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Design of Educational Games for Mathematical Literacy Enhancement in the Educational Metaverse Contexton

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Abstract: With the introduction of the new concept of the Metaverse, artificial intelligence, digital twins, and big data-related industries have ushered in vigorous development. The Metaverse has great energy and potential in promoting the development of mathematical quality education and has promoted the formation of teaching fields in the educational Metaverse. The educational Metaverse can provide users with an immersive and cross-temporal mathematical quality education teaching field. The teaching model for mathematics education has shifted from "monotonous and dry" to one involving "multi-faceted communication." The reception of knowledge has evolved from "one-way transmission" to a "blend of virtual and real experiences," enhancing cognitive engagement through sight, hearing, and touch," so that the flat text and formulas in the book are presented objectively and three-dimensionally in the Metaverse scene, and provide a virtual simulation system based on Unity3D real-time interaction to interact with NPCs (non-player characters) in many aspects, so as to popularize very comprehensive mathematical knowledge to the user group in the field with the educational Metaverse as the background, and realize the purpose of people's comprehensive quality education in many aspects. As VR (Virtual Reality) and AI (Artificial Intelligence) are experiencing explosive growth, we aim to optimize the realism of virtual scenes, promote natural human-computer interaction, and create an interactive platform for popularizing mathematics literacy education.

1. Introduction

Since the release of Apple's groundbreaking wearable device, Vision Pro, in 2023, along with the launch of iFlytek's Xinghuo Cognitive Model, technologies such as motion-sensing hardware and software have advanced rapidly. These advancements have made it feasible to implement interactive quality education science popularization using Unity Engine. Currently, Unity Engine's flexible capabilities allow for content creation and optimization across as many as 20 platforms. With continuous technological iterations, studios can now perform modeling, layout, animation, lighting, visual effects, rendering, and other tasks on a unified platform. This provides creators with a high degree of freedom and significantly enhances their production efficiency.

Existing research, such as the study by Batoon et al. (2022), explored the integration of mathematics teaching and game development by creating a 3D action role-playing game. They found that this approach effectively enhances interest and outcomes in mathematics learning. This study highlights the potential of gamified learning in educational technology, particularly in boosting learning motivation and comprehension [1].

Lindner et al. (2021), on the other hand, took a different perspective by examining how real-world terrain data could be integrated into game engines for augmented reality (AR) and virtual reality (VR) applications. Although the primary focus of their research was on geographic information systems, their techniques are also applicable for simulating environments for ancient mathematics [2].

The study by Khorloo and Ulambayar (2022) utilized Unity Engine to reconstruct a virtual environment of the ancient city of Karakorum, providing an exemplary case of how to digitize ancient cultural sites for educational purposes. Such reconstructions can be used not only for history education but can also be extended to teaching mathematics and architecture, allowing students to gain a deeper understanding of the practical applications of ancient mathematics and engineering techniques through interactive experiences [3].

These studies collectively demonstrate the wide-ranging possibilities that Unity Engine offers in the fields of mathematics education and science popularization, especially in creating interactive learning experiences and enhancing learning efficiency. By combining modern technology with traditional educational content, the interactivity and practicality of education can be significantly improved.

2. The Development of the Metaverse Concept and Its Value in Promoting Quality Education

2.1 Formation of the Metaverse Concept

The concept of the Metaverse first emerged in 1992 in Neal Stephenson's science fiction novel Snow Crash. Subsequently, this concept was mainly visualized through story settings in films, with the most representative examples being Westworld and Ready Player One, which helped audiences understand the Metaverse world. In 2021, technology giants such as Microsoft, ByteDance, and Tencent made official investments and strategic plans in the Metaverse, leading to widespread media coverage and a surge in the popularity of the "Metaverse" concept. As the software and hardware technologies in related industries have become quite advanced, the plasticity and forward-looking nature of the Metaverse hold immeasurable value for various industries. As a result, 2021 is often referred to as the "Year One of the Metaverse.

2.2 Development of the Metaverse in the Field of Education

Compared to traditional teaching methods, the "Metaverse + Education" model demonstrates significant development potential across multiple dimensions, whether in terms of providing an immersive user experience or scientific, personalized instructional guidance. The application of the Metaverse in the field of education is already emerging in various ways. For instance, in 2020, the top AI conference ACAI delivered lectures and discussions within Nintendo's Animal Crossing: New Horizons. Similarly, due to the pandemic preventing in-person graduation ceremonies, the Communication University of China held online graduation pledges, speeches, and award ceremonies in Minecraft.

In recent years, with the acceleration of digitalization in education, the development of foundational technologies, and strong national policy support, the trend of integrating "Metaverse + Education" has shown exponential growth. A comprehensive analysis of five major educational application cases and six potential risks and challenges[4] provides valuable insights and inspiration for the future development of the Metaverse in education.

2.3 The Value of the Metaverse in Promoting Quality Mathematics Education

In education, the Metaverse enhances interactivity, immersion, and a sense of achievement in the learning process by utilizing scenario-based approaches.This also provides a more realistic platform for trial and error in entrepreneurial and innovative education in higher education institutions," said Chen Duanru, Director of the Center for Digital Economy Integration and Innovation Development at the Central University of Finance and Economics, expressing hope for the future of the education-focused Metaverse.

The Metaverse's empowerment of the education sector offers users an immersive learning experience, where designing game-based interactive learning environments plays a crucial role. Users placed in such bidirectional interactive scenarios have a relatively higher acceptance of mathematics-related knowledge. Moreover, educational Metaverse environments can concretize abstract objects or cases.

Unlike the traditional one-to-many classroom teaching model, the personalized learning system for mathematics education makes scientifically reasonable recommendations for difficulty levels based on the user's mastery and interest in the subject. It also incorporates character-level settings for interactions with NPCs (Non-Playable Characters), ensuring that users have an engaging experience while effectively popularizing mathematical knowledge. This helps create a personalized educational Metaverse environment, maximizing the field effect to empower mathematics education.

With continuous technological advancements and strong governmental policy support, the Metaverse holds great potential for advancing the field of mathematics education. If the educational Metaverse remains sufficiently open and aligned with public needs, its impact on mathematics education could significantly promote educational equity. This means that more people would benefit from the advantages of the educational Metaverse, gaining better learning opportunities and experiences.

3. Design of Digital Quality Education Games in the Metaverse Learning Environment

3.1 Game Storyline Design Focused on Mathematics

The design of game storylines focused on mathematics education is based on early mathematical works such as The Zhoubi Suanjing, The Haidao Suanjing, The Sunzi Suanjing, and The Nine Chapters on the Mathematical Art. These storylines incorporate modern virtual reality technologies for interactive expression, language transformation, and scenario generation, transforming traditional mathematics learning, which used to rely on reading or referencing books, into an experiential and interactive learning method. This innovative approach to learning ancient mathematical classics through new interactive experiences has become a new trend in education and popular science.

Inspired by the VR shadow puppet game "Tian Ji's Horse Racing," developed for Chinese museums[5], a virtual simulation platform was created to model the racetrack for this historical event, along with the models of the horses and their running animations. Users can choose superior, average, or inferior horses to compete against others, enhancing the fun and vividness of ancient mathematics education. This design deepens users' understanding of the historical story of Tian Ji's Horse Racing as well as related mathematical concepts such as game theory and probability theory.

The storyline design not only includes game theory related to Tian Ji's Horse Racing but also features concepts like the idea of substitution of equivalents in "Weighing the Elephant on a Sinking Ship" and the exhaustive hypothesis method in the "Chickens and Rabbits in the Same Cage" problem, all centered around mathematics education.

3.2 The Educational Metaverse Empowered by VR and AI Technologies

Human-Computer Interaction (HCI) technology, as an essential component of the Metaverse, is crucially related to the user's experience. With the support of Virtual Reality (VR) technology—where users can have the most direct experience—mathematics education is presented through the medium of modern technology for an innovative experience. This approach guides users to explore key content in the game in an intellectually stimulating way, using vivid and immersive retro scenes that break through the limitations of time and space. In this virtual hyper-realistic space, users can learn about and expand upon the treasures left behind by Chinese mathematicians.

Diverse and varied training data is the foundation for the use of AI technology. As neural networks continue to minimize loss and approach real values to train models, AI achieves a natural and logical flow in human-machine dialogues. AI technology grants NPCs (Non-Playable Characters) human-like traits, significantly reducing performance loss in the game and optimizing the user's experience of the storyline. Essentially, the continuous refinement of AI technology, driven by massive data training, creates the educational Metaverse environment. The two complement and reinforce each other, advancing in synergy.

The proposed solution mainly involves writing C# scripts to enable free interaction with NPCs. The primary method of human-computer interaction is to control virtual characters to trigger relevant events, prompting dialogue boxes to appear for conversations with NPCs[6]. This allows users to learn about the background of the story and explore interesting mathematical knowledge. For example, in "Tian Ji’s Horse Racing," we set parameters related to the horses to control the speed of the race animations. The horses are automatically destroyed when they reach the finish line, and the race results are displayed in an intuitive pop-up UI format. Finally, the player's performance in the scenario determines different outcomes, which, in turn, influence the branching storyline; however, these variations do not affect the core gameplay and main storyline of the work.

3.3 Demonstrating the Comprehensiveness of Mathematical Knowledge Popularization Across Multiple Storylines

From the perspectives of diversified storylines and comprehensive knowledge dissemination, a virtual simulation platform has been developed featuring five large-scale interactive scenarios. These scenarios correspond to five different interactive segments focused on popularizing knowledge related to mathematics education. The interactive scenarios available for experience include, but are not limited to: the clever strategy of "Tian Ji’s Horse Racing" proposed by Sun Bin in Records of the Grand Historian: Biographies of Sun Bin and Wu Qi; the intriguing "Chickens and Rabbits in the Same Cage" problem posed by Sunzi in the Sunzi Suanjing [7]; the wisdom of Cao Chong weighing an elephant in Records of the Three Kingdoms: Book of Wei, Biography of Cao Chong; the beauty of combining numbers and shapes in Yang Hui's triangle from the Nine Chapters on the Mathematical Art; and the exploration of ancient and modern times in the Zhoubi Suanjing[8]. These storylines allow players to explore the charm of mathematics within different narratives in a hyper-realistic dimension.

By experiencing these scenarios from the perspective of a participant in the story, players can feel the sense of accomplishment that comes from solving complex problems and an endless desire to explore new worlds. This multi-faceted, all-encompassing educational model aims to achieve the scientific effectiveness and enjoyment of popularizing mathematical knowledge[9].

4. Research on the Development of Mathematics Quality Education

4.1 Building Educational Metaverse Scenarios

The construction of educational metaverse scenarios is the foundation for the development of mathematics quality education games. To achieve an immersive educational experience, it is essential to employ advanced virtual reality (VR) technology and 3D modeling techniques to create realistic teaching environments that make learners feel as if they are physically present. Scenario construction not only includes the presentation of mathematical knowledge but also integrates interactive elements to enhance the fun and engagement of learning. For instance, ancient mathematicians' practical scenes, the process of solving mathematical problems, and the application of mathematical knowledge can all be vividly presented through virtual reality technology.

1) Selecting the Appropriate Engine

Choosing the right engine is crucial in the scenario-building process. The Unity game engine supports multiple platforms, such as Windows, Mac, iOS, Android, web, and gaming consoles, allowing developers to target multiple markets using the same codebase. The URP (Universal Render Pipeline) optimizes resource management and rendering, ensuring smoother performance on low-end devices. Additionally, the Unity3D environment allows users to freely move and explore within a 3D space, increasing the level of interaction. This freedom offers players a broader range of exploration and diversified gameplay.

2) Scenario Design and Optimization

When designing the scenarios, we consider aesthetics, interactivity, and performance fluidity. By using high-quality 3D models, textures, and animation effects, we ensure the realism and immersive nature of the scenarios. For example, in the "Help the Shopkeeper with Calculations" module, we used a highly detailed abacus model to simulate the real process of using an abacus. Furthermore, continuous optimization of the scenes was conducted using techniques such as LOD (Level of Detail) and lightmap baking to ensure performance across different devices, avoiding issues caused by overly complex scenes. The layout of our game scenes is shown in Figures 1 and 2:

Figure 1: 2D plane top view

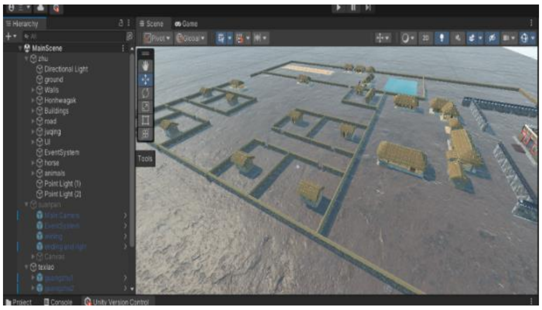

Figure 2: 3D Scene Top-Down View

3) Game logic design

Game logic design encompasses various aspects such as game rules, task systems, and reward mechanisms. The continuous improvement of the overall game logic structure allows players to better visualize mathematical concepts and develop a foundational understanding of relevant knowledge while interacting with the scenes. As shown in Figure 3, the game is structured with multiple levels, each corresponding to one or more mathematical concepts, establishing connections between different knowledge points. This structure lays the groundwork for players to build a cohesive mathematical knowledge system. Additionally, by completing tasks to earn rewards, players' interest in learning is stimulated, providing motivation to continue progressing through the game.

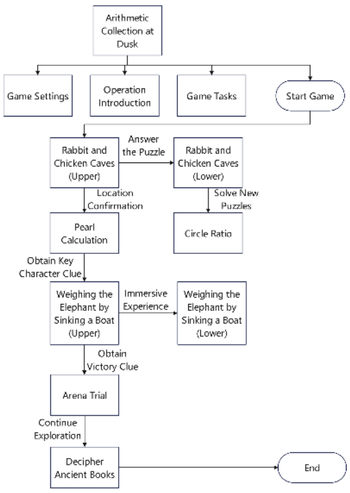

Figure 3: Game Logic Design Diagram

Using the "Shopkeeper's Abacus" module as an example, we simulated the logic of operating an abacus as it is used in real life. Players use the abacus to calculate for the shopkeeper, and based on their results, they receive hints or rewards, thereby gradually advancing through the game. The visual effect of the abacus module is shown in Figure 4. This part of the imple.0mentation was achieved using Unity's scripting system, and the overall algorithm is as follows:

①Create a raycast, passing the click event and the distance of the bead's upward or downward movement to the abacus beads.

②The abacus bead detects whether it can move, and if movement is possible, it further checks whether it should move upward or downward.

③Based on the judgment result and displacement algorithm, the bead is moved accordingly.

```
public void OnPointerClick(PointerEventData eventData)
{
   if (cnt % 2 == 1)
   {
      if (up)
      {
          transform.position += newVector3(0, +1.49f, 0);
       transform.position=newVector3(transform.position.x,Mathf.Clamp(transform.position.y,0.13f,1.36f), transform.position.z);
         test.scorePoint += a;
         cnt++;
      }
```

```
    }
    else
    {
       if (down)
       {
     transform.position=newVector3(transform.position.   x,Mathf.Clamp(transform.position.y,-
    0.13f,1.36f),        transform.position.z);
           test.scorePoint -= a;
           cnt++;
       }
    }
    score.text = "Outcome: " + test.scorePoint.ToString();
}
```

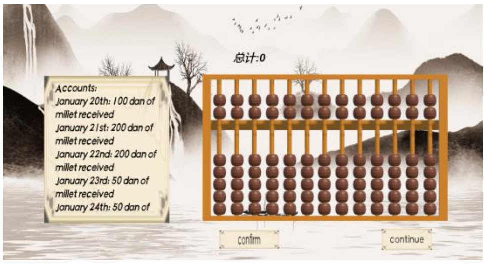

Figure 4: The UI display interface of the abacus

4) Human-Computer Interaction Design

Human-computer interaction (HCI) design is a crucial aspect of enhancing the gaming experience. By designing a user-friendly interface (UI) and utilizing virtual reality (VR) technology, players can engage more immersively in game operations and knowledge learning. Through actions such as clicking buttons, designing narrative branches, and inputting text, intelligent interaction with NPCs (non-player characters) is achieved, thereby enhancing interactivity. As shown in Figure 5, the agorithm for determining the game’s outcome is as follows:

```
Activate 'shuduihua'
Increment 'shu' by 2
Activate 'yingduihua'
Increment 'ying' by 2
Define method 'shuyingfangfa':
        Set 'shu' to 0
        Set 'ying' to 0
If 'count' equals 2:
        Deactivate 'Destory1'
        Activate 'Destory2'
```

Figure 5: "Lose" UI display

In the "Tian Ji Horse Racing" module, we have set up three types of horses: upper, middle, and lower, each assigned different speed levels. Additionally, using a generation and destruction algorithm for horse tokens, the horses are destroyed after reaching the designated finish line, and in the next round, new horses are generated at the starting point. We also embedded hidden victory hints in the storyline and designed different narrative branches for different outcomes, allowing players to fully experience the game's freedom. These two elements ensure the story's multidimensionality, philosophical depth, and flexibility.

In terms of UI display, as shown in Figure 6, the relevant algorithms for generating horses, having them reach the finish line, and automatically destroying them are as follows:

```
If 'other' has tag "tt":
        Increment 'count' by 1 (A horse enters the trigger area, increment count)
        If 'count' equals 1:
            Activate 'shule'
            Activate 'jixu'
            Increment 'Shuyin.shu' by 1
        Destroy the game object represented by 'other'
    If 'other' has tag "ff":
        Increment 'count' by 1 (A horse enters the trigger area, increment count)
        If 'count' equals 1:
            Activate 'yingle'
            Activate 'jixu'
            Increment 'Shuyin.ying' by 1
       Destroy the game object represented by 'other'
```

Figure 6: UI Display of "Tian Ji's Horse Racing"

4.2 Data Collection for an Immersive Metaverse Experience

Data collection is a crucial method for achieving an immersive learning experience. By gathering and analyzing player behavior data during gameplay, particularly through the completion of specific task sets as shown in Figure 7 and Figure 8, we can gain insights into the player's learning progress and effectiveness, providing support for personalized education.

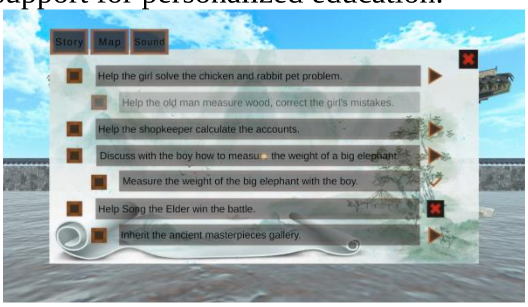

Figure 7: The task starts with the data management interface

Figure 8: Task completion Data management interface

1) Data Collection Technology

Data collection technology can be implemented through scripts to record players' experience information. Using storage variables within the script, player behavior data is captured in real-time and transmitted over the network to a data center for storage and analysis. From a data analysis perspective, this allows the collection of information on players’ behavior patterns, methods of answering questions, error counts, accuracy rates, and more. These data can then be transformed into multidimensional views, helping to foster the development of a personalized learning system. The key algorithms for data collection are as follows:

```
If 'test.scorePoint' equals 500 (After reaching the target score of 500, determine success):
    Activate 'jixu'
    Activate 'right'
  Decrease 'timer2' by the elapsed time (Time.deltaTime)
    If 'timer2' is less than 0:
        Deactivate 'right'
        Reset 'timer' to 4
Else (If the score is not 500, determine failure):
    Activate 'End'
    Decrease 'timer' by the elapsed time (Time.deltaTime)
    If 'timer' is less than 0:
        Deactivate 'End'
        Reset 'timer' to 2
        Deactivate 'check'
```

2) Data Management and Analysis Methods

By utilizing machine learning techniques to filter, process, and analyze the collected player learning data, valuable insights and patterns can be extracted. This helps to better understand players' learning patterns and behavioral characteristics, thereby providing personalized teaching recommendations and guidance. In the game, the data collection system records players' learning behaviors and performance in real time, followed by in-depth data mining and analysis. This allows us to understand players' learning progress and feedback, which in turn helps continuously optimize game design and teaching content to enhance learning outcomes.

5. Conclusion

With the rapid development of metaverse technology, the field of education is experiencing new transformative opportunities. The metaverse integrates cutting-edge technologies such as Virtual Reality (VR) and Artificial Intelligence (AI) into education, creating an immersive learning environment that transcends the limitations of physical space. This innovative model offers rich possibilities for mathematics education, enabling complex and abstract mathematical concepts to be conveyed to students in an intuitive and vivid way through virtual interactions and scene re-creations.

Simultaneously, the metaverse environment supports personalized learning, catering to the needs of different learners and promoting a deeper understanding and mastery of mathematics.

The development of the game is based on the core architecture of the educational metaverse, which includes the physical layer, software layer, application layer, and analytics layer. The primary focus is on constructing an immersive learning environment for mathematics education by leveraging VR and AI technologies.

To validate the effectiveness of the mathematics education game in the context of the metaverse, the research team conducted experimental studies. By evaluating students' immersive learning experiences in various scenarios and processing and analyzing the data collected during these experiences, the findings further demonstrate that mathematics education games in the metaverse can enhance learners' experiences and improve learning efficiency. In different virtual learning environments, as learning tasks progress, students' cognitive engagement increases from a "moderate level" to a "high level." Compared to traditional teaching methods, the interactivity and immersion in the metaverse environment significantly boost students' interest and learning outcomes.

However, there are certain limitations to the study based on the analysis of player behavior data. These limitations are mainly reflected in the need for further optimization of the immersive experience offered by metaverse technology, the small sample size used in the experiment, and the incomplete data collection and analysis methods. Future research should focus on optimizing technical details, improving the monitoring of teaching effectiveness, and enhancing equipment, in order to further empower the education field through the metaverse.

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References

[1] Batoon, J. A., Antonio, L. G., Dongsa, J. P., et al. (2022). Mathematics ntegration on the development of a 3D action role-playing game: The Light of End. International Journal of Advanced Trends in Computer Science and Engineering.

[2] Lindner, C., Ortwein, A., Staar, K., & Rienow, A. (2021). Different levels f complexity for integrating textured extra-terrestrial elevation data in game ngines for educational augmented and virtual reality applications. KN-Journal f Cartography and Geographic Information.

[3] Khorloo, O., & Ulambayar, E. (2022). Virtual reconstruction of the ancient ity of Karakorum. Computer Animation and Virtual Worlds.

[4] Lan, G., Wei, J., Huang, C., Zhang, Y., He, Y., & Zhao, X. (2022). Metaverse for learning empowering education: Constructing a new pattern of Internet+ education application. J. Distance Educ, 40, 35-44.

[5] Zhang, Q. (n.d.). The interactive expression and language transformation of virtual reality technology in Chinese museum exhibitions: A case study of the development and application of the VR shadow puppet game "Tian Ji's Horse Racing". China Museum.

[6] Chen, Y., & Yao, H. (2020). Design and implementation of the dialogue tree script module in Unity games. Computer and Information Technology.

[7] Yin, Y. (n.d.). Using the cross method to solve the rabbit and chicken in the same cage problem and its types. [Journal Name].

[8] Sun, Y., & Yao, D. (2024, January 26). Calculation of Pi: A gem in the history of ancient Chinese mathematics development. Science and Technology Daily.

[9] Wang, Y. (2022). Research on the creation of science popularization games based on the Unity physics engine: A case study of "Clever Bobby" [Doctoral dissertation, Lanzhou Jiaotong University.