Conversational Agent Framework in Mathematics Education

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Abstract: Students' negative attitude toward mathematics is always associated with a decline in math performance. This often discourages students from pursuing STEM fields and careers. Efforts such as incorporating technology in educational settings to alleviate math anxiety by boosting students' motivation to explore and appreciate the subject were made. Conversational agents present an opportunity to enhance educational support for teaching and learning. However, despite almost six decades of development, the use of conversational agents in education remains limited. The impact of integrating a conversational agent on students' attitudes toward mathematics is essential to be investigated. In this study, an experimental research approach was adopted, involving undergraduate students at a Malaysian university. The control group received only traditional classroom instruction, while the experimental group received traditional instruction supplemented by interaction with a conversational agent. Following the intervention, participants completed a questionnaire assessing their attitudes toward mathematics. This paper aims to present the research design and framework of a conversational agent in mathematics education.

1 INTRODUCTION

Mathematics education is a cornerstone for developing essential analytical skills that benefit students across academic disciplines and professional paths (Boaler, 2016). Beyond fulfilling academic requirements, mathematics promotes logical reasoning and problem-solving skills that are critical in fields ranging from science and engineering to economics and technology. Despite its importance, many students find mathematics challenging, leading to issues such as high dropout rates, anxiety, and negative attitudes toward the subject. These struggles can discourage students from pursuing math-intensive careers and contribute to the gender and skills gap in STEM fields (Szczygiel & Perez, 2021; Ashcraft & Moore, 2009). Math anxiety, which affects students at various educational levels, can severely impair performance by hindering cognitive processing and reducing motivation (Dowker, Sarkar, & Looi, 2016). Addressing these challenges requires understanding and intervention at both the instructional and emotional levels.

Interactive teaching strategies, such as open-ended discussions and personalized feedback, have been shown to support learning and engagement. However, large class sizes and time constraints can limit opportunities for individualized interactions (Hattie & Timperley, 2007). Additionally, students who are more reserved may hesitate to participate in class discussions, preferring more private modes of communication (Gleason, 2020). This dynamic can lead to disengagement and lower performance among students who need additional support, emphasizing the importance of adaptable, student-centred approaches in mathematics education.

Research highlights the potential of technology in addressing these needs. Integrating digital tools such as interactive software and conversational agents has been shown to engage students and create a more personalized learning experience. Studies indicate that technology can increase student motivation, facilitate instant feedback, and provide a safe environment for practice, all of which help to reduce math-related anxiety (Cheung & Slavin, 2013). Conversational agents, in particular, present a promising solution by enabling interactive learning experiences where students can ask questions and receive real-time support. These agents also promote a more relaxed learning environment, allowing

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students to practice complex problem-solving without fear of judgment, thereby enhancing confidence and enjoyment in mathematics (D'Mello & Graesser, 2013).

Students' attitudes toward mathematics evolve based on their experiences of success and failure. Positive experiences build confidence and a favourable outlook on learning, while negative experiences can foster anxiety and disinterest. This balance of emotions underscores the importance of creating a nurturing and adaptive learning environment that celebrates student progress and addresses setbacks with constructive feedback (Pekrun, 2020).

The current study explores the role of conversational agents in mathematics education, particularly their potential to positively impact students' attitudes toward the subject. With the advancement of technology, conversational agents provide an opportunity for a more engaging and supportive educational experience. By integrating these tools, educational institutions can contribute to an inclusive and effective learning environment that supports students' academic journeys and prepares them for success in math-related fields.

2 RELATED WORKS

This section presents literature review related to the study such as the attitude towards mathematics and conversational agents.

2.1 Attitude

Attitude refers to an individual's emotional, cognitive, and behavioural responses to a specific situation or object (Rosenberg & Hovland, 2022). Like other academic subjects, mathematics can evoke various emotions, such as enjoyment, frustration, anxiety, or admiration. Research indicates that a positive attitude towards mathematics is often linked to better academic outcomes, while a negative attitude can hinder performance. Consequently, fostering a positive attitude toward mathematics is crucial, as it can significantly influence a student's depth of understanding and willingness to engage with the subject (Ramirez et al., 2022).

Students encounter various challenges in mathematics, such as difficulties with conceptual understanding, problem-solving, and motivation. These challenges often lead to feelings of anxiety or inadequacy, collectively known as mathematics anxiety. This anxiety is commonly rooted in negative or discouraging past experiences, which can shape students' beliefs about their mathematical abilities and impact their willingness to persist in the subject (Dowker, Sarkar, & Looi, 2016). A recent study by Fletcher and Dowker (2023) found that students who perceive mathematics as difficult and disconnected from real-life applications often hold negative views of the subject. Furthermore, student attitudes are influenced by their interactions with teachers. Educators who display empathy, encouragement, and constructive feedback can foster a more positive learning environment, whereas those who appear overly critical may inadvertently contribute to student anxiety and avoidance of the subject (Beilock & Maloney, 2022).

Perceptions of mathematics are complex, encompassing cognitive, emotional, and behavioral components. Researchers have emphasized the need to adopt a multidimensional approach to better understand these perceptions (Kolar & Hodis, 2021). For example, in a study of European middle school students, three primary dimensions were identified in students' perceptions of mathematics: personal beliefs about mathematical competence, emotional reactions to the subject, and attitudes towards the utility of mathematics in everyday life (Lucangeli, Galli, & Mammarella, 2022). Furthermore, the Trends in International Mathematics and Science Study (TIMSS) has shown that student attitudes toward mathematics include enthusiasm, confidence, and perceived relevance, all of which correlate with performance and engagement (Mullis, Martin, Foy, & Hooper, 2020).

Measuring attitudes towards mathematics is critical in educational research, as it helps identify factors influencing students' engagement and performance in the subject. Various methods have been employed for this purpose, including self-report measures, behavioral observations, psychological assessments, and implicit association tests (Eagly & Chaiken, 2022). Self-report measures are among the most used to gauge levels of agreement or disagreement with statements related to mathematics. These tools provide accessible ways to capture students' attitudes but may be influenced by social desirability biases. Behavioral measures, which focus on observable actions like the time spent on mathematics tasks or the willingness to seek additional practice opportunities, provide an alternative view of student engagement. These measures are beneficial in assessing attitudes through action rather than self-report, though they may be limited in capturing internalized attitudes toward mathematics.

Psychological measures, such as monitoring heart rate, cortisol levels, or skin conductance, offer insights into the physiological responses associated with mathematics-related anxiety or excitement. Such physiological indicators are valuable in cases where students might find it difficult to articulate their feelings toward the subject, as they reveal underlying emotions that may not be overtly expressed. Additionally, implicit measures, such as the Implicit Association Test (IAT), have been used to assess the subconscious associations individuals hold toward mathematics, particularly in distinguishing between positive and negative attitudes (Greenwald et al., 2021). This method helps address potential biases found in self-reported data, providing a deeper understanding of implicit attitudes.

Attitudes are multi-dimensional and could not be observed directly and easily, thus the task of measuring students' attitudes toward mathematics is complex. The reliability and validity of the tools used are often questioned, as attitudes are inherently subjective and may be challenging to quantify accurately (Peterson & Flanders, 2019). Traditional methods, which often posit a link between positive attitudes and mathematical success, rely on measuring attitudes as a critical component in understanding and improving student performance. To this end, a variety of instruments have been developed, each focusing on different attitude dimensions. For example, Wong and Wong (2022) created an instrument that assessed students' attitudes toward math based on enjoyment, motivation, and confidence, and Stroet et al. (2021) designed a scale emphasizing self-efficacy and interest, while Tapia and Marsh (2002) developed a four-factor questionnaire. Despite the challenges, many studies continue to utilize Likert scale-based self-report questionnaires to assess students' attitudes toward mathematics, as these remain the most practical for capturing diverse attitude dimensions in educational settings.

2.2 Conversational Agents

Conversational agents (CAs), also known as chatbots or intelligent tutoring systems, are software programs designed to simulate human conversation, allowing users to interact using natural language. These systems function as dialogue interfaces capable of understanding and responding to user inputs in ways that resemble human communication (Shawar & Atwell, 2021). CAs are typically employed in applications such as chatbots for customer service or virtual assistants on mobile devices. They utilize computational linguistics, allowing them to process user queries and generate contextually appropriate, human-like responses.

At the core of CAs are technologies like natural language processing (NLP) and machine learning (ML). NLP allows the agent to interpret the meaning behind human language, enabling the bot to engage in more sophisticated dialogue. Meanwhile, ML empowers the CA to learn from each interaction, improving its ability to tailor responses and understand user preferences over time. While chatbots have been around since the 1960s, recent advancements in artificial intelligence, NLP, and ML have expanded their potential, increasing their integration into various sectors, including education (Wu et al., 2022).

In the context of education, the role of conversational agents is an important consideration. Educators can deploy CAs in diverse roles, such as tutors, mentors, or peer collaborators, based on the instructional goals and learning environments. For instance, some researchers have explored how CAs function as personalized assistants in virtual classrooms, adapting their support to the individual needs of students (Jou & Huang, 2021). Additionally, studies have highlighted that CAs can be designed to facilitate interactive learning, enhancing the educational experience by engaging students in dynamic problem-solving activities (Yin et al., 2022).

One recent study by Abdullah et al. (2024) examined the use of CAs as virtual tutors in higher education. Their findings suggested that CAs, when used as part of an interactive learning platform, improved students' understanding of complex concepts by providing immediate feedback and personalized support. The study further emphasized the advantages of CAs over traditional e-learning tools, noting that their ability to respond in real-time to students' queries fosters a more engaging, responsive, and individualized learning experience (Zhou & Wang, 2023).

Moreover, CAs are found to be particularly effective in non-technical fields where students may struggle to grasp complex material without additional guidance. For example, a recent investigation by Chen et al. (2023) into CAs in humanities courses highlighted their potential to assist non-technical students by guiding them through difficult concepts and ensuring timely interventions when students face challenges. This adaptability positions CAs as a powerful tool for expanding access to personalized education and offering support that complements traditional teaching methods.

The application of conversational agents (CAs) has been widespread in various industries, but their integration within educational settings, particularly mathematics education, remains relatively underexplored. Despite growing interest in CAs, their adoption in mathematics education is still nascent, as highlighted by recent studies (Guszcza, Smetana, & Waguespack, 2020; Zhang & Choi, 2023). This gap presents a valuable opportunity for further research and development to enhance the integration of conversational agents as pedagogical tools in mathematics learning.

CAs are proving to be beneficial in education by providing immediate feedback, responding to student queries, and offering personalized support throughout the learning process (Wang, Yu, & Yang, 2023). Moreover, they contribute to enhancing educational efficiency by automating routine tasks, streamlining access to learning materials, and saving valuable time for both educators and students (Patel et al., 2023). The use of CAs also optimizes learning outcomes by ensuring that students receive individualized attention, which is particularly important in large classrooms or online learning environments. Incorporating challenging questions into CAs has been found to improve student confidence and foster a sense of accomplishment (Xiao et al., 2023). As students tackle more complex problems, they gain a better understanding of their progress, which not only enhances their problem-solving skills but also builds their self-assurance in overcoming mathematical obstacles. These incremental successes encourage students to continue engaging with challenging content, promoting a positive cycle of learning and growth.

Additionally, CAs also enhance student motivation and engagement by offering greater control over their learning experience. Studies have shown that interactive tools such as CAs can sustain students' interest and participation, creating a more enjoyable and supportive learning environment (Dale & Choi, 2021; Lee et al., 2022). This personalized approach helps students to absorb knowledge more effectively and reduces feelings of frustration or boredom. Furthermore, CAs' ability to provide instant feedback is crucial for improving both academic performance and motivation. By allowing students to receive immediate corrective feedback, CAs help them rectify mistakes and solidify their understanding of complex mathematical concepts (Wang & Zhang, 2021).

3 METHODOLOGY

This section will discuss the design, sample, materials and instrument used in the study as well as the research procedure to provide a lucid picture.

3.1 Design

This study employed a quasi-experimental design with convenience sampling. Due to limitations in scheduling and venue arrangements, as well as the desire to maintain classroom norms, pre-existing groups were used instead of randomly assigning students to experimental and control groups. Within these groups, students who were easily accessible and willing to participate were selected. A consent form was distributed to all students, and only those who consented to participate were included in the study.

3.2 Sample

A total of 200 undergraduates who were voluntarily participated in the study. The sample consisted of both male and female students from various ethnic backgrounds such as Malay, Chinese, Indian, and others, as well as a mix of local and international students. The experimental group comprised 115 students, while the control group consisted of 85 students. Students were asked to voluntarily select their group—either experimental or control—resulting in unequal sample sizes. A quantitative research methodology was employed to collect and analyze data on students' attitudes toward mathematics.

3.3 Conversational Agent and Material

A conversational agent, integrated into Facebook Messenger, was developed for educational purposes, functioning as a tutor in this study. This agent was designed by blending key elements such as affective learning, experiential learning, social dialogue, and scaffolding. It broke down complex learning material into manageable, bite-sized segments, making it easier for students to grasp concepts quickly without feeling overwhelmed. Motivation in the form of inspirational messages was given to the students by the agent. Constructive feedback and motivational quotes were integrated to bolster students' confidence. The agent assisted students stay focused during their problem-solving process. Alongside clear explanations, examples, and exercises, the agent provided step-by-step solutions, reinforcing learning. Furthermore, it allowed students to attempt questions

multiple times, regardless of previous mistakes, fostering a sense of growth and resilience in their learning journey.

3.4 Mathematics Attitude Dimension

The objective of this project is to assess the influence of integrating a conversational agent on students' attitudes toward mathematics, thus the instrument, Mathematics Attitude Dimension, was developed. It was a questionnaire which comprised a combination of adopted, adapted, and self-designed items. This instrument included 11 questions and served as pre-test and post-test, focused on students' perspectives regarding their attitude towards learning the mathematics topic 'Integration,' using a 5-point Likert scale. "The importance of mathematics" and "anxiety towards mathematics" were two dimensions focused on this instrument, and were adapted from the four-factor questionnaire developed by Tapia and Marsh (2002).

Before the study, participants were asked to sign a consent form, confirming their voluntary participation in the study. They were then asked to provide confidential general information such as age, gender, race, and nationality. The questionnaire was thoroughly reviewed and validated by experienced mathematics lecturers from the private university to ensure the quality and relevance of the questions for the study. To assess the reliability of the instrument, Cronbach's Alpha was calculated using SPSS, yielding a value of 0.921, which indicates excellent reliability according to Amirrudin et al. (2021). This high Cronbach's Alpha not only confirms the instrument's reliability but also demonstrates its internal consistency, ensuring its effectiveness in measuring each variable. Table 1 presents an example of the questions used in the mathematics attitude dimension questionnaire.

Table 1: Example of Questions in Mathematics Attitude Dimension.

Dimensions	Item
Importance of mathematics	Mathematics helps to develop my thinking skills.
Anxiety towards mathematics	To even consider having to complete a math problem makes me anxious.

3.5 Procedure

The field study was conducted in a period of 5-weeks with three distinct phases. Before the first phase, the students were briefed by the researcher on the study's objectives, and they were asked to sign a consent form indicating their voluntary participation. Participation was entirely optional. Those students who agreed to participate in the study were then asked to participate in either the control or experimental groups voluntarily. The first phase involved administering a pre-test to both control and experimental groups' students before they were introduced to the topic of 'Integration' by the university lecturer.

In the second phase, a conversational agent was incorporated into the teaching and learning process for the mathematics syllabus for the experimental group. Students in the experimental group were briefed on the purpose of the conversational agent before using it for learning. While both groups received traditional instruction on the 'Integration' topic from the same lecturer, only the experimental group had access to the conversational agent. This intervention lasted for 3 weeks, during which the experimental group used the conversational agent independently, at their own pace, and at times and locations that were most convenient for them outside of their regular class schedule.

The administration of the post-test was conducted on both groups in the last phase after the completion of the 'Integration' topic. The post-test assessed the mathematics attitude dimension to determine the effectiveness of the conversational agent in improving students' attitudes toward mathematics.

4 CONCLUSION

This paper has outlined a conversational agent framework, alongside a research design employing a quasi-experimental with convenience sampling method approach. The design utilizes a mathematics attitude dimension instrument. Reliability and validity tests have shown that the instrument is reliable and valid, ensuring that the subsequent data collection process will yield meaningful and valuable interpretations. As the project is still ongoing and data analysis is in progress, no finding is available at this stage to conclude the study. It is hoped that favourable findings will be obtained and will be significant to many parties such as educators, students, curriculum designers, etc.

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