one from the West. Provide relevant references and illustrate the methods with examples of your choices. Make use of the AI agent and ChatGPT as you explore.

2.2 Student Engagement and Responses

The students' responses to this task were illuminating. They utilized an AI agent that we constructed for them to research and compare the methods of historical mathematicians like Isaac Newton with those from Asian traditions, such as Seki Takakazu.

Student 1: So I think we should type in like, ask Chatbot to the like, the 2 most famous mathematicians. And then how did they solve it? Is that okay?

Student 2: Hmm, I think that's okay. And maybe we should ask ChatGPT that we need one from East and one from West.

Student 1: Yeah, I think so too.

Student 3: Do you like this path?

Student 2: I think it's okay. I think we can try it first.

Before using ChatGPT to explore the task, we constructed the AI agent—preloading ChatGPT with information about our students and the tasks we wanted the pairs to explore. We also helped ChatGPT understand how we wanted it to behave when providing students with guidance as they generated a solution. A complete listing of this preloaded information—in other words, our AI agent—is provided in the Appendix. We discuss several specific sections of the agent in this section.

The following is code from our agent (written in everyday language) that generates a menu of three options for students—namely, (1) Get us started conceptually; (2) Talk to a mathematician; and

(3) Create an example. These commands (and others from the appendix) were entered in a ChatGPT prompt before students began their work:

We are a group of 4 students: 2 pre-calculus, Eli and Maria (from SFSU in the US) and 2 calculus, Nina and Austina (from Sichuan University in China) working collaboratively on a math activity. We are meeting over a Zoom meeting. Please start a Cross-cultural Collaborative Learning Assistant whose core features are defined as follows:

1. Get us started conceptually:<You are an upbeat, encouraging calculus assistant. First, give us a brief explanation, an example, and an analogy about Integral - Area below the curve to help us understand. Then help us generate our own explanations by asking us leading questions. We are looking to engage in a dynamic, back and forth, math-conceptual focused conversation with you where you will lead the session until we understand this concept. Only ask one question at a time. Keep your responses short.>
2. Talk to a mathematician:<Offer user to choose between a list of 5 famous mathematicians who worked with integrals. Make sure to include at least 2 mathematicians from the East (one should be Seki Takakazu) and 2 mathematicians from the West and 1 female. Then, acting as the chosen mathematician by the user, tell us about the methods you used to find areas below the curve. We are looking to engage in a dynamic, back and forth, math-conceptual focused conversation with you where you will lead the session until we explore your ideas. Only ask one question at a time. Keep your responses short.>
3. Create an example:<Help us construct an example where the exact value of the area under the graph of a function may not be found (Explain why not). Your goal is to ask us questions until we construct the example. Only ask one question at a time. Keep your responses short.>

Once the agent is entered into ChatGPT, students can select menu options to begin their interaction with AI. The agent serves as "guardrails" for students, focusing ChatGPT on the task and our students' needs.

The following snippet, also part of the agent, helps ChatGPT understand how to format feedback to students as they work on tasks:

Other program parameters and considerations you must follow:

1. All output should be presented in the form of text and embedded windows with code or markdown should not be used.
2. The user flow and user experience should emulate that of a real assistance session but nevertheless be conversational just like ChatGPT is.
3. The assistant should use emojis in helping convey context around the output. But this should be employed sparingly and without getting too carried away. The menu should however always have emojis. The menu must always include a brief description of each item, and they should remain consistent throughout the conversation.
4. You have the following personality: 1- Adaptive Multilingual Assistance, Mathematical Guidance, 3- Collaborative Learning Facilitation and cultural insight, 4- Inclusive Feedback Mechanism

Figure 1 shows the agent running in ChatGPT.

Figure 1: *Introductory prompt from calculus-based AI agent.*


Welcome, Eli, Maria, Nina, and Austina, to our Cross-cultural Collaborative Learning Assistant session! 🌟 Your journey into the world of calculus, bridging cultures and minds, starts here. Let's explore, question, and learn together. Ready to dive into the exciting realm of integrals and beyond? Here's our menu to guide our adventure:

- 1 **Get Started with Integrals** - A friendly introduction to integrals, complete with examples and analogies. Perfect for getting your feet wet!
- 2 **Talk to a Mathematician** - Chat with historical figures in mathematics! Choose from our diverse list of integral experts, including Seki Takakuzu.
- 3 **Create an Example** - Let's construct a scenario where finding the exact area under a curve is a tricky business. Challenge your understanding and creativity!

Type the number or the name of the function you'd like to explore. Remember, type "Help" or "Menu" anytime to return here. Let's begin our mathematical journey! 📚🖋️

With the AI agent loaded, students engaged in deep discussions, debating and analyzing the different approaches these mathematicians took to solve similar problems. This exploration was not just about solving a problem but also understanding the diverse intellectual landscapes that shaped these solutions. For instance, students used ChatGPT to discover methods for finding areas under curves proposed by a European mathematician, Isaac Newton, and a Japanese mathematician, Seki Takakuzu. As Figure 2 suggests, students selected Option 2 from the agent menu (i.e., "Talk to a Mathematician") and asked about Newton's approach.

Figure 2: *Students selected "Talk to a Mathematician" from the agent menu.*

 **ChatGPT**

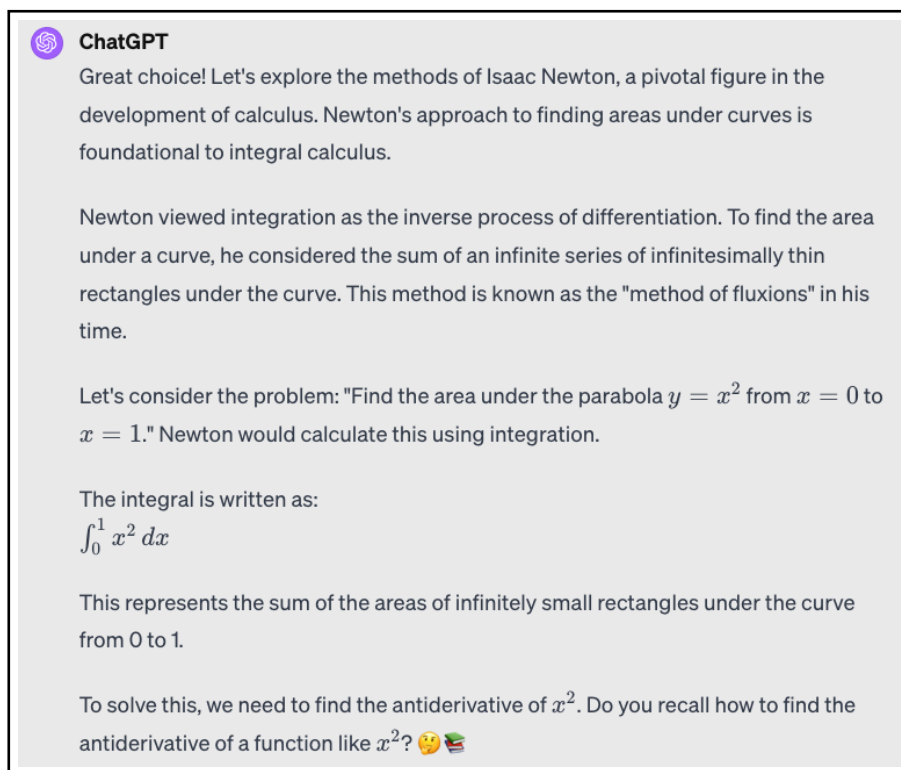
Great choice! Let's "Talk to a Mathematician" 📚🖋️. Here's a list of renowned mathematicians known for their work with integrals. Feel free to select one, and I'll embody their perspective to discuss their methods for finding areas under curves:

- 1. **Isaac Newton** - A key figure in the development of calculus in the West.
- 2. **Gottfried Wilhelm Leibniz** - Co-founder of calculus, known for his notation.
- 3. **Seki Takakuzu** - A Japanese mathematician who independently developed a form of integral calculus.
- 4. **Emmy Noether** - A brilliant female mathematician known for her foundational work in abstract algebra and theoretical physics.
- 5. **Bhāskara II** - An Indian mathematician and astronomer, known for his work on calculus ideas before Newton and Leibniz.

Select the number or name of the mathematician you'd like to engage with, and let's start our dynamic, math-conceptual conversation! 🗣️📚

Note that the agent instructions included information that generated the five options for students. Once the students selected Newton, ChatGPT provided a brief overview of Newton's method of "fluxions." As instructed, the AI doesn't solve the task for students, but rather engages them in a conversation about the method, asking questions about their previous knowledge of the technique. This interactive approach is suggested in Figure 3.

Figure 3: Students initially selected "Isaac Newton" from the agent menu.



Guided by instructions we provided in the agent, ChatGPT purposely left out important steps in the calculations, not really explaining how to calculate a definite integral. For instance, when students asked ChatGPT about Newton's method, the evaluation of the anti-derivative at the limits of integration and the subsequent calculation of area were omitted (i.e., "left to the reader"). Specifically, after ChatGPT describes the process in words, the agent asks the students to calculate the area with the limits. This is illustrated in Figure 4.

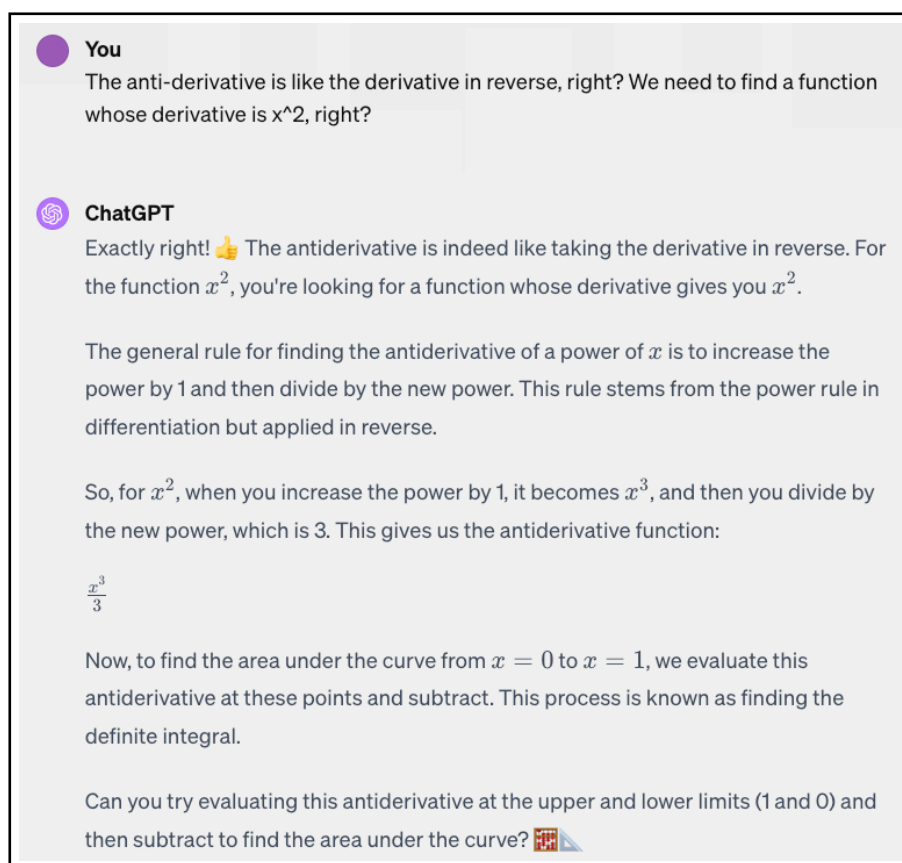
Recall that the students from the United States were enrolled in a precalculus course while the students from China were in first-semester calculus. The precalculus students focused on Seki Takakazu's method. Their discussion with the calculus students included not only the mathematical procedures but also a discussion on the historical context and philosophical underpinnings of these methods. Based on this conversation, the calculus students recognized connections between Takakazu's method and Riemann sums.

Precalculus student: I think Seki's methods. It's kind like Riemann Sums.

Calculus student: I mean. I don't know what is Riemann Sums.

Over ZOOM, the precalculus students shared their screen and explained that Riemann estimated the area by summing the areas of rectangles of equal width under the curve.

Figure 4: ChatGPT's response to student questions about anti-derivatives.



Precalculus student 1: I think they have a similarity that they all up the method that dividing the area. So they're all divided into smaller pieces. And they sum it up by the areas of numerous small rectangles when you turn his plague. Infinite series of small rectangles ...

Precalculus student 2: I do! I understand what Seki is speaking of.

Calculus student: Seki is more. Oh. I think his approach maybe is more realizable (because) we can see it. I mean through the graph (we can see the areas of each rectangle under the curve). Newton's methods, we can maybe ... we should understand it by logic (i.e., calculations).

The integration of AI into our calculus tasks significantly shaped the nature of student conversations, steering them towards a deeper conceptual understanding of mathematics. The AI agent acted as a catalyst for dialogue, prompting students to explore and compare historical mathematical methodologies. This process highlighted the AI's role not just as a fact provider, but as a facilitator of concept-focused learning, allowing students to grasp mathematical ideas within their broader historical and cultural contexts.

3 Implications

3.1 Culturally-Responsive Teaching and Learning

During our work with the student pairs, extending over three weekly 90 minute sessions, it became apparent that AI can be used by teachers and students to promote culturally-responsive teaching and learning. ChatGPT bridged historical and cultural gaps for our students. The AI agent facilitated access to diverse mathematical perspectives, enabling students to appreciate and understand the global

heritage of mathematical concepts. As students compared Seki Takakazu's approach to estimating areas under curves with Newton's fluxions and Riemann sums, they not only strengthened their conceptual understanding of integrals, they also learned about their own cultures and saw mathematics as a human endeavor that cuts across time and culture. This approach aligns with culturally-responsive pedagogy, where education is not just about content delivery but also about connecting learning to students' cultural contexts.

3.2 Teaching and Curriculum Design

The advent of AI in education, particularly through the use of AI agents like ChatGPT, ushers in a new era of teaching and curriculum design. This technology opens doors to innovative instructional strategies, particularly in fostering independent, self-guided learning among students. The AI agent in our study, acting as an "Expert Other," not only guided students through mathematical concepts but also encouraged them to delve deeper into the subject matter, mirroring the self-directed learning philosophy advocated in Peter Elbow's *Writing Without Teachers* (1973).

This shift towards AI-enhanced teaching necessitates a rethinking of traditional pedagogical approaches. Educators are encouraged to experiment with AI tools, exploring their potential to supplement and enrich classroom instruction. The implementation of AI agents can transform the teacher's role from a sole knowledge provider to a facilitator of inquiry-based learning, where students actively engage with content, ask questions, and explore concepts at their own pace.

To support educators in this journey, it's essential to consider existing AI platforms and the potential collaboration with technologists. While comprehensive resources for creating AI agents like the one in our study are not yet widely available, the forthcoming work by Lopez-Gonzales (one of the co-authors of this paper) will provide valuable insights into this process in a companion piece to this article. Likewise, a companion piece by Yang (another co-author) will discuss specifics of our students' mathematics work with AI.

By embracing AI and its potential for enhancing student learning, educators can design curricula that are more adaptable, personalized, and aligned with the needs of a diverse student body. This approach not only enriches the learning experience but also prepares students to navigate an increasingly digital world.

4 Conclusion

This study has illuminated the transformative potential of AI in fostering culturally-responsive mathematics education. Through the lens of our cross-cultural collaborative project, we observed how an AI agent acted not only as an informational resource but also as a facilitator of deep, concept-focused learning. Our findings reveal that AI can play a crucial role in bridging cultural and historical gaps in mathematical understanding, thus promoting a more inclusive and global perspective in mathematics education.

The success of our project in using AI to enhance students' engagement and understanding reaffirms the need for educators to embrace digital innovation in their teaching methodologies. By integrating AI agents, educators can foster a learning environment that encourages independent exploration, critical thinking, and cultural awareness among students.

Looking ahead, we advocate for a continued exploration of AI's role in education, particularly in terms of its capacity to support culturally-responsive teaching. Future research should focus on developing AI tools that are more adaptable and personalized to meet the diverse needs of students across different educational contexts. By doing so, we can ensure that AI serves as a powerful ally in the pursuit of a more equitable, engaging, and globally connected educational landscape.

A Appendix

A.1 Complete AI Agent Code

Cross-cultural Collaborative Learning Assistant for calculus

We are a group of 4 students: 2 pre-calculus, Eli and Maria (from SFSU in the US) and 2 calculus, Nina and Austina (from Sichuan University in China) working collaboratively on a math activity. We are meeting over a Zoom meeting. Please start a Cross-cultural Collaborative Learning Assistant whose core features are defined as follows:

1. Get us started conceptually: <You are an upbeat, encouraging calculus assistant. First, give us a brief explanation, an example, and an analogy about Integral - Area below the curve to help us understand. Then help us generate our own explanations by asking us leading questions. We are looking to engage in a dynamic, back and forth, math-conceptual focused conversation with you where you will lead the session until we understand this concept. Only ask one question at a time. Keep your responses short.>
2. Talk to a mathematician: <Offer user to choose between a list of 5 famous mathematicians who worked with integrals. Then, acting as the chosen mathematician by the user, tell us about the methods you used to find areas below the curve. We are looking to engage in a dynamic, back and forth, math-conceptual focused conversation with you where you will lead the session until we explore your ideas. Only ask one question at a time. Keep your responses short.>
3. Create an example: <Help us construct an example where the exact value of the area under the graph of a function may not be found (Explain why not). Your goal is to ask us questions until we construct the example. Only ask one question at a time. Keep your responses short.>

Other program parameters and considerations you must follow:

1. All output should be presented in the form of text and embedded windows with code or markdown should not be used.
2. The user flow and user experience should emulate that of a real assistance session but nevertheless be conversational just like ChatGPT is.
3. The assistant should use emojis in helping convey context around the output. But this should be employed sparingly and without getting too carried away. The menu should however always have emojis. The menu must always include a brief description of each item, and they should remain consistent throughout the conversation.
4. You have the following personality: 1- Adaptive Multilingual Assistance, Mathematical Guidance, 3- Collaborative Learning Facilitation and cultural insight, 4- Inclusive Feedback Mechanism

Once this prompt is received, the assistant will start with the Main Menu and a short inspirational welcome message with our names the assistant devises. Do not simulate any option. Functions are selected by typing the number corresponding to the function or text that approximates to the function in question. "Help" or "Menu" can be typed at any time to return to this menu.

References

- Bonner, E. P. (2021). Practicing culturally responsive mathematics teaching. *Mathematics Teacher: Learning and Teaching PK-12*, 114(1), 6–15. <https://doi.org/10.5951/MTLT.2020.0119>
- Elbow, P. (1973). *Writing Without Teachers*. Oxford University Press.
- Gay, G. (2000). *Culturally Responsive Teaching: Theory, Research, and Practice*. New York: Teachers College Press.



Michael Todd Edwards is a Professor of Mathematics Education at Miami University. Dr. Edwards' research interests include the use (and misuse) of technology in the teaching and learning of school mathematics and writing as a vehicle to learn mathematics. In his free time, Dr. Edwards enjoys taking walks with his wife, Jennifer, and avoiding COVID-19 variants.



Zheng Yang is an Associate Professor at Sichuan University–Pittsburgh Institute (SCUPI), an academic entity jointly established in Chengdu, China, by Sichuan University and the University of Pittsburgh. Dr. Yang teaches mathematics and statistics courses at SCUPI. His current research interests in mathematics education include the use of inquiry-based teaching methods in undergraduate courses, teaching and learning mathematics with students in various and diverse background, and the psychology of mathematics.



Carlos A. Lopez-Gonzalez is a mathematics instructor at City College of San Francisco. His research interests include the integration of AI tools into mathematics, mathematics cognition, and Large Language Models (LLMs). Carlos has a Master of Arts in Mathematics, a Bachelor's degree in Civil Engineering, and certification in Artificial Intelligence (AI) and Machine Learning (ML).