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RESEARCH ARTICLE

Examining the Impact of Pedagogical Agents on Student Performance in Mathematics

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ABSTRACT

Improving student performance in mathematics remains a continuous challenge in education. Online learning offers a flexible and adaptable approach that can enhance the teaching and learning process. This study aims to incorporate pedagogical agents in online learning platform to enhance student performance in mathematics. This study investigated the influence of integrating pedagogical agents in an online learning platform for teaching Mathematics to undergraduate students. Using a quasi-experimental design, the participants were divided into a control group (32 students) and an experimental group (57 students) which used the LearnWithEmma platform featuring a 3D animated agent, Emma. The Discrete Mathematics Achievement Test measured students' performance before and after the intervention. The research's findings reveal that integration of the pedagogical agent significantly improved students' mathematics performance. Independent sample t-tests comparing pre-test and post-test scores showed no significant difference in pre-test scores between control and experimental groups across all achievement levels. However, post-test results indicated substantial improvements in the experimental group's scores, with high, medium, and low achievers all showing significant gains (p-values < .001). This suggests that the intervention positively impacted mathematical achievement. This study is significant as it provides empirical evidence on the effectiveness of pedagogical agents, in online learning platforms to enhance mathematics performance. Educational institutions, educators, and instructional designers can benefit from these findings, as they highlight a promising approach to improve student learning outcomes through technology. This study's innovative aspect is using a human-like pedagogical agent that delivers instructional content and motivational messages.

INTRODUCTION

Before the global pandemic, education primarily relied on traditional classroom settings, limiting access for geographically distant students, working professionals, and those with specific learning styles [1]–[3]. The COVID-19 outbreak forced a rapid shift towards online learning platforms, ensuring educational continuity despite physical restrictions [4], [5]. This large-scale adoption of e-learning presented a unique opportunity to explore its potential benefits in a post-pandemic world. However, online learning environments can pose specific challenges for subjects like mathematics.

Mathematics, with its emphasis on logical reasoning and problem-solving, plays a vital role in developing cognitive and non-cognitive thinking skills [6]. However, the online learning environment can hinder student understanding. Abstract concepts, a hallmark of mathematics, can be difficult to grasp without visual aids or hands-on experiences, which might be limited online. Additionally, the lack of immediate feedback, a key strength of traditional classrooms where teachers can address mistakes as they occur, can be absent in online learning. Reduced motivation and engagement, stemming from the absence of a physical classroom and peer interaction, can further impact student learning outcomes in online mathematics courses[7].

This is where pedagogical agents emerge as promising tools. These interactive virtual characters, integrated into online learning platforms, can potentially address these challenges. Pedagogical agents can provide personalized explanations and examples tailored to individual student needs, catering to different learning styles and addressing specific areas of difficulty[8]–[10]. By utilizing multimedia elements like animations, simulations, and interactive exercises, these agents can visualize abstract concepts, making them more accessible and engaging for students. Furthermore, pedagogical agents can be programmed to offer real-time feedback on student responses, helping them identify and correct mistakes as they progress through the learning materials. Finally, by being designed to be interactive and engaging, these virtual tutors can foster dialogue and encourage students to participate actively and dynamically in the learning process, potentially enhancing their motivation and overall engagement with online mathematics learning.

The significance of utilizing pedagogical agents was highlighted on the online learning platform. Pedagogical agents are emerging as a promising tool. By incorporating interactive virtual characters into online learning platforms, this study proposes to investigate the effectiveness of pedagogical agents on student performance in online mathematics learning by involving the students in pre- and post-mathematics achievement tests.

LITERATURE REVIEW

2.1 Online Learning

Recent research suggests that online learning can be just as effective as traditional classroom learning in terms of student performance. Similarly as mentioned by [11], [12] found no significant difference in learning outcomes between students who participated in online and in-person mathematics courses. Additionally, [13], [14] observed high student satisfaction with online learning due to its flexibility and the availability of diverse learning materials, potentially leading to improved engagement and self-directed learning.

Furthermore, online learning platforms offer the potential for personalized instruction. Adaptive learning technologies can tailor course content and difficulty levels to individual student needs, addressing knowledge gaps and reinforcing areas of strength [15]–[18]. This personalization can lead to a more efficient and effective learning experience for students.

Despite its advantages, online learning also presents challenges. A key concern is the potential lack of social interaction and the feeling of isolation that can arise in virtual environments. Studies by [19] and [20] highlight the importance of fostering a sense of community and peer interaction in online learning to combat student isolation and maintain motivation.

Another challenge is the requirement for robust technological infrastructure and digital literacy skills to participate effectively in online learning environments. The digital divide, where certain populations lack access to reliable technology or internet connectivity, can exacerbate educational inequalities [21]–[23]. Addressing this digital divide is crucial to ensure equitable access to online learning opportunities.

Looking ahead, online learning is likely to play a significant role in a post-pandemic world, but it may not entirely replace traditional classroom settings. A blended learning approach, combining online learning modules with in-person classroom sessions, may offer an optimal solution. This approach can leverage the flexibility and accessibility of online learning while maintaining the social interaction and collaborative learning benefits of face-to-face instruction [24], [25].

Furthermore, ongoing research is exploring ways to enhance the effectiveness of online learning. The development of more sophisticated pedagogical agents, virtual tutors that can provide personalized feedback and support, shows promise in improving student engagement and learning outcomes in online mathematics courses [26].

The COVID-19 pandemic has undeniably accelerated the adoption of online learning, revealing its potential to democratize access to education and cater to diverse learning styles. As schools and universities were forced to shift to remote instruction, both educators and students had to adapt quickly to new technologies and teaching methods. This rapid transition highlighted the flexibility of online learning platforms to provide education regardless of geographical constraints, thus offering opportunities to students who might otherwise face barriers to traditional classroom settings. While challenges like the digital divide and the lack of social interaction persist, they also underscore the necessity of addressing these issues to ensure equitable access for all learners. Efforts to bridge the digital divide include increasing internet accessibility and providing necessary technological tools to underserved communities. Moreover, innovative solutions are being developed to enhance virtual social interactions, such as virtual study groups, interactive forums, and collaborative projects that mimic in-person engagement. Ongoing research and pedagogical advancements are paving the way for a future where online learning can be a valuable tool to complement and enhance traditional classroom learning. These advancements include the use of technology to personalize learning experiences, adaptive learning technologies that adjust to individual student needs, and immersive learning environments like virtual and augmented reality. Such innovations aim to create a more engaging and effective educational experience. Ultimately, by integrating the strengths of online learning with traditional methods, can create a more inclusive and effective educational system that benefits all students, regardless of their circumstances.

2.2 Pedagogical Agent

The rapid rise of online learning platforms in the wake of the COVID-19 pandemic has necessitated innovative approaches to engage students and promote effective learning in virtual environments. Pedagogical agents, also known as virtual tutors or learning companions, have emerged as a promising tool to address this need. This literature review explores recent research on pedagogical agents, examining their functionalities, effectiveness in online learning, and potential future directions.

Pedagogical agents are software programs that take the form of virtual characters integrated into online learning platforms. These agents can interact with students, providing a range of functionalities such as: Agents can tailor their explanations and examples to individual student needs, catering to different learning styles and addressing specific areas of difficulty [27].

Visualizing abstract concepts: Through multimedia elements like animations, simulations, and interactive exercises, agents can make abstract concepts more accessible and engaging for students [28][29].

Real-time feedback and guidance: Pedagogical agents can be programmed to offer immediate feedback on student responses, helping them identify and correct mistakes as they progress through learning materials [30][31].

Enhancing motivation and engagement: Designed to be interactive and engaging, these virtual tutors can foster dialogue, encourage active participation, and combat feelings of isolation sometimes experienced in online learning environments [19].

Research suggests that pedagogical agents can have a positive impact on student performance and learning outcomes in online settings. A study [32], [33] found that students who interacted with a pedagogical agent in a web-based statistics course demonstrated significantly higher scores compared to a control group without an agent. Similarly, [34] observed increased student engagement and knowledge retention in an online science course that incorporated a pedagogical agent.

The effectiveness of pedagogical agents appears to extend beyond simply providing information. Research by [35] suggests that agents can foster a sense of social presence and emotional connection within the online learning environment, which can be crucial for student motivation and self-directed learning. This highlights the potential of pedagogical agents to not only deliver content but also create a more supportive and engaging learning experience for students.

Despite their promise, pedagogical agents are not without limitations. Developing engaging and effective agents requires careful design and consideration of factors such as the agent's personality, level of interactivity, and the specific learning context [36]. Additionally, ensuring equitable access to online learning platforms that utilize pedagogical agents is crucial to avoid exacerbating the digital divide [37], [38].

Future research directions include exploring the integration of artificial intelligence (AI) to personalize agent interactions further and tailor their responses to individual student needs in real-time. Additionally, investigating the effectiveness of pedagogical agents in different subject areas and for diverse student populations can provide valuable insights into their broader applicability in online learning environments.

Pedagogical agents represent a promising innovation in online learning, offering the potential to personalize instruction, enhance engagement, and improve student learning outcomes. Recent research highlights their positive impact on student performance and their ability to create a more supportive virtual learning environment. As the field continues to evolve, ongoing research and development efforts can further refine pedagogical agents and unlock their full potential to revolutionize online education.

2.3 Discrete Mathematics

Discrete mathematics, unlike its continuous counterpart, deals with distinct, countable objects. Its applications are vast, permeating various fields like computer science, cryptography, information theory, and even game theory. This literature review explores the significance of discrete mathematics, and the challenges associated with teaching it online, and investigates the potential of pedagogical agents as a solution to enhance online learning in this domain.

The pervasiveness of technology in today's world necessitates a strong foundation in discrete mathematics. Research by [39] emphasizes its critical role in computer science, forming the bedrock for algorithms, data structures, and graph theory, all fundamental concepts in software development. Furthermore, cryptography, a cornerstone of cybersecurity, relies heavily on discrete mathematics for encryption techniques, as highlighted by [40].

Beyond computer science, discrete mathematics finds applications in various disciplines. Information theory, essential for data compression and transmission, utilizes concepts like entropy and information channels, as explained by [41]. Even game theory, which analyzes strategic interactions, relies on discrete mathematics to model games and analyze optimal strategies [42].This widespread applicability underscores the importance of effective learning methods for discrete mathematics.

While online learning platforms offer flexibility and accessibility, teaching discrete mathematics online presents unique challenges. One critical hurdle is the inherent abstract nature of many discrete mathematical concepts. Proofs, logical reasoning, and set theory can be difficult to grasp without clear visualization and hands-on activities, according to [6]. Traditional classroom settings often utilize physical manipulatives or diagrams to aid understanding, which might be limited in online environments.

Another challenge is the potential for student isolation and lack of interaction in online learning. Discrete mathematics often involves problem-solving and collaborative reasoning. The absence of peer interaction and immediate feedback from instructors can hinder student engagement and make it difficult for them to clarify doubts and learn from each other, as noted by [43].

Pedagogical agents, and virtual tutors integrated into online learning platforms, hold promise in addressing these challenges. Their ability to personalize learning experiences aligns well with the diverse learning styles encountered in discrete mathematics. Studies by [33] suggest that pedagogical agents can tailor explanations and examples to individual student needs, catering to visual learners through animations and simulations, or providing step-by-step guidance for logical reasoning tasks.

Furthermore, research by [44,55] highlights the potential of pedagogical agents to bridge the gap between abstract concepts and real-world applications in discrete mathematics. These virtual tutors can present interactive exercises and simulations that engage students in actively exploring and applying mathematical concepts, fostering deeper understanding.

Beyond content delivery, pedagogical agents can address the isolation experienced in online learning. By providing immediate feedback and guidance, they can mimic the role of a human instructor, enhancing student engagement and motivation. Studies by [10,54] suggest that pedagogical agents can create a more interactive learning environment, encouraging students to ask questions and participate in problem-solving activities.

Recent research findings support the potential of pedagogical agents in enhancing online learning for discrete mathematics. However, further investigation is needed to optimize their effectiveness. Research by [45] emphasizes the importance of agent design, including personality traits, level of interactivity, and the specific subject matter being taught. Additionally, exploring the integration of AI could allow for real-time adaptation of agent responses to address individual student needs in discrete mathematics courses.

Discrete mathematics underpins various technologies and scientific advancements shaping our world. Effectively teaching this subject online requires innovative approaches to address the challenges of abstract concepts and student isolation. Pedagogical agents, with their ability to personalize learning, bridge the gap between theory and application, and create a more interactive environment, offer a promising solution for online learning in discrete mathematics. Future research can refine agent design and leverage AI to unlock their full potential, ultimately fostering a more engaging and effective learning experience for students venturing into the fascinating world of discrete mathematics.

2.4 Integration of Pedagogical Agent in Online Learning

Various online learning platforms incorporate pedagogical agents to improve students' mathematics performance. Here is a discussion on some of these platforms along with relevant research articles.

Online learning platforms incorporating pedagogical agents have become increasingly popular in recent years due to their potential to improve students' mathematics performance. These platforms use artificial intelligence to provide personalized feedback, individualized learning paths, and adaptive assessments, among other features, to help students learn mathematics effectively. Several studies have examined the effectiveness of these platforms in improving students' mathematics performance.

Smart Sparrow is an innovative adaptive learning platform that utilizes a pedagogical agent to provide personalized feedback and create individualized learning pathways for students. Research has demonstrated that students who used Smart Sparrow exhibited substantial improvements in their mathematics scores compared to those who received traditional classroom instruction. To gain deeper insights, researchers conducted focus groups involving two distinct groups of students. These focus groups were designed to collect comprehensive feedback and gauge the students' perceptions and experiences with the adaptive learning platform. The findings highlighted the platform's effectiveness in enhancing learning outcomes and underscored the positive reception from students who appreciated the tailored educational support provided by Smart Sparrow. One group of students was made up of white male students who are usually the majority in engineering schools in the United States. The other group of students was students who were not white males [46]. The goal of comparing the perspectives of these two groups was to gain insight into whether the adaptive learning platform was equally effective for students of different demographic backgrounds. Both groups of students identified benefits to using the platform, but the group of students who were not white males expressed more positive feelings about it overall. This suggests that the adaptive learning platform may be particularly effective for students from diverse backgrounds, and could help bridge gaps in achievement between different groups of students [31].

On the other hand, SCeLE Moodle-based learning environment was developed to provide automized personalized feedback to students during learning. The participants were from a University in Indonesia. The study reveals that the pedagogical agent can guide and motivate the participants in their learning. the participants have mentioned that the pedagogical agent has helped them to comprehend the materials easily. On top of that, they also mentioned that the simplicity of the agent makes us feel more connection and engaged [47].

Matific is an online learning platform that uses a pedagogical agent to provide personalized feedback to students. Students who used Matific showed significant improvement in mathematics scores compared to those who did not use the platform [48]. The study also found that students who used Matific showed higher levels of motivation and engagement in mathematics learning [49]

Overall, these online learning platforms demonstrate the potential of pedagogical agents to improve students' mathematics performance. By providing personalized feedback and individualized learning paths, these platforms can help students learn at their own pace and improve their understanding of mathematical concepts. However, it is important to note that the effectiveness of these platforms may vary depending on factors such as student motivation, engagement, and prior knowledge of mathematics. Therefore, further research is needed to fully understand the impact of these platforms on student learning outcomes.

RESEARCH METHODOLOGY

The methodology employed to investigate the integration of pedagogical agents in online learning to teach Mathematics and its impact on student performance. It includes the research design, population and sample details, research procedures, materials used, instruments for data collection, data analysis procedures, and a pilot study.

3.1 Research Design

A quasi-experimental research design was chosen for its suitability when randomization is not feasible with pre-existing groups. The study was conducted on undergraduate students enrolled in Mathematics subjects at a private university for one trimester. The non-equivalent control group design was utilized, with one group exposed to the conventional approach and the other to the learning agent approach. Pre- and post-tests were administered to both groups to compare outcomes.

3.2 Participants

The participants were undergraduate students pursuing degrees in Information Science and Technology at University X in Malaysia. The total number of participants was 89, with 32 in the control group and 57 in the experimental group. The sampling method employed was convenience sampling, utilizing pre-existing tutorial groups taught by the lecturers.

System

The study focused on the LearnWithEmma platform, integrating a pedagogical agent named Emma. The system was developed using WordPress, HTML, and CSS. It included lecture videos, tutorials, downloadable notes, and a help desk for student support. The system with a pedagogical agent used in this study is named LearnWithEmma. It contains teaching and learning materials for Logic and Proofs topics. The participants must register through the learning platforms to use the system.

The pedagogical agent is named Emma. Emma was designed in three-dimensional design. It was designed as a human-like animated character. The pedagogical agent Emma, heavily relies on pre-programmed scripts to interact with learners. Emma was created using iOS animated emoji. The voice of a pedagogical agent is a pre-recorded voice of a real human. The agent is a female and a young character. Emma has facial expressions and can communicate with students in a natural tone.

During the lecture session, Emma advises the students to pause and re-watch the video to understand the context of the subject. Though the pedagogical agent's behavior is limited in terms of artificial intelligence, the agent Emma is useful in effectively engaging learners and supporting their learning. Emma was designed without artificial intelligence as the agent was focused on providing guidance, tutoring, lectures, and support such as instructional explanations, and motivational messages. In addition, Emma provides motivating and encouraging statements to students. Emma extensively explains each sub-topic and walks through the participants with examples.

3.3 Instrument: Discrete Mathematics Achievement Test (DMAT)

The Discrete Mathematics Achievement Test (DMAT) was the primary instrument used to assess students' mathematical performance before and after the intervention. It comprised twelve validated questions designed to cover key concepts in Discrete Mathematics. The questions were aligned with the syllabus and approved by experienced lecturers. Each question was structured to evaluate students' understanding and application of mathematical principles.

The DMAT was administered to both the control and experimental groups at two points in time: before the intervention (pre-test) and after the intervention (post-test). This allowed for the measurement of any changes in students' mathematical achievement as a result of the intervention.

3.4 Data Analysis

Quantitative data obtained from the DMAT were analyzed using appropriate statistical methods. Descriptive statistics such as mean scores, standard deviations, and percentages were calculated to summarize students' performance on the test. Additionally, inferential statistics, such as t-tests, were used to compare pre- and post-test scores between the control and experimental groups, determining the effectiveness of the intervention.

3.5 Research Procedure

Before students commenced learning Logic and Proofs, they were briefed on the experiment's purpose. Students were given consent forms and personal information sheets to fill out, indicating their agreement to participate and providing demographic details. Participants were then divided into control and experimental groups and given pre-test to assess their knowledge in Logic and Proof topic. Then upon completion, the experimental group were granted access to the LearnWithEmma system.

During this stage, the intervention commenced, with the experimental group utilizing the LearnWithEmma system to study Logic and Proofs. Students registered on the platform and were approved by the researcher before gaining access. The experimental group accessed lecture videos, notes, and tutorial questions provided by the system for a duration of four weeks.

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RESULTS

An independent sample t-test was conducted to analyze the collected data in this study. An independent sample t-test is used to compare differences between control and experimental groups in both pre-test and post-test on mathematics achievement. The t-test generates t-values and p-values for statistical significance testing at a significant level of 5%.

Table 1: Independent sample t-test on pre-DMAT for high, medium, and low achievers between control and experimental groups

	Pre-DMAT	N	Mean	SD	t-value	df	p-value
High	Control	8	10.13	.99	.21	15	.84
	Experimental	9	10.00	1.41			
Medium	Control	18	6.50	1.04	-.24	47	.81
	Experimental	31	6.58	1.21			
Low	Control	6	3.50	.84	-.35	21	.73
	Experimental	17	3.71	1.36			

The table shows the results of an independent sample t-test conducted on the pre-DMAT scores for high, medium, and low achievers of both the control and experimental groups. The purpose of the test was to determine if there was a significant difference between the mean scores of the two groups on the pre-test for different levels of achievement. For the high achiever, the control group had a mean of 10.13 (SD = 0.99) while the experimental group had a mean score of 10.00 (SD = 1.41). The t-value was 0.21, resulting in a p-value of 0.84. This indicates that there was no significant difference between the mean scores of the high achievers for the two groups in pre-DMAT, suggesting that both groups had similar starting points in terms of high achievement in mathematics.

Similarly, for the medium achiever, the control group had a mean score of 6.50 (SD = 1.04), while the experimental group had a mean score of 6.58 (SD = 1.21). The t-value was -0.24 resulting in a p-value of 0.81. This also indicates that there was no significant difference between the mean scores of the medium achievers for the control and experimental groups in pre-DMAT, implying that the students with medium achievement levels were equally matched in both groups before any intervention took place.

For the low achiever, the control group's mean score is 3.50 (SD = 0.84), while the experimental group's mean score is 3.71 (SD = 1.36). The t-value was -0.35 resulting in a p-value of 0.73. This, once again, shows that there was no significant difference between the mean scores of the low achievers for the control and experimental groups in pre-DMAT, indicating that students with lower achievement levels were comparable across both groups at the outset of the study.

Overall, the results suggest that the two groups had similar mathematics performance levels on the pre-DMAT test across all achievers, indicating that they were comparable before the intervention stage. This comparability is crucial for the validity of the study, as it ensures that any subsequent differences observed can be attributed to the intervention rather than pre-existing differences in mathematics ability.

Table 2: Independent sample t-test on post-DMAT for high, medium, and low achievers between control and experimental groups

	Post-DMAT	N	Mean	SD	t-value	df	p-value
High	Control	8	6.38	1.69	-4.57	15	.00
	Experimental	9	10.27	1.81			
Medium	Control	18	5.33	2.28	-5.18	47	.00
	Experimental	31	8.48	1.91			
Low	Control	6	4.83	2.22	-3.68	21	.00
	Experimental	17	7.98	1.64			

The table shows the results of the Independent Sample T-Test conducted on post-DMAT scores for both the control and experimental groups.

For the high achievers, the control group had a mean score of 6.38 (SD = 1.69), while the experimental group had a higher mean score of 10.27 (SD =1.81). The t-value was -4.57 with a p-value of .00, indicating a significant difference in the post-DMAT scores between the control and experimental groups for the high achiever.

Similarly, for the medium achiever, the control group had a mean score of 5.33 (SD = 2.28) while the experimental group had a higher mean score of 8.48 (SD = 1.91). The t-value was -5.18 with a p-value of .00, indicating a significant difference in the post-DMAT scores between the control and experimental groups for the medium achiever.

For the low achiever, the control group had a mean score of 4.83 (SD = 2.23), while the experimental group had a higher mean score of 7.98 (SD = 1.64). The t-value was -3.68 with a p-value of .00, indicating a significant difference in the post-DMAT scores between the control and experimental groups for the low achiever. This result indicates that intervention had a positive effect on the post-DMAT scores for all levels of achiever. Overall, the results suggest that the system had a significant positive impact on the mathematics achievement of the students in the experimental group.

Further analysis of both groups using the independent Sample T-test with different achievement levels shows a significant difference between the groups. The high, medium, and low achievers have shown significant differences during post-test which shows that the intervention has a positive impact on the performance of the experimental group students. The mean value shown for the experimental group is higher than the control group. The experimental group outperformed the control group.

DISCUSSION

From the results of the study, the involvement of the pedagogical agent has also improved the performance of the experimental group students even when comparing within the group. The number of low achievers in pre-DMAT for the experimental group decreased after the intervention period. The number of high and medium achievers has drastically increased. To support the mean score for the pre-DMAT for the experimental group medium achievers drastically increased from 6.58 also for the low achiever the mean score for pre-DMAT was 3.71. However, it significantly increased in post-DMAT to a 7.98 mean score. The findings firmly enhance that LearnWithEmma is suitable for all levels of achievers, especially for the experimental group as it facilitates knowledge and enhances the students' performance. The platform can be leveraged by students to improve their knowledge in Logic and Proofs as it shows that the number of low achievers has reduced in post-DMAT for the experimental group [50]. As supported by [28], [47], the students were able to enhance their performance in learning mathematics.

In contrast, the control group who learned without the agent shows a reduction in the number of high achievers in post-DMAT compared to pre-DMAT. The high achiever in pre-DMAT for control was 8 then reduced to 5. In addition, the mean score of the high achiever in the control group for pre-DMAT was 10.13, however, after the intervention the mean score of post-DMAT has reduced to 7.65. This result again emphasizes that students who have to learn mathematics without the presence of the pedagogical agent have no significant improvement in mathematics.

The results of this study suggest that integrating a pedagogical agent into an online learning platform can have a significant positive impact on students' performance in Mathematics. The experimental group, which used an online learning platform integrated with a pedagogical agent, showed significant improvement in their Mathematics performance compared to their post-test and pre-test.

Significance of Study

This study holds value for students, educators, researchers, system developers, and the Ministry of Education.

Conducted during the pandemic, this study offers a new learning environment, particularly in mathematics, with the help of a pedagogical agent, LearnWithEmma. It aids students in improving their mathematical skills and performance in the absence of a physical lecturer by boosting their interest through technology-enhanced learning.

The study provides insights for lecturers on using LearnWithEmma as an additional tool, especially during the pandemic. This platform offers extensive learning materials, and tutorial questions, and serves as an alternative for students hesitant to approach lecturers, ultimately helping educators incorporate technology to enhance student performance in mathematics.

The findings offer a deeper understanding of factors affecting students' performance in mathematics, such as anxiety, low interest, and learning methods. Researchers can explore the effectiveness of pedagogical agents, gain the latest information in this field, and build upon these insights for further studies.

The study highlights the current issues in learning mathematics and how pedagogical agents can address them. It provides valuable insights (5W1H: When, Where, Who, Why, What, and How) for developers to create more effective learning systems and understand existing platforms better to meet students' needs.

The findings support the Ministry's efforts to improve distance learning during the pandemic. They provide evidence for enhancing online learning approaches, integrating technology, and addressing challenges such as providing free laptops, internet incentives, hybrid learning, and teacher training.

CONCLUSION

In conclusion, this study has shed light on the significant findings regarding the integration of pedagogical agents in online learning to enhance students' mathematics performance, particularly in the domain of Logic and Proofs. Through meticulous examination and analysis, this research has addressed the objectives by providing valuable insights into the impact of pedagogical agents on students' perceptions and performance in mathematics.

The finding has revealed that the incorporation of pedagogical agents in online learning platforms positively influences students' engagement, motivation, and satisfaction [9], [38], [51], [52]. The presence of a friendly and knowledgeable pedagogical agent, such as Emma, has been shown to enhance students' learning experiences by providing encouragement, clear explanations, and interactive engagement.

Furthermore, the study's results indicate that the use of pedagogical agents in online learning platforms can lead to significant improvements in students' mathematics performance, as evidenced by the significant differences observed within the experimental group[53]. Despite the lack of significant differences between the control and experimental groups in pre-test and post-test comparisons, the experimental group's performance notably improved after the intervention period, highlighting the efficacy of the pedagogical agent.

The implications of this study extend beyond its immediate findings, offering valuable insights for educators, instructional designers, and researchers in the field of online learning. The integration of pedagogical agents in online learning platforms presents a promising avenue for enhancing students' learning experiences and academic performance in mathematics. Additionally, the study underscores the importance of personalized learning approaches and user-centered design principles in the development of online learning platforms.

However, the study also acknowledges several limitations, including the need for further research to explore the effectiveness of pedagogical agents across diverse populations and instructional contexts. Recommendations for future research emphasize the importance of expanding the scope of investigation to include different subjects, topics, and intervention approaches, as well as the development of more advanced and interactive systems.

In summary, this research contributes valuable insights into the potential of pedagogical agents to improve mathematics performance in online learning environments. By leveraging the findings and recommendations outlined in this study, educators and researchers can continue to innovate and enhance online learning experiences, ultimately benefiting students' academic achievement and engagement in mathematics and beyond.

Limitation of the Study

The study has some limitations that need to be considered. Firstly, the generalization of the study's findings to other populations is limited. The study was conducted on a sample of students from a specific faculty at University X in Malaysia, taking a particular mathematics subject consisting of the topic of Logic and Proofs. Therefore, the extent to which the findings can be applied to other subjects, topics, schools, or locations remains uncertain.

Secondly, the sample of the study was the students who registered for the Discrete Mathematics subject and reshuffling these groups would involve major changes in the timetable, classroom allocation, assignment of lecturers or tutors, and other related concerns. In addition to that, the freedom has been given to the students to choose to be part of the control or experimental group. This has caused the size of both groups to be inconsistent.

Thirdly, the development of the system was limited due to the absence of a team of professionals such as animators, graphic artists, and sound engineers to create an interactive animated learning agent. The system that was implemented in this study focuses on delivering the lecture and improving the performance of students. Hence the learning system was developed by satisfying the minimum requirement.

Fourthly, the study is limited to a particular instructional design that is integrated with a pedagogical agent. This design may not be suitable for all students, and other instructional designs may need to be explored to maximize the effectiveness of the pedagogical agent. In addition, there was only one pedagogical agent has been developed to teach. Multiple agents would provide choice to the students to choose the pedagogical agent that they want to learn with.

The final limitation of the study is the lack of significant differences between the control and experimental groups for the pre-test and post-tests. This non-significance suggests that the study may not have been able to fully evaluate the effectiveness of the DMAT intervention in comparison to the standard care or non-intervention approach. This limitation could be due to a variety of factors, such as sample size, the timing of the intervention, or the nature of the intervention itself. Hence future research with larger sample sizes and different intervention approaches may be needed to address this limitation and provide more robust evidence on the effectiveness of the DMAT intervention.

AUTHORS' CONTRIBUTIONS

CKTAN conceived the idea, designed the project and helped in writing the manuscript. CS participated in the design of the study, developed the agent, wrote the manuscript, conducted the study and statistical analysis. All authors read and approved the final manuscript.

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