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Developing Educational AR Games for School Students: Impact on Academic Performance

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***Abstract*— In the current educational landscape, there is a growing need to address the engagement and effectiveness of learning methods for primary school students. Traditional teaching approaches often struggle to capture students' interest and accommodate diverse learning styles, which can impact academic performance. This study aims to address these challenges through the development of Augmented Reality (AR) games integrated with Artificial Intelligence (AI) and Machine Learning (ML) technologies. These AR games are designed to create interactive and personalized learning experiences that engage students more deeply and cater to individual learning needs. The research evaluates the impact of these innovative tools on student motivation, knowledge retention, and overall academic performance. By analyzing the effectiveness of AR and AI/ML-enhanced educational games, the study seeks to provide actionable insights for improving educational practices and leveraging advanced technologies to foster a more dynamic and effective learning environment.**

***Index Terms*— Augmented Reality, Machine Learning, Artificial Intelligence, Knowledge Retention, Interactive Learning.**

I. INTRODUCTION

The integration of advanced technology into education is revolutionizing the traditional classroom experience, especially for primary school students. These young learners are increasingly familiar with digital and interactive technologies, making conventional teaching methods less effective in engaging them according to Fig 2. This discrepancy often results in reduced motivation and academic performance.

Augmented Reality (AR), along with Artificial Intelligence (AI) and Machine Learning (ML), offers a solution by creating immersive and interactive educational experiences. AR can vividly illustrate concepts, while AI and ML personalize the learning process to cater to individual student needs. These technologies can significantly enhance engagement and learning outcomes.

Fig 1: SmartVerse Collaboration

This study investigates the development of AR games enriched with AI and ML technologies for primary education. The research evaluates the impact of these tools on student motivation, knowledge retention, and academic performance. By providing customized and engaging learning experiences, the study aims to identify practical strategies for integrating these technologies into educational practices.

Building on previous research into interactive technologies like Web3D and WebXR [1], and the use of mobile AR in education [2], this study seeks to explore the broader implications of AR and AI/ML in enhancing primary school education. The goal is to offer insights into the potential of these technologies to transform teaching methods and improve student outcomes.

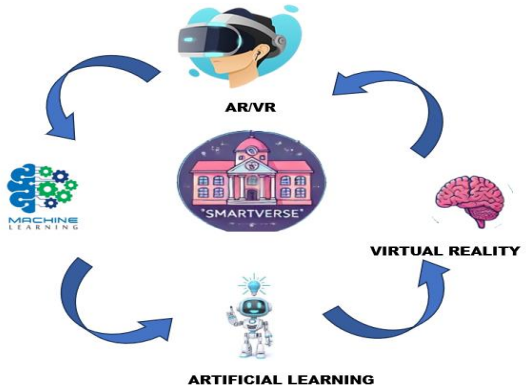

Fig 2: Introduction diagram for SmartVerse

II. BRIEF LITERATURE REVIEW

A. WebXR technology for children's education

X. Guo and I. Mogra (2022), explore using Web3D and WebXR technologies to teach primary school children about plastic recycling. It combines Virtual Reality (VR) and

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Augmented Reality (AR) to create engaging, immersive learning experiences. The "Let's Go Green" project demonstrates that these technologies can successfully deliver personalized, mixed-media educational content in classroom settings, enhancing children's understanding of sustainability.[1]

I. Horváth (2018) his research examines the efficiency of the MaxWhere 3D Virtual Learning Environment, highlighting its ability to streamline digital workflows and reduce the workload for educators. The study underscores the platform's potential to optimize content delivery and improve educational efficiency.[8]

B. AR based elements in Higher Education

L. V. Kurzaeva, T. A. Bondarenko, G. A. Kameneva, Y. A. Maznina and S. V. Akmanova (2020) found that virtual and augmented reality (VR/AR) are emerging technologies enhancing education through interactive, immersive experiences. They offer unique benefits like increased engagement and better visualization, particularly in underutilized fields like mathematics. The growing accessibility of digital devices supports their integration, making learning more intuitive and aligning with the digitalization of education.[2].

Y. -J. Chang, H. -H. Liu, Y. -s. Kang, C. C. Kao and Y. -S. Chang (2016) their research explores the use of augmented reality (AR) and smart glasses for cognitive rehabilitation. It highlights AR's potential in enhancing task prompting systems, specifically for vocational training. The study emphasizes the advantages of using smart glasses over large displays and smartphones, offering hands-free,real-time guidance for users with cognitive impairments during activities such as virtual food preparation.[3]

P. A. LØvsletten, L. KiØnig and T. Vold (2019) their study explores the use of Augmented Reality (AR) in real estate education, focusing on its application for visualizing properties and environments.AR offers a unique way to represent digital objects in real-world settings, aiding in tasks such as property visualization, training simulations, and crisis management. Unlike Virtual Reality (VR), which creates a fully virtual environment, AR overlays digital elements on the real world, enhancing user interaction and decision-making. The research examines how AR can support real estate students by providing practical training and engaging customers in the design process, ultimately benefiting knowledge management in real estate agencies.[6]

C. Game Based Learning

Deliyannis, I., Kaimara, P. researches that the development of Smart Learning Environments (SLEs) integrates software engineering with pedagogical principles, leveraging advanced technologies like augmented reality, virtual reality, and holograms. These environments utilize gamification and game technologies to create multisensory, media-rich experiences. However, the design process remains complex, requiring collaboration between content experts and developers, often hindered by a lack of programming knowledge among educators and the absence of standardized development frameworks.[4]

Lampropoulos, G., Kinshuk (2024) studies that the integration of virtual reality (VR) and gamification in education offers transformative potential, enhancing engagement, motivation, and learning outcomes. By blending immersive experiences with game elements, these technologies foster personalized and collaborative learning environments. Studies reveal that such approaches can improve cognitive, emotional, and social development, making them effective tools for modern education.[10]

D. AR based Experiential learning

H. Wei, Y. Liu and Y. Wang, (2019) their research focuses on the application of AR in engineering education, specifically in simulating optical experiments. It highlights AR's ability to bridge theoretical concepts and practical skills, enabling students to engage deeply with complex engineering topics through hands-on projects.[5]

S. Paul, S. Hamad and S. Khalid (2019) their study explores the use of Augmented Reality (AR) in education, focusing on its potential to create engaging, interactive learning experiences. The research emphasizes developing and evaluating AR-based educational tools to enhance student understanding and engagement.[7]

E. AR Multi-User Learning Environment

D. Schott (2021) he found that The multi-user VR/AR learning environment provides a dynamic platform for liver surgery education, offering interactive modules such as an interactive liver shelf and an information board. It facilitates collaborative learning by allowing students to explore medical data, enhancing their understanding of complex anatomical structures through immersive experiences.[9]

III. PROPOSED METHODOLOGY

In today's educational landscape, traditional teaching methods are often insufficient to engage young students effectively, especially in an age of technology-driven learning. The **SmartVerse** project aims to bridge this gap by developing an interactive, game-based learning application for primary and kindergarten students. Built using the Unity engine, SmartVerse integrates Augmented Reality (AR), Virtual Reality (VR), Artificial Intelligence (AI), and Machine Learning (ML) to create personalized and adaptive learning experiences. This methodology enables students to learn through play, enhancing their motivation and educational outcomes in a fun, interactive way.

A. Methodology Framework:

The SmartVerse app is developed using the Unity game engine, which serves as the foundation for creating immersive and interactive games. The following steps outline

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the core methodology behind SmartVerse's adaptive learning approach:

B. Unity Games Development for SmartVerse

The core of SmartVerse is developed using Unity, a powerful and versatile game development engine. Unity allows the creation of immersive, game-based environments that are designed specifically for younger learners. The educational games are tailored to subjects like mathematics, science, reading, and general knowledge, which align with standard curricula for primary and kindergarten students. These games are built with interactive 3D environments that immerse students in learning tasks, enhancing their engagement and retention.

C. Multi-Level Game Design

Smart Verse's games are designed with multiple levels of difficulty, allowing for gradual progression in learning. Each game starts at a basic level, and as students demonstrate their mastery of the content, they are automatically moved to more challenging levels. This progression is not arbitrary; rather, it is determined by the student's performance in previous levels, ensuring that the learning pace is adapted to their individual needs. This approach not only ensures that the content remains challenging but also prevents students from becoming overwhelmed or disengaged.

D. AI/ML-Based Adaptive Learning

The most innovative aspect of SmartVerse lies in its use of AI and ML algorithms to deliver adaptive learning experiences. As students engage with the games, the AI tracks their performance across various metrics, including speed, accuracy, and comprehension. Based on this data, the system adjusts the difficulty level of the games in real time, tailoring the learning experience to the individual student's capabilities. This adaptive learning feature ensures that students are consistently challenged at the appropriate level, promoting steady progress and reducing frustration.

E. Weekly Performance Tracking and Reporting

One of the key features of SmartVerse is its ability to generate comprehensive weekly performance reports. These reports, powered by AI-driven analytics, offer detailed insights into each student's progress. The reports include data on the subjects and levels completed, strengths and weaknesses, and areas that require further practice. This information is invaluable for both teachers and parents, allowing them to track the student's progress over time. Additionally, these reports can be used to identify learning gaps and to offer personalized support where needed.

F. Enhanced Learning Outcomes through Gamification

The gamification of learning in SmartVerse is designed to keep students motivated and engaged. By incorporating elements such as points, rewards, badges, and levels, students are incentivized to continue learning and improving. The adaptive nature of the games ensures that students feel a sense of achievement without the content becoming too easy or too difficult. This approach fosters a positive learning environment where students are eager to learn and improve.

G. Methodology Diagram Explanation:

The methodology of SmartVerse is visually represented through the following Fig 3. It illustrates the entire process flow, from game development in Unity, AI/ML-based adaptive learning, to performance reporting and feedback.

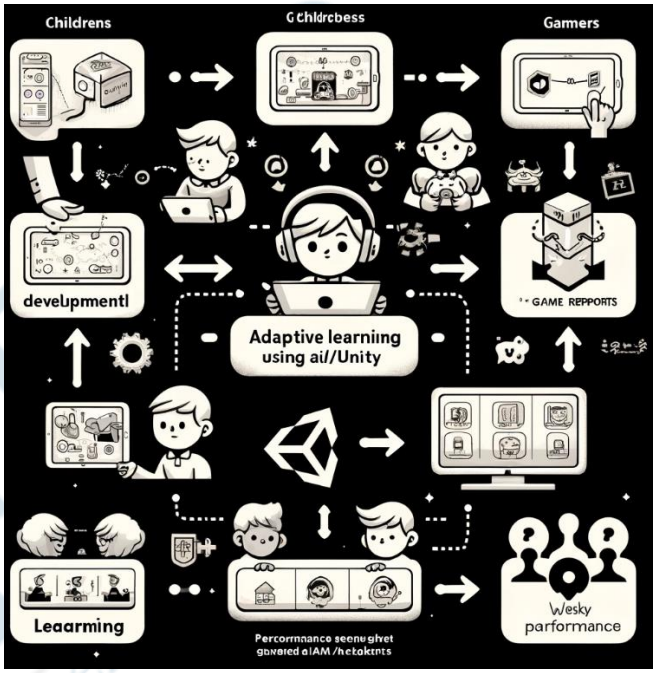

Fig 3: Methodology diagram for SmartVerse,

H. Weekly Performance Tracking and Reporting:

At the heart of SmartVerse, the Unity engine is used to create a variety of educational games, each designed to teach specific subjects through interactive, game-based methods. The games incorporate 3D environments, making the learning experience visually engaging and immersive.

AI/ML-Powered Adaptive Learning:

The AI/ML algorithms are integrated into the games to track student performance and adapt the game difficulty based on real-time analytics. This ensures that each student receives a personalized learning path that adjusts as they advance through the game.

Performance Feedback Loop:

Every interaction and game session is recorded and analyzed by the AI system. At the end of each week, a detailed report is generated that provides insights into the student's strengths, areas for improvement, and overall progress. This feedback loop not only helps in improving the student's knowledge but also assists teachers and parents in tracking educational development.

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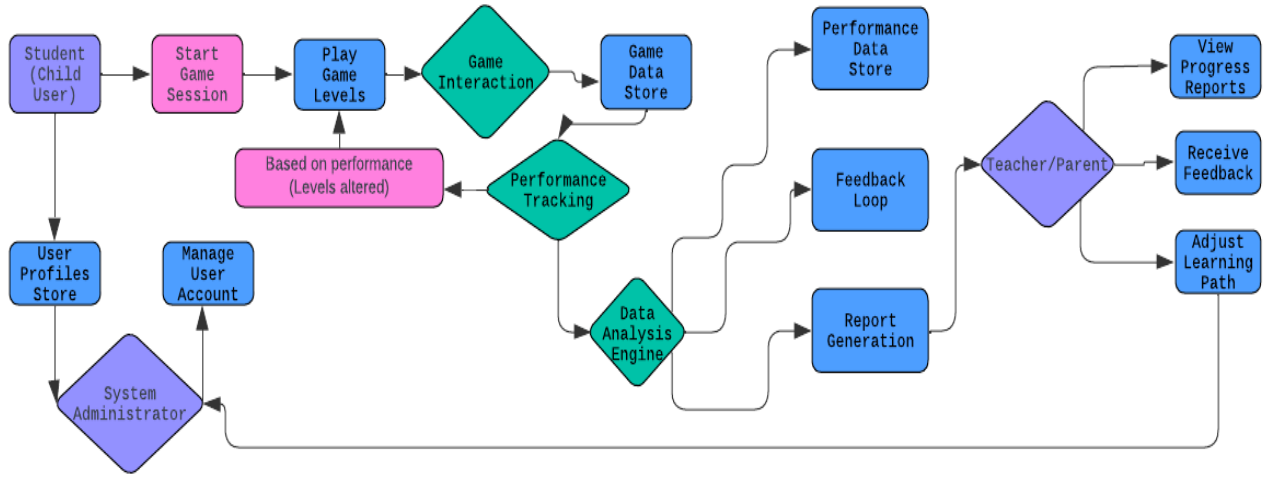

Fig 4: Data Flow diagram for SmartVerse

Game Levels and Progression:

Students are presented with challenges and tasks within the game. The complexity of these tasks increases as students demonstrates proficiency. The AI dynamically adjusts the learning path, ensuring students are neither overwhelmed nor bored, but consistently challenged in line with their capabilities.

Reports for Teachers and Parents:

The weekly reports generated by the AI algorithms serve as a tool for parents and teachers to understand how well students are performing. It helps in identifying learning gaps and offers a roadmap for addressing them in future learning sessions. [Fig 4]

IV. ARCHITECTURAL REPRESENTATION

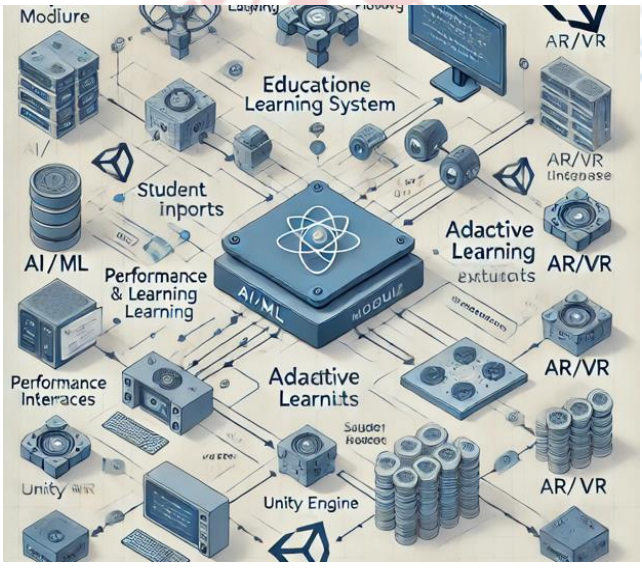

Fig 5: Architectural diagram for SmartVerse

Fig 4 illustrates a conceptual framework for a "SmartVerse," an integrated learning environment combining Augmented Reality (AR), Virtual Reality (VR), Artificial Intelligence (AI), and Machine Learning (ML). At the center, AI acts as the core driver, facilitating adaptive learning and personalized education. The framework emphasizes data flow from various sources, including student databases and performance reports, to enhance the learning experience through immersive AR/VR technologies. This approach aims to create an interconnected educational ecosystem that adapts in real-time to learner needs, fostering more effective and engaging learning outcomes.

V. SOFTWARE SYSTEM DESIGN AND IMPLEMENTATION

The design of the "SmartVerse" application focuses on integrating adaptive learning methodologies through interactive games, designed specifically for primary and kindergarten students. The main challenge of the system is to effectively combine various gaming components, AI/ML algorithms for adaptive learning, and real-time data analysis to provide a personalized educational experience. The system architecture is modular, ensuring scalability, flexibility, and ease of maintenance. The application is developed using the Unity game engine, known for its robust support for cross-platform deployment, and enhanced with AI/ML models for adaptive learning as mentioned in Fig. 6.

The overall architecture follows a client-server model with three main layers: **Application Layer**, **AI/ML Engine Layer**, and **Data Management Layer**.

A. System Architecture Overview:

1. *Application Layer:*

- This layer serves as the front-end interface where users interact with the "SmartVerse" games. It includes various game modules, which are designed to cater to different subjects and learning levels. Each module contains multiple levels of difficulty, and progression is based on the student's performance.
- Unity is used for game development to create a visually engaging environment. The use of 3D elements and

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animations helps in enhancing the learning experience by making it interactive and immersive.

2. ***AI/ML Engine Layer***:

- This layer is responsible for the adaptive learning functionality of the system. It utilizes AI/ML algorithms to analyze the user's in-game performance data, such as time spent on each level, the number of attempts, and success rates.
- Based on the analysis, the system dynamically adjusts the difficulty level of the games. Machine Learning models such as Reinforcement Learning are employed to fine-tune the adaptation, ensuring a personalized learning experience for each student.

3. ***Data Management Layer***:

- The Data Management Layer handles all data-related activities, including storage, retrieval, and processing. It consists of two databases: one for user profiles and another for game performance data.
- A **SQL database** is used to maintain user information, preferences, and settings, while a **NoSQL database** stores the gameplay interaction data, including logs, performance metrics, and analytics data.

B. Design Details:

The **Application Layer** leverages reusable components that handle standard functions such as user authentication, game initiation, and in-game feedback. These components are shared across different game modules to maintain consistency and efficiency.

- The **AI/ML Engine Layer** is built to integrate seamlessly with the Unity game engine, using Python-based AI/ML scripts. The scripts are deployed as microservices that communicate with the game client over REST APIs.
- The **Data Management Layer** ensures data integrity and security, with encryption mechanisms for sensitive user data and access control policies to manage different user roles (students, teachers, parents, administrators).

C. Integration and Deployment:

The system is deployed on a cloud server, ensuring high availability and scalability. The Unity application is hosted on AWS, with the AI/ML models running on an Azure-based ML platform to take advantage of their specialized computing resources.

The databases are hosted on a hybrid cloud model, where the SQL database runs on a private cloud environment for enhanced security, and the NoSQL database is managed on a public cloud for flexibility and scalability.

D. Implementation Strategy:

1. **Prototype Development**: Initial versions of the game modules are developed using Unity, with basic adaptive algorithms implemented in Python.
2. **Integration Phase**: The game modules are integrated with the AI/ML engine and databases. API endpoints are created for data exchange between components.
3. **Testing and Feedback Loop**: Continuous testing is performed to evaluate system performance and user experience. Feedback is collected from initial users (students and teachers) to refine game levels and AI/ML models.
4. **Deployment and Monitoring**: The system is deployed on cloud servers with monitoring tools to track performance and detect any anomalies.

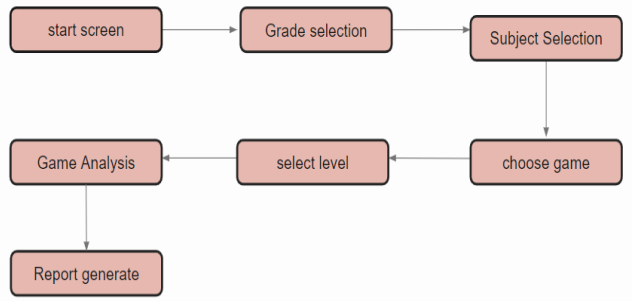

Fig 6: System architecture

COMPONENT	SOFTWARE/HARDWARE	USAGE
Game Engine	Unity	Development of 2D interactive educational games and managing cross-platform compatibility.
AI/ML Platform	Python, TensorFlow, PyTorch	Implementation of adaptive learning algorithms to analyze user performance.
Database System	MySQL, MongoDB	MySQL for storing user information; MongoDB for storing gameplay interaction data.
Cloud Services	AWS, Azure	AWS for hosting Unity-based game components; Azure for running AI/ML models.
Operating System	Windows Server, Linux	Windows Server for Unity deployment; Linux for database and backend management.
User Devices	Android, iOS	Devices such as smartphones and tablets used by students to interact with the application.

VI. OUTPUT & TEST RESULT

In this study from Fig 7-11, we assessed the effectiveness of the SmartVerse educational gaming application through a controlled pilot trial. The evaluation involved a cohort of early learners, specifically targeting children aged 5 to 6 years. The participants were engaged in a series of interactive sessions designed to integrate the SmartVerse platform into their daily learning routine. The sessions were conducted within their usual classroom environments, which were adapted to enhance interaction with the application.

The experiment focused on observing the application's capacity to adapt to each child's learning pace through AI-driven algorithms. These algorithms modified game difficulty and progression based on real-time performance metrics, ensuring a personalized educational experience.

Throughout the trial, we monitored the children's engagement levels and the responsiveness of the AI system to

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their learning needs.

Data collection included weekly performance reports generated by the application, which were analyzed to gauge the overall impact on learning outcomes. These reports provided insights into each child's progress, areas of improvement, and engagement patterns. Feedback from educators and parents was collected to assess the practical benefits of integrating SmartVerse into the learning environment.

The results indicated a positive reception of the SmartVerse platform, with notable improvements in learning engagement and progression tracking. The adaptive nature of the application facilitated tailored educational experiences, and the feedback mechanism proved valuable for ongoing educational support.

Output:

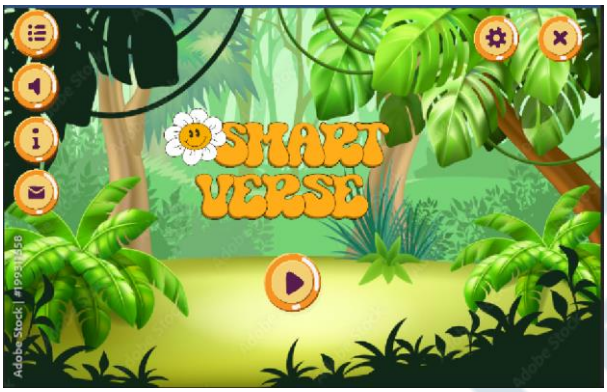

Fig 7: Main menu

Fig 8: Grade selection

Fig 9: Subject selection

Fig 10: Game selection

Fig 11: Level selection

VII. CONCLUSION AND FUTURE WORK

The SmartVerse project has shown significant promise in enhancing early childhood education through its innovative use of gaming and AI-driven adaptive learning. The pilot study demonstrated that the application successfully engages young learners by personalizing educational experiences and providing valuable progress insights for educators and parents. Moving forward, expanding the study to include a larger, more diverse group of participants will offer a broader perspective on the application's effectiveness. Additionally, incorporating more educational content and features, conducting longitudinal assessments, and providing targeted training for educators will further enhance SmartVerse's impact. Continuous feedback from users will also be crucial in refining the application to address emerging needs and opportunities.

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