To Enhance the Pedagogy of Personalized Learning by Utilizing Multi-Robot Systems (MRS)

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Abstract
Personalized learning has been a significant educational approach since the early 1960s, aiming to tailor learning experiences based on individual student needs. There is potential to further enhance personalized learning in large classrooms with advanced technologies such as multi-robot systems (MRS). This study proposes to explore the implementation of MRS in educational sectors to improve student engagement, motivation, and learning outcomes. The proposed research design includes surveysand interviewswith the educator andthe student, followed by a proposed solution. This research carries on qualitative and quantitative data analysis&theirrespective results are involved in the proposed methodology. The anticipated impact is a significant improvement in learning experiences and outcomes for the students, including those with additional learning needs.

Keywords: multi-robot system (MRS), personalized learning, improved student engagement, interactive learning, educational robot, adaptive learning, classroom robotics, human-robot interaction, collaborative learning, artificial intelligence in education.

1. Background

Personalized learning has been popular in the educational sector since the early 1960s (Epstein, 1961), providing approaches that customize students' learning experience based on their strengths and needs (Miliband, 2006; Chatti, Jarke and Specht, 2010). Educators have been implementing personalized learning in the classroom to increase students' engagement and motivate them to be more curious, confident, and creative learners; resulting in drastic improvements in students' learning outcomes from engagement to achievements to well-being (Pane et al., 2015). But only traditional personalized learning is not sufficient anymore to cope with the modern world, itrequires the augmentation of the traditional "one-size-fits-all" approaches to learning, along with the leverage of modern technologies.

2. Objective of the Research

The objective of this research is to explore and evaluate the effectiveness of implementing a Multi-Robot System (MRS) in the educational environment. This study seeks to determine how MRS technology can be utilized to address the challenges of each educator and student by dynamically adapting to their requirements and effectively facilitating personalized learning in large classroom settings. Specifically, the focus is to improve student engagement, motivation, and learning outcomes by providing individualized support tailored to each student's needs, as well as identifying the practical implications foreducators in implementing such technology. The primary aim is to design, develop, and asses a MRS prototype that can adapt to the diverse learning requirements of students, thereby creating a more interactive and supportive educational environment. Ultimately, by providing actionable insights into the feasibility and benefits of integrating MRS into diverse educational contexts, this study intends to contribute to the development of scalable educational strategies.

3. Problem Statement

In large classroom environments, implementing personalized learning often becomes a significant challenge due to various factors such as the diverse needs of students, the limited ability ofeducators to address these

needs on an individual basis, minimal resources, and the wide range of learning styles and paces among students. Traditional teaching methods struggle to engage every student effectively, leading to reduced motivation, disengagement and inconsistent academic performance.The generalized teaching strategies are becoming less effective in today's large and diverse classroom environments since they can't fully address the specific needs of individuals. This gap emphasizes the need for innovative solutions that can offer personalized learning on a broader scale.

The integration of advanced technologies, such as Multi-Robot Systems (MRS) presents not only a potential solution to the challenges faced by the educator and the student but also a promising opportunity to deliver tailored educational support and improve learning experiences. However, there is limited research on the practical implementation of MRS in educational settings to support personalized learning. This research seeks to address this gap by investigating the potential of MRS technology to provide individualized support, enhance student engagement, and improve overall learning outcomes in large, diverse classrooms.

4. Literature Review

The literature review of this research primarily focuses on the advanced technologies that have been utilized in the educational sector and how they have been providing support to both the educator as well asthe student. On the other hand, it also presents the current applications of Multi-Robot Systems (MRS) across various domains.

4.1. Integration of Advanced Technologies:

Artificial intelligence, robotic technology, data mining, and intelligent technologies are empowering learning environments to effectively advance the development and increase the integration of personalized learning (Peng, Ma and Spector, 2019). Teachers can challenge, intervene, dynamically track, and support students where necessary with the implementation of advanced technologies like robots Nao (SoftBank Robotics, 2008), Robosem (Saenz, 2011), and Edison (Edison, 2014) in the classroom. Students can easily adapt to the learning materials with the assistance of digital tools that help them process information and demonstrate their learning pathways in their preferred way. Numerous case studies indicate that implementing technology in the classroom to systematize personalized learning has a positive impact on students' learning achievements (Bahçeci and Gürol, 2016; Schmid and Petko, 2019).

4.2. Multi-Robot Systems (MRS) and its applications:

The multi-robot system (MRS) is a group of robots designed to perform collective behaviors, so the goals that are time-consuming or impossible or hard for a single robot to achieve may become achievable and expedient. Because of the scalability, flexibility and robustness of MRS and its advantages of supporting situational awareness in potentially hazardous environments without exposing humans to danger (Barca, Rumantir and Li, 2008), many researchers investigate the applicability of MRS in many pertinent areas such as intelligent security (Yi-Lin and Kuo-Lan, 2011), search and rescue (Nagatani et al., 2009), surveillance (Marino et al., 2013), humanitarian demining (Khamis and ElGindy, 2012), environment monitoring (Espina et al., 2011), healthcare (Shiomi et al., 2013), cooperative mapping (Burgard et al., 2005), autonomous surveillance of buildings (Gerkey, Thrun, and Gordon, 2005), monitoring of forest areas (Lemaire, Alami, and Lacroix, 2004), exploring unknown zones (D'Emidio, Frigioni, and Navarra, 2013), teamwork in higher RoboCup leagues (Vail and Veloso, 2003), flying robots (Hauert, Zufferey, and Floreano, 2008), ground moving robots (Trianni, 2007), robots in water (Yildiz, Gokal, and Yilmaz, 2011), and social robots (Terrence, Nourbakhsh, and Dautenhahn, 2003).

5. The Importanceof Integrating MRS in Modern Education

As educational environments continue to evolve, the integration of advanced technologies has become increasingly crucial to meet the diverse needs of the studentsto make them more confident,skilled&

competent in the global environment. The following sections explore the role of MRS in modern education and discuss the anticipated significance and impact of their implementation.

5.1. Educational Robots and MRS:

Despite the extensive research on MRS in various fields, limited research has been conducted on their implementation in education. The unique characteristics of MRS, such as task allocation, goal reasoning, group formation, cooperative object detection and tracking, communication relaying, and self-organization, including their ability to do multiple tasks at once, make them firmly suitable for delivering personalized learning to multiple students (Vitanza, 2019). This is particularly important for students with learning challenges and additional learning needs who must rely on their educators in physical classrooms to help them through their lessons (Catlin and Blamires, 2018). Educational robots have been succeeding in bridging the communication gap when face-to-face interaction has failed to do so, even for students with special needs as they are more comfortable communicating with robots, such as Nao (SoftBank Robotics, 2008), Millenia (International Robotics Inc, 2001), Kaspar (Kaspar, 2005) than with adults.

Studies have shown that educational robots can accelerate students' interests and engage them in innovative ways in STEM (science, technology, engineering and mathematics) classrooms (Kim et al., 2015; Mohr-Schroeder et al., 2014) improving problem-solving and teamwork abilities (Merdan, 2017) and guiding them through different types of learning from robotic subjects to non-robotic subjects.

5.2. Anticipated Significance and Impact

Children perform better when the learning process involves robots (Crompton, Gregory and Burke, 2018; Kanero, 2018; Neumann, 2020; Konjin et al., 2021). Due to the extensibility, resilience, and efficiency of MRS, its implementation in education has shown a significant positive result in interaction and communication skills in collaborative learning (Vitanza, 2019), in students' improved learning experiences (McLurkin et al., 2013; Avanzato, 2013), in helping students with special needs (Kaburlasos et al., 2018; Zhang et al., 2019).

The MRS in our proposed study will not only work as a passive learning tool by acting as an interactive mediator to increase students's engagement in a large classroom and motivate them to gain a deeper understanding of the curriculum than in traditional classroom settings, but also as a peer in the learning process by creating interesting communication, cooperation, and coordination strategies through mapping out what each student needs to learn, measure what each student already knows, and then create the optimal path for the student to learn the rest. Study shows that when robots cover the role of both learning tools (Mitnik et al., 2009) and peers (Okita, Ng-Thow-Hing and Sarvadevabhatla, 2009), students are more interactive and motivated in different kinds of learning experiences (Chevalier et al., 2016).

6. Research Methodology

The proposed research will adopt a mixed-methods approach, combining quantitative surveys, qualitative interviews, and Design-Based Research (DBR) to develop and evaluate an MRS prototype.Both qualitative and quantitative data will provide a comprehensive understanding of how MRS can improve student engagement, motivation, and learning outcomes. Through iterative design and evaluation, the methodology will focus on developing a robust MRS prototype that can be practically implemented and scaled in diverse educational contexts.

Research Design:

The study will utilize surveys, interviews, and prototype testing to gather insights from the educator and the student, ensuring that the findings are grounded in real-world educational experiences. The research will be carried out in three distinct phases:

Phase 1: Surveys

- **Objective:**This phase aims to identify the challenges related to student engagement and motivation in large classrooms.
- **Participants:** Educators and students from various educational institutionswill beinvitedasparticipantsin the surveys.
- **Data Collection:**Surveys will be conducted to collect quantitative data on the perceived effectiveness of current personalized learning strategies. They will also identify specific challenges faced by both teachers and students. Furthermore, the surveys will assess the potential acceptance of MRS technology in educational settings.
- **Data Analysis:**Descriptive statistics will be utilized to summarize the survey data. Also,inferential statistics (such as t-tests, and ANOVA) will be employedto identify significant differences and trends.

Phase 2: Interviews

- **Objective:**The goal here is to gain a more profound understanding of individual student needs and expectations.
- **Participants:** A portion of survey participants will be selected for follow-up interviews based on their prior survey responses.
- **Data Collection:**Semi-structured interviews will be administered to explore detailed insights into students' and educators' experiences with personalized learning. These interviews will also examine their expectations regarding the potential use of MRS in educational settings. Additionally, the interviews will assess the anticipated learning and teaching outcomes associated with implementing MRS technology.
- **Data Analysis:**Thematic analysis will be utilized to identify key themes and patterns in the interview data. In addition, qualitative analysis software such as NVivowill be used to generate code transcriptsthat will facilitate the systematic categorization and interpretation of the data.

Phase 3: Proposed Solution

- **Objective:** The focus of this phase is to develop and test a prototype of MRS for personalized learning.
- **Approach:** By utilizing the Design-Based Research (DBR) methodology, the MRS prototype will be designed, implemented, and evaluated iteratively.
- **Analysis and Exploration:**Data gathered from the surveys and interviews will be used as the design requirements for the MRS prototype.
- **Design and Construction:**The MRS prototype will be developed focusing on key features of multi-robot systems such as task allocation, group formation, cooperative object detection, and personalized learning pathways.
- **Evaluation and Reflection:** The prototype will be tested in a controlled educational setting while data on its performance, effectiveness, and user satisfaction will be collected and analyzed.
- **Iteration:**Based on the prior outcomes and evaluation, the prototype will undergo multiple refinements and re-evaluations until the desired outcomes are achieved.

The research methodology also encompasses a data analysis plan of the research design, which will be discussed in the subsequent section.

7. Data Analysis of the Research Design

The analysis will use a mixed-methods approach, combining quantitative and qualitative data to fully comprehend the potential impact of MRS on personalized learning.

7.1. Quantitative Analysis:

Quantitative analysis will be used to examine numerical data gathered through surveys and experimental results. This data will be analyzed using statistical methods to identify trends, relationships, and differences in student engagement, motivation, and learning outcomes before and after implementing MRS.

- **Survey Data:**Statistical analysis methods will be used to identify key trends and patterns in survey data. Descriptive statistics (mean, median, mode) will provide an overview. On top of that, inferential statistics (e.g.,t-tests, ANOVA) will be employed to test hypotheses about differences in engagement and motivation before and after hypothetical MRS implementation.
- **Engagement Metrics:**Hypothetical pre- and post-implementation engagement metrics (e.g., participation rates, time on task)will be compared by using paired sample t-tests. It will evaluate the potential effectiveness of MRS in educational settings.
- **Academic Performance:**Hypothetical student performance datasuch as grades and test scores will be analyzed to assess potential improvements in academic outcomes. Moreover, regression analysis will be used to hypothesize the extent to which MRS implementation could contribute to these improvements.

This will provide measurable evidence of the effectiveness of MRS in educational settings.

7.2. Qualitative Analysis:

Qualitative analysis will involve collecting non-numerical data, such as insights from interviews and observations, to understand the experiences, perspectives, and needs of students and educators regarding the use of Multi-Robot Systems (MRS) in education.

- **Interview Data:**Thematic analysis will be used to analyze qualitative data from hypothetical interviews. Key themes and sub-themes will be identified to understand students' and educators' perceptions of the potential impact of MRS on learning experiences.
- **Coding Process:**Hypothetical transcripts from interviews will be used in the coding by leveragingqualitative analysis software such as NVivo. Open coding will be used to identify initial themes, followed by axial coding to link themes and establish relationships between them.
- **Triangulation:**Findings from qualitative analysis will be triangulated with quantitative data to ensure the robustness and validity of the anticipated results.
- This approach will help identify common themes and patterns that highlight how MRS can enhance personalized learning and engagement in the classroom.

7. Implementation

The implementation of the Multi-Robot System (MRS) in a large classroom setting aims to enhance personalized learning by addressing individual student needs more effectively. This section illustrates how MRS technology in educational settings can improve student engagement, motivation, and learning outcomes with real-life scenarios.

Enhancing Student Engagement:

The MRS will facilitate an interactive learning environment by assessing each student's specific needs through Multi-Robot Task Allocation (MRTA) algorithms and Goal-Driven Autonomy (GDA). Each robot will be assigned to assist individual students based on these needs. The assessment will then leverage real-time feedback from robots to keep them engaged.

For instance, a group of students struggling with any real-time problem-solving task or any academic course or project in a large classroom where each student's needs are different from the other. After determining each student's unique needs, the MRS will send robots to work one-on-one with the students. The system will then monitor student progress and adjust learning paths dynamically, ensuring that each student receives the appropriate level of challenge and support. This adaptability will help maintain student interest and participation.

Motivation Enhancement:

Throughout the interactions between individual students and their robots, the robots will deliver personalized feedback and encouragement based on each student's progress. Recognizing individual achievements and providing targeted encouragement can significantly boost student motivation. The MRS will facilitate collaborative tasks where students work with robots and peers as a team, fostering a sense of community and shared goals. This interaction will not only help students build confidence but will also motivate them to participate actively.

For example, consider a classroom where students are working on a group project. The MRS can help by assigning robots to different groups that can assist students by providing guidance and feedback in conducting experiments and analyzing results. It will make the learning process more dynamic and motivate students through hands-on activities.

Improving Learning Outcomes:

The MRS will continuously monitor and assess each student's performance while collecting real-time data so that both students and teachers can receive ongoing feedback. Based on the collected data, the system will adjust learning paths to ensure students fully understand the material and are appropriately challenged. Educators can utilize this information to tailor their instructional strategies.

On the other hand, students often feel hesitant to ask questions in front of peers in a large classroom. With MRS, a student struggling with a specific topic can receive one-on-one tutoring from a robot without the fear of embarrassment. The system will modify the learning path according to the students' necessity and revisit foundational concepts before progressing. This ensures that the student builds a strong understanding of the particular topic and gradually improves overall academic performance.

This practical implementation strategy ensures that the MRS technology enhances student engagement, motivation, and learning outcomes by providing personalized assistance and adaptive learning experiences.

8. Expected Outcomes of the Research:

The expected results will be presented in an organized way, highlighting the key findings from both quantitative and qualitative analyses.

8.1. Quantitative Expected Results:

The quantitative analysis will measure the impact of MRS on student engagement and academic performance, using data from surveys and performance metrics to provide evidence of effectiveness.

- **Tables and Graphs:**To graphically represent anticipated trends and patterns, expected survey and performance data will be presented using tables and graphs. Bar charts, line graphs, and scatter plots will be included to illustrate potential changes in engagement and academic performance.
- **Statistical Significance:**Statistical results, such as hypothetical p-values and confidence intervals, will be provided to demonstrate the significance of the findings.

This will help to provide objective evidence of how MRS implementation influences educational outcomes in large classroom settings.

8.2. Qualitative Expected Results:

The qualitative analysis will explore insights from the student and the educator, using themes from interviews to understand how MRS influences personalized learning and teaching experiences.

- **Thematic Maps:**Anticipated themes and sub-themes identified from interview data will be presented using thematic maps. These maps will visually depict the connections between different themes, offering a clear overview of the qualitative insights.

- **Participant's Feedback:**Hypothetical feedback from participants will be included to support the themes, providing a deeper understanding of their anticipated experiences and perceptions.
- This will offer valuable insights into the subjective impact of MRS on personalized learning, highlighting the nuanced ways in which these systems can enhance the teaching and learning environment.

9. Discussion

The findings from this study have several important implications for educational practice and theory.

Practical and Theoretical Significance

The expected results indicate that MRS can be effectively integrated into existing educational system to enhance personalized learning. Activities in personalized learning along with their real-time feedback from the MRS helps educators address individual student's needs more effectively. This adaptive learning approach ensures that every student progresses at their own pace, thereby increasing engagement and motivation.Whereas traditional personalized learning methods may fall short, this MRS method provides an extensible solution, especially for large classrooms.

It is imperative that educators play a crucial role in facilitating the use of MRS in educational institutions. In order to maximize the benefits of this technology, teachers will require sufficient training and support. To ensure the successful adoption and use of MRS in the classrooms,equipping teachers with the skills to operate the MRS, interpret data, integrate robotic activities into their teaching strategies, and technical assistance and peer collaboration networks will be essential.

The integration of MRS in education aligns with and extends several established learning theories. Constructivism, social learning theory, developing communication and teamwork skills etc. are the key theoretical frameworks the system fostered in students.

Future Studies

Initial pilot programs will be implemented in selected classrooms to test the system's effectiveness. Feedback from both students and teachers will be used to identify strengths and areas for improvement. Based on pilot feedback, the MRS system will be refined through iterative cycles of testing and improvement, ensuring optimal performance and user satisfaction.Successful pilot tests will lead to scaling up the MRS implementation across more educational institutions. Over time, the MRS could be scaled to different schools and colleges, adjusting to fit diverse learning contexts.

Further research should consider longitudinal studies to evaluate the sustained impact of MRS on learning outcomes. Additionally, investigating how to combine MRS with other cutting-edge technologies, such as augmented reality (AR) and virtual reality (VR), could further enrich personalized learning experiences.

10. Conclusion

The implementation of Multi-Robot Systems (MRS) in educational settings represents a revolutionary approach to personalized learning. This study aims to contribute significantly to the field of educational technology by leveraging MRS technology to create a more interactive, engaging, and supporting learning environment for both the teacher as well asthe student.

The proposed methodology comprises a mixed-methods approach of quantitative surveys, qualitative interviews, and iterative design-based research (DBR). This research design will ensure that the development and implementation of the MRS prototype meet the demands of real-world educational experiences and requirements. The expected outcomes suggest that MRS can effectively bridge the gap

between traditional teaching methods and modern technological advancement. MRS can alsoprovide a scalable and sustainable solution to the challenges faced by the stakeholders withinthe teaching-learning environment.

The findings from this research will offer significant knowledge about the practical application of MRS in education and also expedite opportunities for advanced teaching and learning methods in the future. As we progress towards a more technology-driven educational environment, the importance of MRS in improving personalized learning will become more vital, guaranteeing that education stays adaptable, accessible, and attentive to the needs of individual students.

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Appendix

Appendix A: Research Questions (RQ)

The following research questions guided this study on the implementation of Multi-Robot Systems (MRS) to support personalized learning in large classrooms.

- **RQ-1.** How can implementing MRS technology in a large classroom ensure the creation of personalized learning to help students highlight their abilities rather than illuminate their disabilities?
- **RQ-1.1** How can MRS engage and motivate students to express their curiosity to gain a deeper understanding of the curriculum?
- **RQ-1.2** How can MRS improve students' learning experience to progress their outcomes from engagement to achievement?